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Relationship between Wetland Plant Communities and Environmental Factors in the Tumen River Basin in Northeast China

Xiaojun Zheng [1], Jing Fu [2,*], Noelikanto Ramamonjisoa [1], Weihong Zhu [3,4,5,6,*], Chunguang He [6] and Chunyan Lu [7]

[1] Graduate School of Environmental Studies, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 4648601, Japan; zhengxj233@hotmail.com or zheng.xiaojun@e.mbox.nagoya-u.ac.jp (X.Z.); noelikanto@gmail.com (N.R.)
[2] East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Shanghai 200090, China
[3] Jilin Provincial Joint Key Laboratory of Changbai Mountain Wetland & Ecology, Changchun 130102, China
[4] Key Laboratory of SFGA (SPA) on Conservation Ecology in the Northeast Tiger and Leopard National Park, Hunchun 133300, China
[5] Geography Department College of Sciences, Yanbian University, Yanji 133002, China
[6] State Environmental Protection Key Laboratory of Wetland Ecology and Vegetation Restoration, Northeast Normal University, Changchun 130024, China; he-cg@nenu.edu.cn
[7] College of Computer and Information Sciences, Fujian Agriculture and Forestry University, Fuzhou 350002, China; suzi26@163.com
* Correspondence: fu.28z@hotmail.com (J.F.); whzhu@ybu.edu.cn (W.Z.); Tel.: +86-0433-243-6450 (W.Z.)

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Abstract: Understanding what controls wetland vegetation community composition is vital to conservation and biodiversity management. This study investigates the factors that affect wetland plant communities and distribution in the Tumen River Basin, Northeast China, an internationally important wetland for biodiversity conservation. We recorded floristic composition of herbaceous plants, soil properties, and microclimatic variables in 177, 1 × 1 m^2 quadrats at 45 sites, located upstream (26), midstream (12), and downstream (7) of the Basin. We used TWINSPAN to define vegetation communities and canonical correspondence analysis (CCA) to examine the relationships between environmental and biological factors within the wetland plant communities. We recorded 100 plant species from 93 genera and 40 families in the upstream, 100 plant species from 57 genera and 31 families in the midstream, and 85 plant species from 76 genera and 38 families in the downstream. Higher species richness was recorded upstream of the River Basin. The plant communities and distribution were influenced by elevation, soil properties (total potassium, pH, and available phosphorus), and microclimate variables (surface temperature, precipitation, average temperature, sunshine hours, and relative humidity). More than any other factor, according to our results, elevation strongly influenced the structure of wetland plant communities. These findings support prevailing models describing the distribution of wetland plants along environmental gradients. The determination of the relationship between soil and plants is a useful way to better understand the ecosystem condition and can help manage the wetland ecosystem.

Keywords: canonical correspondence analysis; classification; plant community; multivariate analysis; environmental factors

1. Introduction

Freshwater wetlands are one of the most productive ecosystems and are indispensable for the countless benefits or "ecosystem services" they provide, such as biodiversity support, food and building materials, flood abatement, freshwater supply, and carbon sequestration [1–3]. Plant communities play key roles in maintaining wetland functions, and understanding the ecology of these communities is an important component of wetland conservation. Thus, information on the factors that govern community assembly rule and distribution is required [4]. Such information can particularly benefit restoration programs, particularly in regard to choosing suitable species/communities to initiate re-vegetation [5] as well as site improvement in degraded wetlands [6,7].

Many factors typically influence plant wetland communities. Among these, elevation, disturbance, and soil properties are prominent in the literature [8–10]. Still, the existing studies yield mixed results, from which no generalization emerges. One body of literature found a greater influence of soil properties such as soil moisture, salt content [11], soil organic matter [12], nitrate-N [13], and soil microbial communities [14]. Another body of research revealed that, more than soil properties, geographical attributes are more influential. For example, [8] and [15] highlighted the contribution of elevation and spatial factors, respectively, in governing plant community assembly in wetlands. Other studies found a stronger influence of hydrology [16,17], although this relation may not be clear since hydrology may also influence soil properties which itself is impacted upon by geographic location. Overall, the literature suggests that (i) changes in environmental variables can have important effects on species composition and establishment, though stochastic processes may also be operating [18,19], and (ii) the driving factors affecting wetland plant communities could be site specific and depend on the actual plant community [20].

China has lost 23% of freshwater marshes, 16.1% of lakes, 15.3% of rivers, and 51.2% of coastal wetlands as well as the services associated with these ecosystems [21]. The wetland area in the Tumen River Basin of China, characterized by its abundant biodiversity, has not been exempt from anthropogenic disturbance. The total area of wetlands here has markedly dropped off due to reclamation (e.g., construction of golf course), resulting in soil desertification and fertility loss [22]. Climate change has further accelerated wetland desiccation in the area [23]. This factor has led to significant changes in precipitation and temperature, which determine plant distribution patterns. Accordingly, as a previous study has shown, the annual average rainfall decreased by 127.4 mm and the annual average temperature increased by 2.27 °C over the past 50 years in the Tumen River area [22].

Previous studies on wetland ecology in the area have focused on wetland ecosystem health assessment, the effects of land use changes on ecosystem services, and land use dynamics [22,24], as well as the effects of wetland vegetation on soil microbial composition [14]. However, the community assembly rule and distribution of wetland plants in the Tumen River Basin still remains poorly understood. This information could be particularly important in designing wetland restoration and species conservation programs. Here, we investigate the plant communities in wetlands at upstream, midstream, and downstream locations within the Tumen River basin. Our study was motivated by two questions: what factors structure wetland plant communities in the Tumen River Basin? Are plant communities structured by similar factors at different levels of the basin?

