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Effects of soil water content and light intensity on the growth of *Molinia japonica* in montane wetlands in South Korea

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Abstract

Background: Montane wetlands are unique wetland ecosystems with distinct physicochemical characteristics, and *Molinia japonica* often makes dominant communities in montane wetlands in South Korea. In order to figure out the environmental characteristics of *M. japonica* habitats and the major factors for the growth of *M. japonica*, field surveys were conducted in five wetlands from September to October 2019. Also, soil was collected at every quadrats installed in surveyed wetlands to analyze the physicochemical features.

Results: The relative coverage of *M. japonica* was higher in low latitude wetlands than in high latitude. Redundancy analysis showed that soil water content had the strongest effect on the growth of *M. japonica* ($F = 23.0$, $p < 0.001$). Soil water content, loss on ignition, and relative light intensity showed a high correlation with the density ($R =$ 0.568, 0.550, 0.547, respectively, $p < 0.01$) and the coverage of *M. japonica* ($R =$ 0.495, 0.385, 0.514, respectively, $p < 0.01$). Soil water content, loss on ignition, and pH were highly correlated with each other.

Conclusions: *Molinia japonica* lives in acidic wetlands at high altitude in temperate zone of low latitude, with peat layer placed on the floor. Also, *M. japonica* prefers open spaces to secure enough light for photosynthesis. High shoot production of *M. japonica* resulted in adding new peat material in every year, and this layer enforces the environmental characteristics of *M. japonica* habitats. This study may provide insights for further understanding of the method how wetlands maintain acidic condition by itself in montane wetlands in temperate zone.

Keywords: Redundancy analysis, High altitude, Montane wetland, Peat, pH, Relative light intensity, Soil water content

Background

Montane wetlands in temperate zone are characterized by relatively low temperature and low pH, reduced decomposition rate of organic matter by saturation of water, and formation of peat layers, causing specific plants adapted to this environment to live (Kim et al. 2014). Distributed in high degree of elevation while forming a unique ecosystem blocked from outside, montane wetlands have a high value because they function as a gene pool of distinctive species (Kim et al. 2015). Montane wetlands are classified into bog, fen, and marsh according to the characteristics of their substrate, but they mostly have precipitation and groundwater as the main source of water regardless of wetland types (Ryan et al. 2014; Ahn et al. 2016). Hence, montane wetlands are prone to exposure to dry conditions and are highly sensitive to environmental changes than other wetlands. Therefore, it is necessary to understand the environmental characteristics of montane wetlands preferentially for precise and detailed prediction of future changes.

Among various biotic factors in montane wetlands, vegetation is most closely related to the hydrological characteristics of montane wetlands (Koerselman et al.

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1990; Crowe and Clausnitzer 1997; Park et al. 2013). In particular, dominant plant species, having an important role in vegetation structure, can affect significantly both biotic and abiotic factors, and vice versa (Tscharntke 1992). Because of their high proportion of biomass in community, changes in dominant species by environmental factors often cause several consequences in community level (Berendse 1998; Koukoura et al. 2003). Additionally, alterations in abiotic factors including soil characteristics caused by dominant plant species can act as selective forces to other species (He et al. 2008; Mulhouse et al. 2005). Considering these facts, understanding ecological characteristics of dominant plant species in montane wetlands is of importance, yet little understanding has been made (Moon and Koo 2014; Kim et al. 2015). Therefore, approaches to examine the ecological characteristics of typical dominant species are needed.

Molinia japonica Hack., distributed in various sites in South Korea and Japan, is one of the most common dominant plant species of montane wetlands in South Korea (Kim et al. 2005). They grow about 30~110 cm and tend to form many hummocks, growing together in dense form (Lee 2003). Also, they produce a lot of shoots and expected to play a major role in the plant community of montane wetland. Nevertheless, information about their growth characteristics is very insufficient, and they are only included in the vegetation list of the studies focusing on other factors of wetlands (Yi and Nam 2008; Choung et al. 2009; Park et al. 2011). Here, our study first examined the growth characteristics of *M. japonica* and the most influential abiotic factors for the plant species.

In this study, field survey was conducted in several montane wetlands in South Korea to identify the growth characteristics of *M. japonica*. The purpose of our study was to identify the environmental variables important for the growth of *M. japonica*. It is believed that this study will enable to figure out the overall growth characteristics of *M. japonica* and provide basic data to understand the environment of montane wetlands in South Korea.