2. Materials and Methods

2.1. Study Area

The study site (Tumen River Basin) is situated on the northeastern part of Jilin Province, China (41°59′47″–44°30′42″ N, 127°27′43″–131°18′33″ E), sharing boundaries with D. P. R. Korea and Russia (Figure 1). It is characterized by a typical temperate monsoon climate, with a mean annual precipitation of 400–650 mm. The average annual temperature is 2–6 °C, and maximum and minimum temperatures are 38 °C and −34 to −23 °C, respectively. The upstream area of the River Basin, encompasses the south of An'tu County and Helong City, and the Chinese side of Changbai Mountain. The first tributary, the Hongqi River, flows through the area. The midstream area is located in Wangqing County, south of Dunhua City, Yanji City, Longjing City, Tumen City and north of Helong City. The rivers Ga'ya, Bu'er hatong, Hailan, Yanji, and Chaoyang flow through the area. The downstream area contains Hunchun City [22]. This area is of great importance for conservation, as it is a transient habitat for endangered migratory birds. Dominant plants are herbaceous species such as *Acorus calamus*, *Equisetum arvense*, and *Deyeuxia angustifolia* etc.

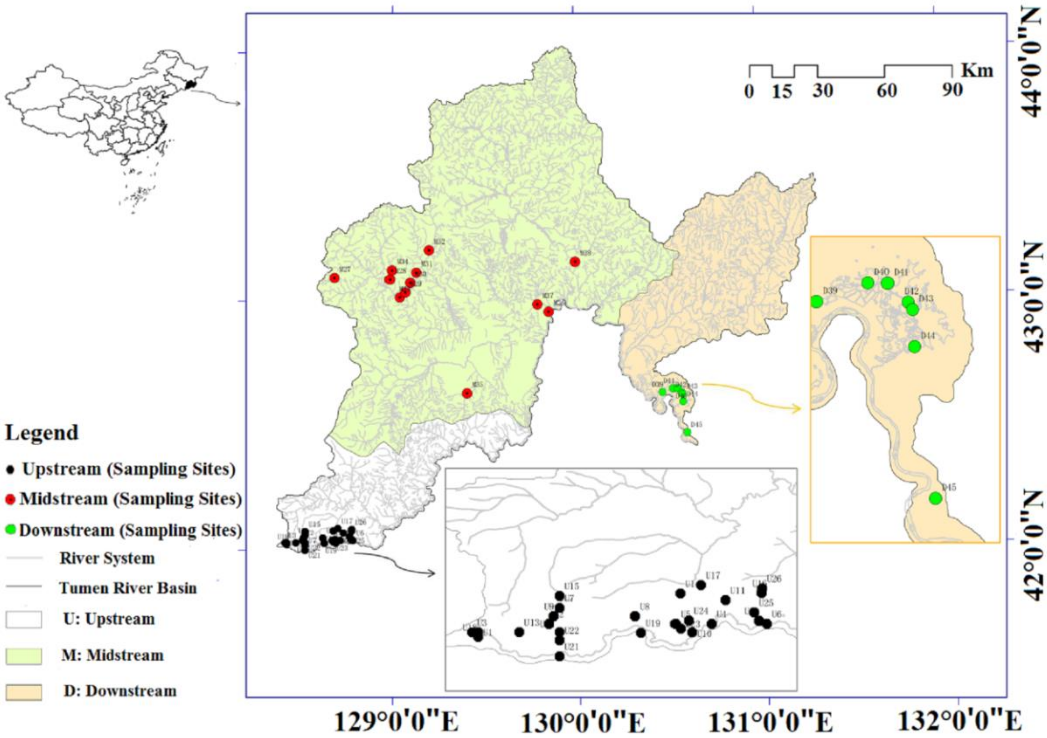

Figure 1. Geographical positon of the study area.

2.2. Data Collection

All data samples were conducted during August of 2011, the month when plant growth is most productive in Jinlin Province [25]. Sample vegetation quadrats of 1 m^2 were established at 26 sites upstream (five 1 m^2 quadrats at each of 8 sites and three at each site of 18 sites), 12 sites midstream (five and three 1 m^2 quadrats at six sites), and 7 sites downstream (five 1 m^2 quadrats at each site) of the Tumen River Basin [26]. A total of 177 quadrats were sampled across 45 sites. All quadrats were established within 10 m from streams and other water bodies.

At each site, five quadrats were positioned in open ground and three quadrats in a narrow strip 25 m apart [27,28] to sample herbaceous plants. In each habitat, the relative foliage cover on each quadrat by visual(in percentage), number of individuals, and density and frequency of each plant species were quantitatively estimated using random quadrat methods [29]. A professional botanist helped identify the plants in the field.

Three soil columns (0–15 cm depth) were taken from each quadrat, and combined to form one aggregated sample. The compounded soil samples were divided into two subsamples, one sample to be assessed for soil water content (SWC) and sealed in a polyvinyl bag; another for soil properties (soil organic matter (SOM), total nitrogen (TN), available nitrogen (AN), total phosphorus (TP), available phosphorus (AP), total potassium (TK), available potassium (AK), and soil pH (pH)) and sieved through a 2-mm mesh sieve and root fragments removed. All samples were transported to the Soil Laboratory of Yanbian University and stored at 5 °C.

Elevation (ELV) and climatic data were recorded at each site in the sampled area. Meteorological data were collected from the Jilin Province Meteorological Agency, China during the 2011 field season. The climatic information of each sampling area was based on the data of the meteorological stations in the administrative district where the sampling sites are located. These data included land surface temperature (ST), precipitation (PRE), average temperature (AT), sunshine hours (SH), and relative humidity (RH). Finally, all of the data were treated as environmental variables in this analysis.

2.3. Vegetation Data Analysis

The importance value index (IV_i) of vegetation in each sample plot was calculated as follows:

$$IV_i = DR_i + FR_i + \frac{CR_i}{3}, \quad (1)$$

where DR_i, FR_i, CR_i are the relative density, the relative frequency, and the relative cover rate of species i, respectively [30]. Additionally, the Sørenson's similarity index (SSI) was calculated by the following formula:

$$SSI = 2U_{i\&j}/(U_i + U_j), \quad (2)$$

where U_i and U_j are the number of species in sample units i and j, respectively, and $U_{i\&j}$ is the number of species common to sample units i and j [31].

The species diversity indices applied in this study are Patrich's R, Shannon-Wiener's H, a complement of Simpon's index D, and Pielou's evenness index E [32]. The formulae for the calculation methods of these indices are shown in Table 1. Four indices were selected for the estimation of species diversity, because they have low or moderate sensitivity to sample size and have been widely used in the literature [33].

Table 1. Formulae for the measurement of species diversity.

Index	Formula	Note
Patrich	$R = S$	S: the number of species recorded in the sample.
Shannon-Wiener	$H = -\sum_{i=1}^{S} p_i \log_{p_i}$	P_i: the proportional abundance of the i-th species in N individuals of S species in total, i.e. $P_i = N_i/N$.
Simpson	$D = 1 - \sum_{i=1}^{S} p_i^2$	N: the number of individuals recorded in the sample.
Pielou	$E = H/\ln S$	

2.4. Soil Properties Analyses

Soil properties were analyzed through conventional approaches [34,35]. SWC (g of water per 100 g dry soil) was analyzed by oven-drying for 48 h at 105 °C. SOM (g/kg dry soil) was measured by the heated potassium dichromate and concentrated H_2SO_4 oxidation method. pH was measured on a 1:2.5 (w/v) soil-water mixture by a pH meter. AN (mg/kg dry soil) was analyzed with alkaline hydrolysis and diffusion. TN (g/kg dry soil) was calculated using the semi-trace Kjeldahl method. AP (mg/kg dry soil) was analyzed by $NaHCO_3$ and the silica-molybdenum blue colorimetry method. AK (mg/kg dry soil) was measured with NH_4OAc extraction and flame photometric spectrophotometry. TP was analyzed with a spectrophotometer after wet digestion with H_2SO_4-$HClO_4$ (GB7852-87). TK was measured by the HF- $HClO_4$ melt flamer method.

2.5. Floristic Analysis

Floristic data were analyzed by a series of multivariate techniques. TWINSPAN analysis is a numerical method for the classification of vegetation belonging to similar groups, allowing the determination of homogenous groups [36]. This process was undertaken initially to define vegetation groups (communities), followed by canonical correspondence analysis (CCA) (conducted with CANOCO Windows 4.5 [37]), to illustrate the correlations between environmental variables and defined plant communities.

A data matrix of environmental factors (arranged in a 14 variable x 177 quadrat data matrix) and vegetation communities (arranged in a 284 species x 177 quadrat data matrix) was established. The WinTWINS (Version. 2.3, Centre for Ecology and Hydrology & University of South Bohemia, Huntingdon Ceske Budejovice, Czech Republic) computer program [38] was used to classify and ordinate the vegetation data in the gradient of environmental factors.

The significance of the resulting ordination was evaluated by a Monte Carlo test (1000 permutations). Prior to the analysis, all variables were assessed for normality, and cooperating interval transformation analysis was performed [39]. All ordinations, including CCA and principal component analysis (PCA), were performed using CANOCO version 4.5 [37].

All statistical analyses were conducted in Microsoft Excel 2010 and SPSS 19.0. Differences among groups (upstream, midstream, and downstream) in diversity indices were assessed by one-way analysis of variance (ANOVA). The least significant difference (LSD) test was used to contrast the means at $p < 0.05$. Pearson's product moment correlation coefficient was used to express the significance of a linear relationship between multiple parameters [40].

3. Results

3.1. Species Composition and Diversity Indices

The 177 sample quadrats yielded a total of 284 taxa of plants, from 148 genera and 62 families. One hundred taxa were found in the upstream area, from 93 genera and 40 families, and 100 taxa were in the midstream area from 57 genera and 31 families. Eighty-five taxa in the downstream area belonged to 76 genera and 38 families.

Sørenson's similarity index (*SSI*) was calculated to compare similarity among three different areas within family and genera level. Additionally, the results indicated that the similarity of family and genera is decreasing generally from upstream to downstream (Table 2).

Table 2. Sørenson's similarity index (*SSI*) of family and genera of the Tumen River Basin.

SSi	Upstream and Midstream	Midstream and Downstream	Upstream and Downstream
Family	0.3934	0.5614	0.2942
Genera	0.3784	0.5271	0.2454

Figure 2 demonstrates the change of wetland plant diversity from upstream to downstream, as depicted by the four diversity indices. Species richness displayed a fluctuating rising tendency from top to bottom, and species rose from less to more. The dominance and diversity index illustrated a minor fluctuating rising tendency, and the evenness index did not change markedly.

3.2. TWINSPAN

The TWINSPAN results analyzing 177 quadrats are presented in Tables A1–A3 of Appendix A.

Vegetation in the study area was classified into eight main groups in upstream, five main groups in midstream and three main groups in downstream. Each group differs from the others in its environmental needs. All groups are shown in Table 3.

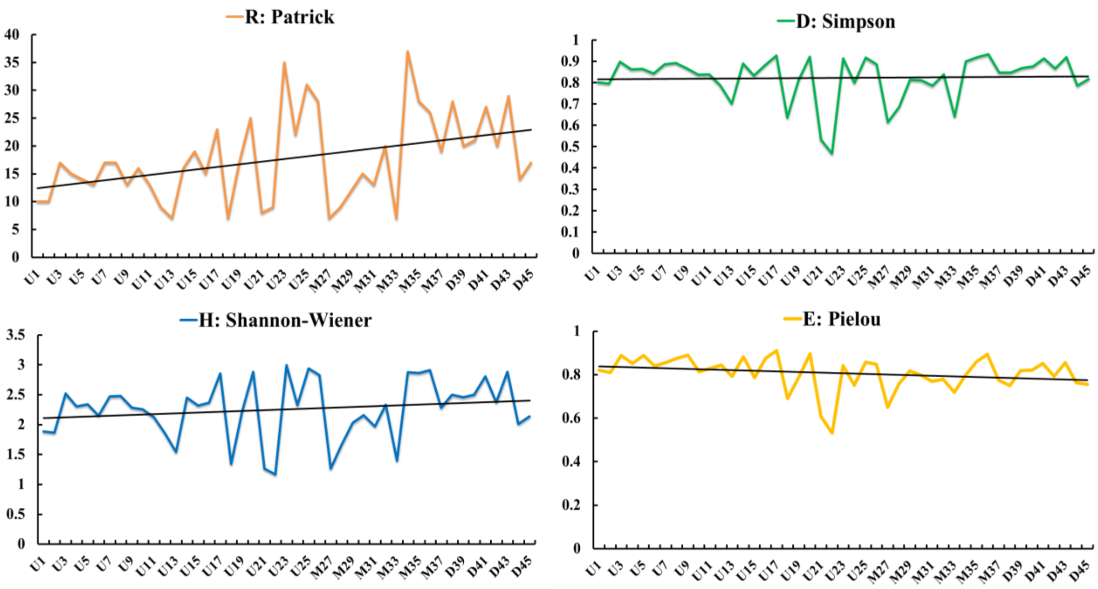

Figure 2. Plots of differing indices of plant diversity in the upstream (U), midstream (M) and downstream (D) portions of the Tumen River Basin.