Materials and methods

Study sites

Based on literature research and field investigation, 13 montane wetlands located in the country were identified. Considering the possibility of access and community survey, and the size of *M. japonica* dominant community, five wetlands were selected as study sites: wetlands in Mt. Horyonggok (HRG) (26 m asl), Mt. Chilbo (CB) (120 m asl), Mt. Geumjeong (GJ) (560 m asl), Mt. Hwangmae (HM) (760 m asl), and Mt. Sinbul (SB) (739 m asl) (Fig. 1). HRG and CB are in relatively high latitude and low altitude than GJ, HM, and SB. *Molinia japonica* was not dominant in wetlands in high latitude and high altitude and not found in wetlands in low latitude and low altitude. *Phragmites australis*, *Oplismenus undulatifolius*, *Potentilla fragarioides*, and *Sanguisorba tenuifolia* were distributed in HRG and CB. *Pinus densiflora* surrounded these two wetlands. *Miscanthus sacchariflorus*, *Carex maximowiczii*, and others were distributed in GJ, HM, and SB. *Salix* spp. and *Alnus japonica* surrounded these three wetlands. HRG and CB were smaller and steeper than GJ, HM, and SB. The annual average temperature of the region of HRG, CB, HM, and "GJ and SB" in 2019 were 13.2 ± 2.7 °C, 13.2 ± 2.8 °C, 13.8 ± 2.5 °C, and 15.4 ± 2.3 °C (mean ± SE), respectively. The annual total precipitation of the region of HRG, CB, HM, and "GJ and SB" in 2019 were 919.5 mm, 914.8 mm, 1190.6 mm, and 1536.1 mm, respectively. All meteorological data of HRG, CB, HM, and "GJ and SB" were from stations in Incheon, Suwon, Hapcheon, and Yangsan, respectively (Korea Meteorological Administration 2019).

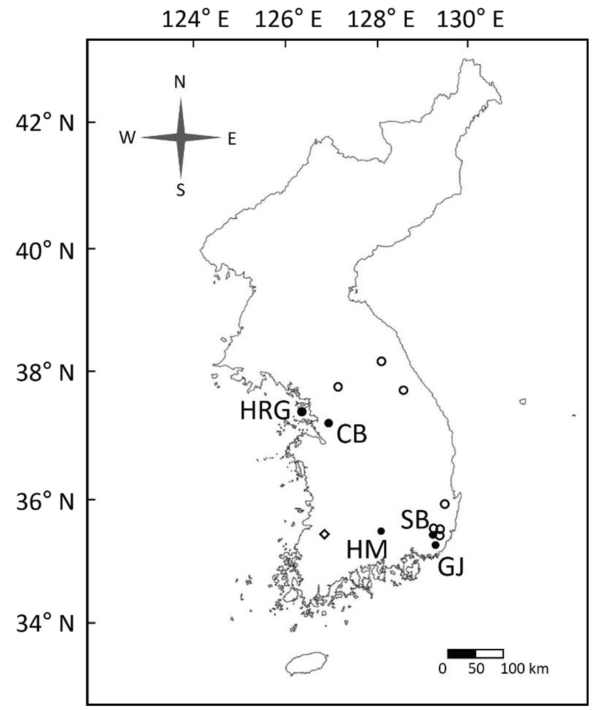

Fig. 1 Study sites of *M. japonica*; HRG, wetland in Mt. Horyonggok; CB, wetland in Mt. Chilbo; GJ, wetland in Mt. Geumjeong; HM. wetland in Mt. Hwangmae; SB, wetland in Mt. Sinbul; black circle indicates study sites; white circle indicates *M. japonica* habitats where vegetation survey could not be done; white diamond indicates the site known as *M. japonica* habitat by literature, but not in present

Field survey

Survey was conducted during the period from September to October in 2019. A total of 47 quadrats in 2 m × 2 m were randomly established for 5 study sites considering the range of *M. japonica* community distribution in each wetland (8 quadrats in HRG, 3 quadrats in CB, 16 quadrats in GJ, 10 quadrats in HM, and 10 quadrats in SB). Quadrats were installed to satisfy the distance of 8~10 m between quadrats. Average height, density, and coverage of all herbal plants including *M. japonica* were measured in each quadrat, and relative coverage of *M. japonica* were calculated. Light intensity was measured at the top of *M. japonica* at five spots in each quadrat and open area with light intensity meter (LI-250A light meter, LI-COR), then relative light intensity (RLI) was calculated. Measuring light intensity was conducted in the afternoon. Soil samples were collected in each quadrat, blending 4 subsamples at 0~15-cm depth after removal of litter.