Table 3. Wetland plant species groups obtained by TWINSPAN.

Group	Plant Species Types	Sites
Upstream 1	*Gr.Ass. Carex loliacea - Carex heterolepis*	U1, U12, U13, U18
Upstream 2	*Gr.Ass.Carex heterolepis - Rhododendron lapponicum - Vaccinium uliginosum*	U7
Upstream 3	*Gr.Ass. Rhododendron lapponicum - Vaccinium uliginosum*	U3, U8, U 9, U10, U11
Upstream 4	*Gr.Ass. Rhododendron lapponicum - Carex loliacea*	U2, U4, U5, U6
Upstream 5	*Gr.Ass. Deyeuxia angustifolia - Maianthemum bifolium - Melampyrum roseum Maxim*	U14, U16, U17
Upstream 6	*Gr.Ass. Carex subpediformis - Convallaria majalis*	U15, U20, U21, U22
Upstream 7	*Gr.Ass. Carex subpediformis - Maianthemum bifolium*	U19
Upstream 8	*Gr.Ass.Equisetum arvense - Carex heterolepis - Carex pilosa - Deyeuxia angustifolia*	U23, U24, U25, U26
Midstream 1	*Gr.Ass. Carex pseudo-curaica - Lemna minor*	M27, M28
Midstream 2	*Gr.Ass. Carex arnellii - Scirpus orientalis*	M33
Midstream 3	*Gr.Ass. Carex pseudo-curaica - Carex arnellii*	M29, M30, M31, M32
Midstream 4	*Gr.Ass. Deyeuxia angustifolia - Carex flacca*	M34
Midstream 5	*Gr.Ass. Equisetum arvense - Polygonum hydropiper - Scirpus orientalis - Cyperus nipponicus - Cyperus fuscus*	M35, M36, M37, M38
Downstream 1	*Gr.Ass. Aeginetia indica - Phalaris arundinacea. - Salvinia natans*	D40
Downstream 2	*Gr.Ass. Acorus calamus - Panicum bisulcatum - Myriophyllum spicatum - Salvinia natans*	D39, D41, D42, D43
Downstream 3	*Gr.Ass. Carex vesicaria - Aeginetia indica - Acorus calamus - Carex pseudo-curaica*	D44, D45

3.3. Canonical Correspondence Analysis

In this study, we found a gradient length greater than 4 standard deviations (SD), indicating the appropriateness of CCA. In CCA, arrows represent environmental factors, with arrow length proportional to the strength of the effect of each factor. The direction of the vector indicates a negative or positive correlation between the factor and the axes, and the angle between two vectors reflects the degree of correlation between variables.

The results of the CCA ordination of plant and environmental data from 45 sites are shown in Table 4 and Figure 3. The eigenvalue of the strong first axis was 0.897, while that of the second axis was 0.807. As shown in Table 4, the first axis (eigenvalue = 0.897) accounted for 8.0% of the variation of species data, and the 99.3% coefficient of correlation of the environment-species is by far the most important.

Table 4. Results of CCA analysis for vegetation factors in the study area.

Axes	CCA 1	CCA 2	CCA 3	CCA 4
Eigenvalue	0.897	0.807	0.690	0.672
Species-environment correlations	0.993	0.992	0.976	0.969
Cumulative percentage variance of species data	8.0	15.0	20.9	26.2
Cumulative percentage variance of species-environment relation	21.1	35.9	49.8	61.9

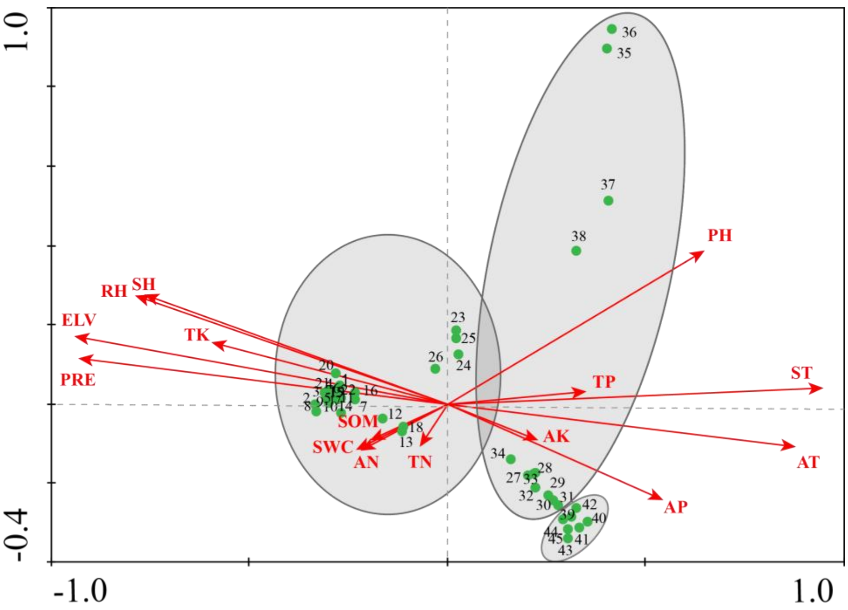

Figure 3. Canonical correspondence analysis (CCA) results—ordination of all communities in relation to environmental factors within the Tumen River Basin.

The first CCA axis was negatively correlated with ELV, TK, PRE, SH and RH (p < 0.001), but positively correlated with soil pH, AP, ST and AT (p < 0.01) (Table 5).

Table 5. Correlation between environmental variables and CCA ordination axes.

	SP1	SP2
ELV	−0.9335 ***	0.1713
TN	−0.0702	−0.1063
TP	0.3491 *	0.0314
TK	−0.5940 ***	0.1555
pH	0.6461 ***	0.3877 *
SOM	−0.1946	−0.0883
AN	−0.2344	−0.1165
AP	0.5410 ***	−0.2414
AK	0.2279	−0.0929
SWC	−0.2239	−0.1190
ST	0.9432 ***	0.0410
PRE	−0.9251 ***	0.1141
AT	0.8753 ***	−0.1071
SH	−0.7676 ***	0.2781
RH	−0.7875 ***	0.2735

Note: *** p < 0.001; ** p < 0.01; *: p < 0.05.

Table 6 shows the relationships of each environmental variable through Pearson coefficients. Among the 14 environmental factors, ELV played an indispensable role in many environmental factors: there was a negative correlation with pH, ST, and AT, and a strong positive correlation with TK, PRE, SH, and RH. Additionally, TN displayed a strongly positive correlation with SOM, AN, and SWC. TP had a strong positive correlation with AP, but a strong negative correlation with TK. Meanwhile, SOM was positively correlated with AN and SWC. The AN was positively corrected with SWC. AP showed a positive correlation with ST, whereas there was a clear negative correlation with PRE. Furthermore, meteorological factors had a significantly positive and negative correlation with each other.

From left to right along the first CCA axis in the ordination diagram (Figure 3), the ELV decreased gradually, the content of TK, PRE, SH, and RH decreased by degrees whereas the soil pH, AP, ST, and AT slowly increased. From bottom to top along the second axis, the soil pH increased only sparingly, while other environmental factors show no obvious trends. This indicates that environmental factors (specifically ELV, TK, PRE, SH, RH, pH, AP, ST, AT) strongly influence the plant species community within the study area. In addition, the results of the Monte Carlo test showed that, among all potentially influential factors, ELV ($p = -0.9335$, $p < 0.001$) indirectly affects the diversity and structure of plant communities along with other major factors.

The 45 sites are plotted along axes 1 and 2 (Figure 3). Three plant community groups could be identified according to the pattern of aggregation along the environmental axes.

Group 1, containing Carex loliacea, Carex heterolepis, Rhododendron lapponicum, Deyeuxia angustifolia, Carex subpediformis, Equisetum arvense, and Saussurea sclerolepis, was found in the upstream area of the Tumen River Basin. The ELV, TK, PRE, SH, and RH are relatively high in the upstream area, and pH, AP, ST, AT are relatively low. The distribution of the plant community in the area upstream of the Tumen River Basin is mainly affected by ELV and meteorological factors. Changes with differences in temperature and precipitation have a great influence on the distribution of the wetland plant community. These two factors affect the sub-surface water level, and the composition of wetland plant species changes and results in plant community succession. In addition, the distribution of wetland plants was influenced by TK, pH, SOM, TN, and AN. In particular, these factors (SOM, TN, and AN) indicated essential positive correlations with wetland plant community distribution. The wetland plant community high in SOM, TN and AN defined significant differences on the CCA ordination graph (Figure A1).

Group 2, containing *Carex pseudo-curaica*, *Carex arnellii*, *Cyperus nipponicus*, *Deyeuxia angustifolia*, *Equisetum arvense*, and *Polygonum hydropiper*, was found in the midstream area of the basin, where the pH, AP, ST, and AT are relatively high, and ELV, TK, PRE, SH, and RH are relatively low. The pH is the most effective for describing the distribution of vegetation in the midstream area of the Tumen River Basin (Figure A2).

Group 3, containing *Aeginetia indica*, *Acorus calamus*, and *Carex magnoutriculata*, was found in the downstream area of the basin, where ELV, TK, PRE, SH, and RH are low, and the pH, AP, ST, and AT are relatively high. Compared with the upstream and midstream areas, the wetland plant communities in the downstream area are concentrated on the right of the CCA ordination graph, and highlight relatively small differences in the environment (Figure A3).

Table 6. Pearson correlation coefficients between the environmental variables (PCA).

	ELV	TN	TP	TK	pH	SOM	AN	AP	AK	SWC	ST	PRE	AT	SH
TN	0.1709	1												
TP	−0.2115	0.2689	1											
TK	0.5500 ***	−0.4369 **	−0.7509 ***	1										
pH	−0.5736 ***	−0.2975	0.2364	−0.2437	1									
SOM	0.2544	0.9701 ***	0.1234	−0.3322 *	−0.3987 **	1								
AN	0.3380 *	0.8590 ***	0.3282	−0.2975	−0.4814 **	0.8521 ***	1							
AP	−0.4101 **	−0.0389	0.5571 ***	−0.4538 **	0.1118	−0.1890	0.0486	1						
AK	−0.0623	0.2023	0.1894	−0.1358	0.0187	0.1330	0.2385	0.3639 *	1					
SWC	0.2918	0.9634 ***	0.1273	−0.3158 *	−0.4199 **	0.9731 ***	0.8547 ***	−0.1787	0.1046	1				
ST	−0.8460 ***	−0.0939	0.4150 **	−0.5627 ***	0.5503 ***	−0.2065	−0.1557	0.6380 ***	0.329 *	−0.2597	1			
PRE	0.9000 ***	0.1489	−0.3703 *	0.5403 ***	−0.5905 ***	0.2630	0.2395	−0.5422 ***	−0.3091 *	0.3137 *	−0.9220 ***	1		
AT	−0.9563 ***	−0.2646	0.1067	−0.4684 **	0.6204 ***	−0.3296 *	−0.4287 **	0.2793	0.0130	−0.3671	0.7901 ***	−0.8722 ***	1	
SH	0.8191 ***	0.2118	−0.1898	0.4154 **	−0.4908 ***	0.2958	0.2956	−0.3520 *	−0.2691	0.3310	−0.7416 ***	0.9227 ***	−0.8671 ***	1
RH	0.8160 ***	0.2022	−0.1535	0.4277 **	−0.4207 **	0.2760	0.2602	−0.4072 **	−0.2872	0.3078	−0.8118 ***	0.8883 ***	−0.8736 ***	0.9443 ***

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ * Elevation (ELV), soil organic matter (SOM), total nitrogen (TN), available nitrogen (AN), total phosphorus (TP), available phosphorus (AP), total potassium (TK), available potassium (AK), soil pH (pH), soil water content (SWC), surface temperature (ST), precipitation (PRE), average temperature(AT), sunshine hours (SH) and relative humidity (RH).