Soil properties analyses

All fresh soil samples were passed through a 2-mm sieve to remove small particles of any plant and gravel. Soil water content (SWC) was measured after samples were dried at 105 °C in an oven (Kim et al. 2004). The organic matter content in the soil samples was determined by loss on ignition (LOI) at 550 °C for 4 h (Boyle 2004). The pH and electrical conductivity (EC) of fresh soil were measured in a 1:5 soil/distilled water suspension using a pH meter (model portable AP63 meters, Accumet) and a conductivity meter (model starter 300C, OHAUS), respectively. NO_3-N and NH_4-N in fresh soil samples were extracted with 2 M KCl solution (Keeney and Nelson 1982) and PO_4-P was extracted with Bray No. 1 solution (Bray and Kurtz 1945). NO_3-N, NH_4-N, and PO_4-P contents of soil were determined by hydrazine method (Kamphake et al. 1967), indo-phenol method (Solorzano 1969), and ascorbic acid reduction method (Murphy and Riley 1962), respectively. For exchangeable cation (K^+, Ca^{2+}, Na^+, and Mg^{2+}) contents in fresh soil samples, cations were extracted with 1 M ammonium acetate solution (Knudsen and Peterson 1982), then measured by an atomic absorption spectrometer (model AA240FS, Varian).

Statistical analysis

To figure out the difference of growth characteristics of *M. japonica* between high and low altitude wetlands, *t* test was conducted after testing the data for normal distribution by Shapiro-Wilk test (Shapiro and Wilk 1965) with R (ver. 3.6.3) (R Core Team 2018). If the data did not follow normality, we used Mann-Whitney *U* test (Mann and Whitney 1947). Preliminary analysis using detrended correspondence analysis (DCA) suggested a linear response (the length of first axes = 1.35) to analyze the relationship between vegetation and environmental factors. To identify the correlation of environmental factors with growth characteristics of *M. japonica*, a redundancy analysis (RDA) was conducted with R. Average height, density, and coverage of *M. japonica* were used for the analysis. Then, we conducted Monte-Carlo permutation test with 999 permutations to determine the major environmental factors affecting the growth characteristics of *M. japonica*. After that, the correlation analysis was carried out using IBM SPSS Statistics (ver. 23) in order to identify the relationship among each environmental factor and growth characteristics. Significance level was 0.05 for all performed statistical tests.

Results

Patterns of distribution and growth of *M. japonica* according to latitude

The locations of *M. japonica* habitats in South Korea were distributed throughout the country except the southwestern region (Fig. 1). Relative coverage of *M. japonica* was smaller in low latitude wetlands (HRG 54.7 ± 6.1%; CB 75.2 ± 5.3%) than in high latitude wetlands (GJ 87.3 ± 2.0%; HM 90.2 ± 2.4%; and SB 98.6 ± 0.4%). In addition, density and coverage of *M. japonica* were smaller in high latitude wetlands than in low latitude wetlands (Fig. 2).

Environmental characteristics of *M. japonica* habitats

The ranges of SWC and LOI were 27.82~83.01% and 5.45~68.48% respectively, and it showed that *M. japonica* lives in a broad range of distribution of soil moisture and organic matter content (Fig. 3). The distribution of *M. japonica* was identified in the range of 3.99~5.60 of soil pH, showing acidic condition of habitats of *M. japonica*. The range of EC was 15.87~82.70 μS/cm. RLI was distributed in a range of 5.86~97.25%, and RLI of sites was divided into two ranges (5.85~34.30% and 57.61~97.25%), according to the presence of trees. The ranges of NO_3-N, PO_4-P, and NH_4-N were 0~3.54 mg/kg, 0~2.23 mg/kg, and 0.63~89.75 mg/kg, respectively, and NH_4-N showed relatively high content. The ranges of Ca^{2+}, K^+, Na^+, and Mg^{2+} were 13.24~435.54 mg/kg, 33.91~286.24 mg/kg, 10.17~93.00 mg/kg, and 19.65~202.56 mg/kg, respectively. Among exchangeable cations, Na^+ content was relatively low compared to Ca^{2+}, K^+, and Mg^{2+} content.