4. Discussion

We investigated the relationships between wetland plant communities and environmental factors in the Tumen River Basin upstream, midstream, and downstream. Communities were strongly structured by the environment, suggesting that stochastic processes may have little influence in delineating communities in this system. Around 60% of the variance explained the relation between the environment and species distribution, and we speculate that the remainder might be in part explained by biotic factors such as competition and facilitation [41]. Plant communities at different levels of the basin were determined by different environmental factors. Upstream communities were mostly affected by elevation, precipitation, and total potassium, whereas midstream and downstream communities appear to be mostly structured by soil properties such as available potassium and available phosphorus. This suggests that the plant communities are limited by different soil properties and this was reflected in the index of similarity of plant communities between the three areas.

Corroborating the results of previous studies [8–10], elevation and soil fertility played important roles in structuring the wetland plant community within our study area. Community distribution was most strongly correlated with nine major environmental factors (elevation, total potassium, soil pH, available phosphorous, surface temperature, precipitation, average temperature, sunshine hours and relative humidity). Among these, elevation is one of the most important factors because it can affect soil chemistry, surface temperature, precipitation, sunshine hours, relative humidity, average temperature, water depth during flood events, and soil moisture, all of which indirectly affect the diversity and structure of plant communities in wetlands [42]. Soil characteristics could be particularly strong predictors of species diversity and composition in harsh environmental conditions, poorly developed soils [27], and in heterogeneous environments where the spatial distribution of plant species depends on a specific niche [43]. For example, the diversity and distribution of plant species are associated with soil available nitrogen and phosphorus [44], soil moisture and nutrients [45,46], as well as soil chemistry (soil pH, calcium, and organic carbon) [47,48]. An earlier study revealed a strong linkage between plant communities and soil microbial communities in the Tumen River Basin [14], and although not investigated here it is possible that soil microbial composition varies with altitude. After all, the variation in altitude from upstream to downstream within the basin is 1029 m.

Some sampling sites with relatively lower diversity at upstream and midstream sections of the basin could be explained by recent anthropogenic disturbances (e.g., construction of golf courses in the midstream and some industrial factories in the upstream). Conversely, some sites in the downstream were relatively species-rich because of the protection afforded by a conservation area (e.g., site D45 is near wetland reserve of Lotus Lake). These could explain why there are differences in community composition. We developed a scheme for wetland plant community conservation according to different types of results in three different areas in the basin.

Finally, it must also be noted that some complex scientific issues were not addressed in our paper. For example, plant degradation of wetlands in response to environmental drivers was outside the scope of our work, as was the role of landscape factors in determining community variation. There is, therefore, a pressing need for ongoing investigation to gain further ecological knowledge of the Tumen River Basin.

5. Conclusions

Our results confirmed that plant community and distribution in the Tumen River Basin were impacted by elevation, soil properties (total potassium, pH, and available phosphorus), and microclimate variables. Knowledge of the influence of soil properties on the plant communities can be utilized in restoration programs where the choice of suitable species/communities is required in revegetation. This study increases our understanding of the distribution patterns of wetland plants and the dominating environmental aspects in the basin, and could provide a theoretical basis for the design of sustainable protection and reclamation of wetland ecological environments [23].

Author Contributions: X.Z. and F.J. collected and processed the data, performed analysis, and wrote the paper. N.R. wrote the introduction. W.Z and C.H. conceived and designed the study. All authors reviewed and edited the draft, approved the submitted manuscript, and agreed to be listed and accepted the version for publication.

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Appendix A

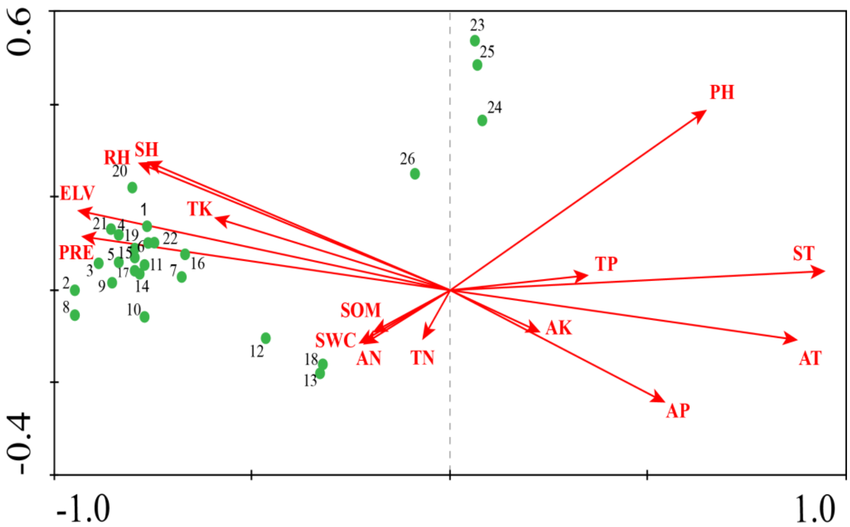

Figure A1. CCA results—ordination of upstream communities in relation to environmental factors within the Tumen River Basin.

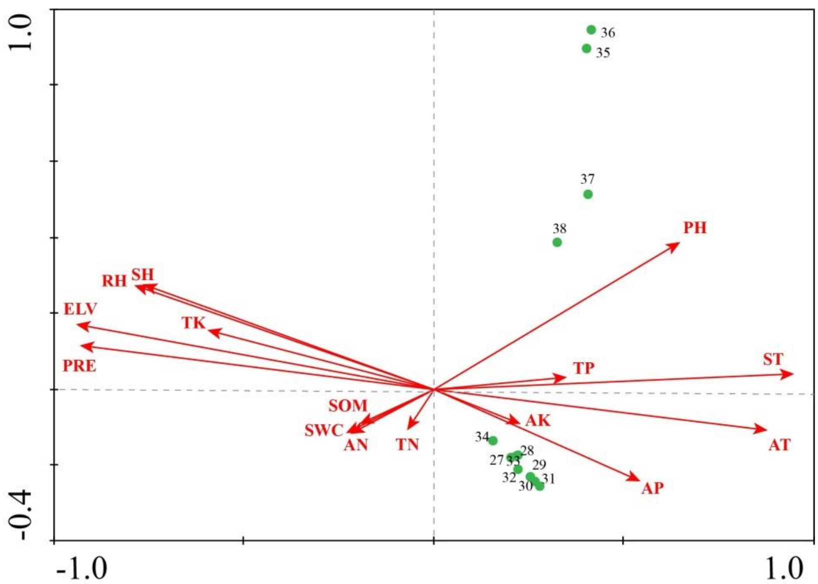

Figure A2. CCA results –ordination of midstream communities in relation to environmental factors within the Tumen River Basin.

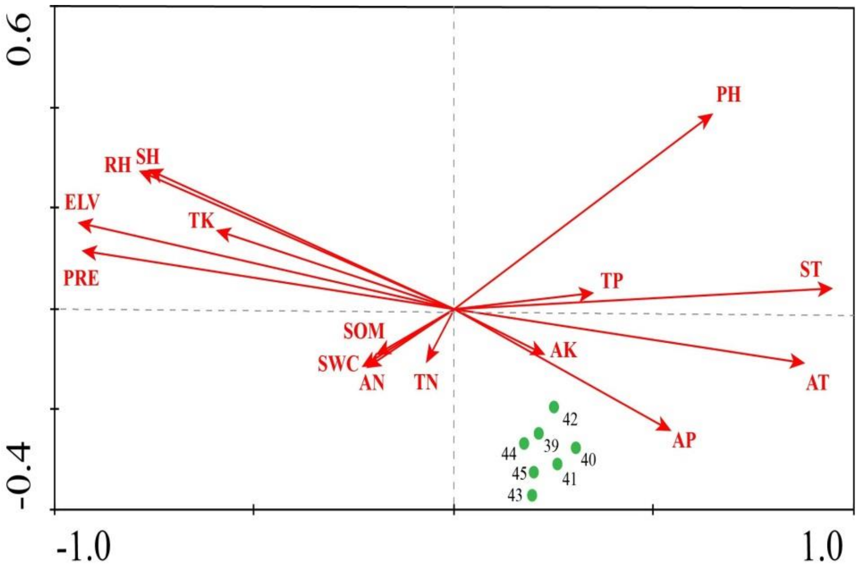

Figure A3. CCA results—ordination of downstream communities in relation to environmental factors within the Tumen River Basin.

Table A1. TWINSPAN of the vegetation cover in 94 quadrats and 100 species in upstream.

Species	Sampling Sites (U)	LSD
	0111000011000011112221 2222	
	1238738901245646750129 3456	
11	11–1————————	000000
13	-111————————-	000000
30	–1————————	000000
37	1————————-	000000
44	-11————————	000000
54	-1————————	000000
100	-1111-1———————-	000000
135	-11—1————1—-	000001
71	—1———-1——1—-	00001
2	————————1—-	000100
5	——————-11—1—-	000100
15	———————111——	000100
19	———————1-1——	000100
21	———————1——	000100
25	———————1——-	000100
27	———————11——	000100
36	———————1——-	000100
59	——————-11111——	000100
69	——————11111-1—-	000100
85	———————1–1—-	000100
96	—————1–11-1——	000100

Table A1. *Cont.*

Species	Sampling Sites (U)	LSD
	01110000110000111122212222	
	12387389012456467501293456	
107	——————1-1-11——	000100
134	——————1111–1—-	000100
146	———————1–1—-	000100
67	—————1–1———	000101
121	—————11111–1—-	000101
98	———1-11-111111-1—-	00011
102	—-1-1——-1111———	00011
50	-111-111–11-1—————	001000
142	–1–1—1——————-	001000
144	1—1—-11-1—————	001000
53	——-111–1111111——-	001001
62	—-1111111-1111111111—-	001001
88	——11111111111111–1—-	001001
145	——1–1-1111-11-1–1—-	001001
4	——1————————	001010
16	—-1111111111–111——-	001010
17	——1————————	001010
18	——11-1–1——————	001010
29	—-1—————————	001010
38	—-1111111111111————	001010
39	—-1—————————	001010
51	——1————————	001010
52	—-1-11—11—————-	001010
65	—-111111-11-1————	001010
101	——-1-11——————-	001010
123	——1111-1111—1———	001010
124	—————11—————	001010
132	—-11111111111—————	001010
12	———————-1————	001011
42	———————-1————	001011
7	—-1-11—1—-1———1	00110
133	—-11——11-1111——-1	00110
139	1—111111—-1———1—1	00110
45	—————111——1—	00111
129	11–111111111111111—111-	00111
28	———————1–11—	01
35	——————1111-1-111-	01

Table A1. *Cont.*

Species	Sampling Sites (U)	LSD
	011100001100001111122212222	
	1238738901245646750129 3456	
112	——————-11–1–	01
140	—-1—————11–	100
117	——————1—11-1	10100
1	———————11–	10101
3	————————-1	10101
6	————————11	10101
8	————————1-	10101
10	———————11–	10101
14	———————1—	10101
20	————————-1	10101
22	———————1—	10101
23	———————1—	10101
24	————————-1	10101
26	————————1-	10101
31	———————11–	10101
32	———————1—	10101
33	———————1—	10101
34	————————-1	10101
40	———————1—	10101
41	———————11–	10101
43	———————1—	10101
46	————————-1	10101
47	————————1-	10101
48	————————1-	10101
49	———————-111-	10101
56	———————-1-1-	10101
84	———————-1111	10101
87	———————1-1	10101
90	————————11	10101
92	———————-1-1-	10101
114	———————-1111	10101
118	———————111	10101
119	———————11–	10101
120	————————11	10101
122	———————11–	10101
131	———————11–	10101

Table A1. *Cont.*

Species	Sampling Sites (U)	LSD
	01110000110000111122212222	
	12387389012456467501293456	
136	———————-11–	10101
137	———————-1111	10101
138	————————11	10101
141	————————11	10101
86	—1——————1111	1011
9	-1-1——————1–	11
	00000000000000000000001111	
	0000111111111111111111	
	000000000000011111	
	000000000011100001	
	0111111111	
	0000001111	

Table A2. TWINSPAN of the vegetation cover in 48 quadrats and 100 species in midstream.