Relationship between growth characteristics of *M. japonica* and environmental characteristics

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). The first two axes

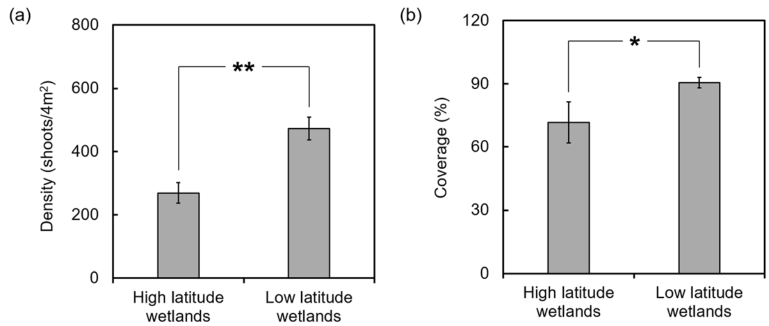

Fig. 2 Differences in density (**a**) and coverage (**b**) of *M. japonica* between high and low latitude wetlands. *$p < .05$, **$p < .01$

explained 53.1% of the variance. SWC was the most important factor contributing to the first axis with 0.78 (Monte-Carlo permutation test with 999 permutations, $F = 23.0$, $p < 0.001$). LOI contributed to the first axis with 0.75 but not statistically significant ($F = 0.4$, $p = 0.55$). Relative light intensity was also the major environmental factor with 0.75 of contribution to the first axis ($F = 7.8$, $p < 0.01$), and Ca^{2+} content was statistically significant ($F = 4.6$, $p < 0.05$). The rest of environmental factors did not have statistically significant effects on the growth of *M. japonica*. The quadrats of low latitude wetlands tended to follow the arrows of SWC, LOI, and RLI, while the quadrats of high latitude wetlands were distributed the opposite side to SWC, LOI, and RLI.

Correlation between the vegetational characteristics including density and coverage of *M. japonica* and environmental factors in all quadrats was analyzed (Table 1). As a result of the analysis, soil water content, LOI, and relative light intensity showed high correlations with density ($R = 0.568$, 0.550, 0.547, respectively, $p < 0.01$) and coverage of *M. japonica* ($R = 0.495$, 0.385, 0.514, respectively, $p < 0.01$). Within the environmental characteristics, soil water content and LOI ($R = 0.934$, $p < 0.01$), soil water content with Na^+ ($R = 0.527$, $p < 0.01$), soil water content

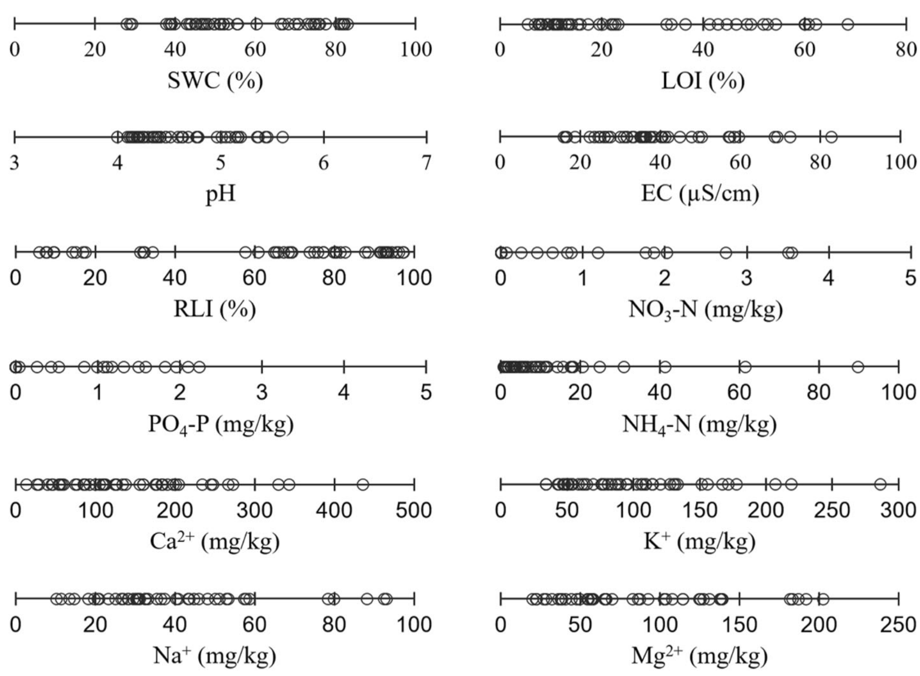

Fig. 3 *M. japonica* distribution patterns according to environmental characteristics. The circles on the line represent the sample distribution (quadrat locations) on the gradient of corresponding environmental factors