Species	Sampling Sites (M)	LSD
	223233333333	
	783901245678	
4	——-1—-	00000
9	——-1—-	00000
10	——-1—-	00000
12	——-1—-	00000
24	——-1—-	00000
37	——-1—-	00000
47	——-1—-	00000
51	——-1—-	00000
52	——-1—-	00000
53	——-1—-	00000
67	——-1—-	00000
72	——-1—-	00000
73	——-1—-	00000
74	——-1—-	00000
76	——-1—-	00000
77	——-1—-	00000
106	-1—-1—-	00001

Table A2. *Cont.*

Species	Sampling Sites (M) 223233333333 783901245678	LSD
25	——11—-	0001
90	——11—-	0001
114	——11—-	0001
41	—-1111—-	00100
49	—-1111—-	00100
83	—111-1—-	00100
97	—-1111—-	00100
13	—1111—–	001010
21	—-1-1—–	001010
28	—1-1——	001010
32	——1—–	001010
54	—–11—–	001010
99	—-111—–	001010
14	–1—1—–	001011
36	–1———	001011
19	-1———-	001100
27	1-1111—–1	001100
30	1111———	001100
43	-1———-	001100
44	1————	001100
57	111-111—–	001100
63	-1———-	001100
66	11-1111—–	001100
69	1–1———	001100
113	1-11111—–	001100
31	-1-1–11—-	001101
103	-1-1–11—-	001101
50	—1111—11	00111
112	—-1-1—-1	00111
11	——-11—	01
45	-1-1—-1-1-	01
93	—-1-111-11	01
110	–1—-1—1	01
107	——-1–11	10

Table A2. *Cont.*

Species	Sampling Sites (M) 223233333333 783901245678	LSD
1	———1–	11
2	——1—	11
3	———1	11
5	——11–	11
6	——1—	11
7	———1	11
8	——1—	11
15	———-1-	11
16	——1—	11
17	———11-	11
18	———1	11
20	——1111	11
22	———1–	11
23	———-1-	11
26	———1–	11
29	———-1-	11
33	———1–	11
34	———1–	11
35	———1	11
38	———1-1	11
39	———1–	11
40	———-1-	11
42	———-1-	11
46	——11-1	11
48	———-11	11
55	———-11	11
56	———1	11
58	———1–	11
59	——1—	11
60	——1—	11
61	———1–	11
62	——1—	11
64	———1–	11
65	———1–	11
68	———1–	11
70	———-1-	11

Table A2. *Cont.*

Species	Sampling Sites (M)	LSD
	223233333333	
	783901245678	
71	———1—	11
75	———11-1	11
78	———1—	11
82	———1-11	11
85	————-11	11
88	———11–	11
89	———11-1	11
91	———1–1	11
92	———11-1	11
105	———11-1	11
109	———11-1	11
111	———1111	11
115	———11-1	11
	000000001111	
	00000001	
	0011111	
	01111	

Table A3. TWINSPAN of the vegetation cover in 35 quadrats and 85 species in downstream.

Species	Sampling Sites (D)	LSD
	4344444	
	0912345	
1	1——	00000
14	1——	00000
25	1——	00000
29	1——	00000
40	1——	00000
44	1——	00000
54	1——	00000
57	1——	00000
60	1——	00000
80	1——	00000
2	11—–	00001
5	1—1–	00001
7	1-1—-	00001
28	1-111–	0001
67	111—-	0001
75	1-11—	0001

Table A3. *Cont.*

Species	**Sampling Sites (D)**	**LSD**
	4344444	
	0912345	
84	11-11–	0001
32	11111–	0010
3	–1—-	0011
9	—11–	0011
10	—-1–	0011
11	–1—-	0011
16	–1—-	0011
19	—-1–	0011
20	–1-1–	0011
22	–1-1–	0011
24	-1–1–	0011
27	—-1–	0011
31	—1—	0011
33	-1111–	0011
37	–1—-	0011
41	–1—-	0011
45	–1—-	0011
46	—-1–	0011
47	—1—	0011
51	-1–1–	0011
53	—-1–	0011
56	-1–1–	0011
58	—-1–	0011
59	-1—–	0011
61	—-1–	0011
64	—1—	0011
65	–1—-	0011
68	—-1–	0011
69	-1—–	0011
70	—-1–	0011
71	—1—	0011
72	-111—	0011
73	-1–1–	0011
74	–1—-	0011
78	-1-11–	0011
81	–1-1–	0011

Table A3. *Cont.*

Species	Sampling Sites (D)	LSD
	4344444	
	0912345	
82	—1—	0011
83	–1—-	0011
85	—-1–	0011
23	11111-1	01
35	1-1111-	01
38	-111–1	01
79	111–1-	01
4	–11-1-	10
17	-1-1–1	10
26	—11-1	10
30	-11—1	10
76	–1-1-1	10
43	1-1–1-	110
6	-1—1-	1110
21	-1—1-	1110
62	—1-1-	1110
8	——1	1111
12	—-1-	1111
13	—-111	1111
15	——1	1111
18	—-1-	1111
34	——1	1111
36	—-1-	1111
39	——1	1111
42	—-1-	1111
48	——1	1111
49	——1	1111
50	——1	1111
52	—-1-	1111
55	——1	1111
63	—-1-	1111
66	—-11	1111
77	——1	1111
	0000011	
	01111	

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