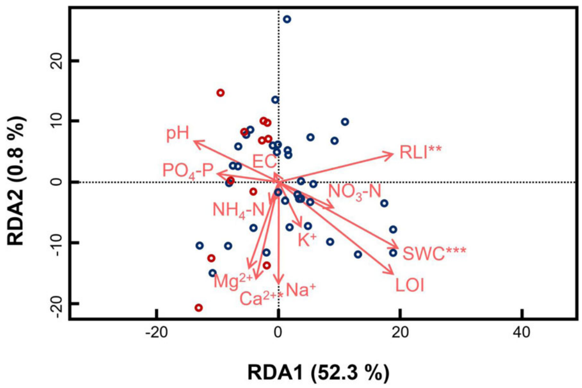

Fig. 4 Redundancy analysis (RDA) of vegetation and environmental characteristics of *M. japonica*. Red circle, quadrats in high latitude wetlands; blue circle, quadrats in low latitude wetlands; SWC, soil water content; LOI, loss on ignition; EC, electrical conductivity; RLI, relative light intensity. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

and pH ($R = -0.523$, $p < 0.01$), and LOI with pH ($R = -0.600$, $p < 0.01$) were highly correlated.

Discussion

In our survey, the most important environmental factors for *M. japonica* growth were soil water content, loss on ignition, and relative light intensity (Fig. 4, Table 1). Additionally, *M. japonica* habitats showed relatively low range of pH, and even the locations where *M. japonica* showed vigorous growth had low pH (Fig. 3, Table 1). Considering that the distribution range of pH of other wetland plants is 5.25~7.26 (Lee et al. 2007; Jeon et al. 2013), low pH condition seems to be important for *M. japonica* population. In peat wetland, thick organic matter layer consisting of peat could keep moisture well without spilling it, conserving high level of soil moisture content, and creating an anaerobic environment on the ground surface and the around of rhizome (Mitsch and Gosselink 2015). In this anaerobic environment, bacteria cannot actively progress decomposition and nitrogen fixation which demand H^+ consummation, and thereby acidic environment could be established (Moore and Dalva 1997). Since most plants cannot grow well in the acidic environment (Pinkerton and Simpson 1986; Rubio et al. 2002), there might be less competitive stress for plants which adapted to acidic conditions. Therefore, it is thought that *M. japonica* could exhibit active growth under acidic environments with low competitive stress because it has high tolerance for low pH condition.

In addition to soil water content and pH, relative light intensity (RLI) was also one of the most influential environmental factors for *M. japonica* growth (Fig. 4, Table 1). In particular, most *M. japonica* habitats showed over

Table 1 Pearson's correlation coefficients on vegetation and environmental characteristics of *M. japonica* ($n = 47$)

	Height	Density	Coverage	SWC	LOI	pH	EC	RLI	NO_3-N	PO_4-P	NH_4-N	Ca^{2+}	K^+	Na^+	Mg^{2+}
Height		.117	.165	− .196	**− .296***	.107	.046	.174	− .067	.004	− .099	**− .409****	− .164	**− .412****	**− .372***
Density			**.622****	**.568****	**.550****	**− .406****	− .021	**.547****	.265	**− .294***	− .043	− .107	.110	.000	− .142
Coverage				**.495****	**.385****	− .195	− .114	**.514****	3194	**− .303***	.050	.025	.050	.067	.030
SWC					**.934****	**− .523****	.071	**.456****	**.489****	− .180	**.375****	**.373****	**.518****	**.527****	.230
LOI						**− .600****	.096	**.428****	**.489****	− .195	.261	**.342***	**.416****	**.487****	.219
pH							− .283	− .135	**− .369***	**.413****	.073	.204	.091	.151	**.318***
EC								− .203	.155	**.323***	.202	− .108	.239	.042	− .208
RLI									.166	**− .411****	− .131	.028	.003	− .061	.075
NO_3-N										− .145	.264	.062	.185	.170	− .049
PO_4-P											**.366***	.233	**.543****	**.356***	.165
NH_4-N												**.310***	**.569****	**.558****	.145
Ca^{2+}													**.467****	**.811****	**.938****
K^+														**.724****	.287
Na^+															**.696****
Mg^{2+}															

SWC Soil water content, *LOI* Loss on ignition, *EC* Electrical conductivity, *RLI* Relative light intensity
$^*p < .05$, $^{**}p < .01$

60% of RLI (Fig. 3). This result is consistent with Hirata and Tsuyuzaki (2016), reporting the light as a major environmental factor for the growth of *M. japonica*. The high RLI is thought to be important for *M. japonica* growth because relatively high light intensity would enable their vigorous growth with high photosynthesis activity. Moreover, *M. japonica* were distributed predominantly in montane wetlands of temperate zone of low latitude with higher density and coverage than high latitude in Korea (Fig. 2). Meanwhile, montane wetlands show lower annual temperature than lowland wetlands in the same latitude since they are located in higher altitude (Hoek et al. 2019), and the low temperature of montane wetlands is beneficial for peat formation and maintenance because of slow decomposition speed (Mitsch and Gosselink 2015).

Because of these several environmental characteristics, it is thought to be possible that *M. japonica* becomes a dominant species in high altitude montane wetlands in temperate zone of low latitude in Korea. Furthermore, as environmental factors affected the growth and development of *M. japonica*, it is likely that the domination of *M. japonica* could cause positive feedback effect, making the environment more suitable for their growth. In particular, their vigorous growth might contribute to the maintenance of acidic condition in montane peat wetland. Indeed, the density of *M. japonica* and pH had a remarkable negative correlation (Table 1). *Molinia japonica* largely contributes to the productivity of montane wetlands with huge biomass production of 1200~1370 g/m^2 in Janggun wetland at Mt. Geumjeong (Son 2020). Thus, huge shoot litter of *M. japonica* covers the floor and forms a new peat layer in winter. Because of low decomposition rate in montane wetlands (Kim 2005; Mitsch and Gosselink 2015), annual large supply of *M. japonica* shoot litter could stimulate peat formation. As the peat layer with high content of organic matter can hold water for long time (Mitsch and Gosselink 2015), the low pH condition could be easily formed in accordance with anaerobic environment. Therefore, high RLI and high altitude would contribute to more developed *M. japonica* population leading to more acidic environments, which further stimulates their growth performance. Further, it seems that the balance between the productivity of *M. japonica* and pH is necessary for the maintenance of this environment, and the vegetation structure of *M. japonica* dominant wetlands is formed with priority given to this balanced state. Known as a late colonizer, *M. japonica* adapted less to strong solar radiation including ultraviolet than an early colonizer (Hirata and Tsuyuzaki 2016), so that it would make peat layer first and drop pH when it settles in new place. To elaborate the relationship between *M. japonica* growth and pH condition, further examination in detail would be necessary for the effect of pH on the growth of *M. japonica*, and also vice versa.

Even though coverage and density of *Molinia japonica* were high in low latitude in Korea, we could not figure out which environmental factor is responsible for the optimal distribution range of this plant. When we consider productivity of *M. japonica* based on coverage and density data (Fig. 2), this might be annual temperature change. This could be figured out more through studies on environmental variables and common garden experiment.

Conclusions

In this study, field survey was conducted in several montane wetlands in order to figure out the important environmental characteristics for the growth and the formation of dominant communities of *M. japonica* in montane wetlands. Soil water content and loss on ignition were major environmental factors in *M. japonica* habitats, and pH was highly correlated with these two factors. Also, relative light intensity played an important role by providing enough light energy for photosynthesis of *M. japonica*. Understanding of the major environmental factors for the growth of *M. japonica* could be used for the further research about the mechanism of retaining acidic environment autonomously in montane wetlands in temperate zone.

Abbreviations

asl: Above sea level; CB: Wetland in Mt. Chilbo; EC: Electrical conductivity; GJ: Wetland in Mt. Geumjeong; HM: Wetland in Mt. Hwangmae; HRG: Wetland in Mt. Horyonggok; LOI: Loss on ignition; RDA: Redundancy analysis; RLI: Relative light intensity; SB: Wetland in Mt. Sinbul; SWC: Soil water content

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Authors' contributions

YSC performed the field survey, analyzed experimental data, and wrote the manuscript draft. HJP participated in the design of the study, conducted field survey, and edited the manuscript. JGK conceived the research idea and reviewed and edited the manuscript. The authors read and approved the final manuscript.

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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 interest

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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