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Impact of human activities on plant species composition and vegetation coverage in the wetlands of Napahai, Shangri-La County, Yunnan Province, China

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Plant species composition and vegetation coverage are critical indicators in vegetation disturbance and restoration, but their correlations are dynamic and complex under human disturbance. Inadequate attention has been paid to the correlations between species composition and vegetation coverage associated with vegetation disturbance on plateaus. We analyze the origin of species, chorological spectra, life-forms and dominant species in the Napahai wetland of Yunnan Province, China. The correlations between species composition and vegetation coverage associated with human disturbance were then investigated by hierarchical partitioning and regression analysis. A total of 71 plant species belonging to 47 genera and 24 families were identified. Our results revealed that the plant composition of the Napahai Plateau vegetation was relatively monotonous, with the three dominant chorological types consisting of 68.4–100.0% of all genera. The wetlands studied have suffered from significant changes in species composition caused by human disturbance, and several plant species might have disappeared following such disturbance. Species richness, the most significant explanatory variable, independently contributed to 25.9% of the variance in vegetation coverage. A model constructed using the three dominant factors explained 68% of the variance in vegetation coverage. Our results highlight the dramatic changes in characteristics of plant species composition after human disturbance, and the effects of human disturbance on vegetation coverage. Several suggestions were also proposed to increase vegetation coverage in degraded wetland plateau areas of Napahai.

Keywords: degraded vegetation; Napahai; plant species; wetland plateau; vegetation coverage; vegetation restoration

1. Introduction

Societies worldwide commonly consider wetlands as being very important and a valuable asset to humanity (Kaffashi et al. 2013). Wetlands provide numerous beneficial ecosystem services, including protecting and improving water quality, providing fish and wildlife habitats, storing floodwaters and maintaining surface water flow during dry periods (EPA 2013). However, in many regions of the world, wetlands are suffering accelerating degradation because of overexploitation, drainage and conversion to other land uses (Zhang et al. 2006; Ren et al. 2012; Xie et al. 2012). Thus, ecological researchers worldwide have attached great importance to the study of the anthropogenic degradation and restoration of wetlands (Chen 1995; Tian 2004; Millennium Ecosystem Assessment 2005; Tang et al. 2013).

One of the most important targets of wetland vegetation restoration is increasing vegetation coverage. Rees et al. (2001) reported that changes in vegetation coverage might influence soil erosion, land degradation, salinization, desertification and even affect the global environment. In China, vegetation coverage refers to the percentage of land covered based on the vertical projection of vegetation (Zhang 1996) and it is used as a basic index

in national environmental assessments. Vegetation coverage is a major part of vegetation and environmental research in China (Liu et al. 2009).

There are direct and indirect factors that influence vegetation coverage. Directly, in a specific area, species composition and the individual size of plants of each species determine vegetation coverage. Indirectly, water resources (especially underwater), slope, land use, soil, climate and human disturbance affect vegetation coverage (Naumburg et al. 2005; Peng et al. 2012; Zhu et al. 2012). The extent to which species composition affects vegetation coverage has, to date, rarely been reported, and the relationship between species composition and vegetation coverage requires further study (Li et al. 2013; Ren et al. 2013; Song et al. 2013).

The Napahai wetland belongs to the category of low-latitude and high-elevation plateau wetlands. The development and evolutionary processes occurring in this kind of wetland are significantly different from other wetlands in China. Although the Napahai wetland is unique in China, the region is still comparatively poorly studied and understood (Tian 2004). However, intensive human disturbance in the Napahai wetland continues to cause increasing environmental degradation. As the spatial extent of the

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wetland continues to shrink, there is concurrent loss of wildlife habitat, soil degradation and a decline in biodiversity (Sun 1988; Wen et al. 1995).

To illustrate the correlations between species composition and vegetation coverage, we investigate the species composition of the degraded plateau wetland in Napahai.

2. Methods

The study site is located in Napahai Shangri-La County, Yunnan Province, China, in the central region of the north-west portion of the Hengduan Mountains within Yunnan (99°37'–99°43'E, 27°49'–27°55'N). The plateau wetlands investigated are classified as low-latitude and high-elevation plateau swamp wetlands, representing the most typical wetlands in the Yunnan Plateau swamp. The elevation is 3260 m above sea level and annual average precipitation is around 625.4 mm. Napahai has a west monsoon climate. The soil is mainly swamp soil, peat soil and cultivated soil. A preliminary field survey found the vegetation in the plateau wetland to be mainly herbs and the study site to be composed mainly of four types of wetlands, i.e. riverine wetland, wet meadow, seasonally flooded wetland and disturbed wet meadow.

The riverine wetland on the plateau is a natural open conduit that contains water throughout the year. Wet meadow is a type of semi-wetland meadow that is saturated with, but not covered by, water for most of the year. Seasonally flooded wetland is a type of wetland that is flooded in some season(s). It exhibits the characteristics of wet meadow in a non-flooded season(s). Disturbed wet meadow is a type of wet meadow that has been disturbed by farming animals, primarily pigs, and suffers from degradation.

2.1. Study sites

We chose the degraded plateau wetlands in Napahai as our case study. Plant species composition was analyzed by documenting the characteristics of each site's species diversity, original composition, chorological spectra, dominant species and life-form composition. Prior to vegetation analysis, stratified random selection was performed to select representative plots. Area-proportional plots were randomly selected in each type of wetland. The vegetation investigation covered the main types of wetlands in Napahai. Our entire study site was covered by herbs, so we used $1 \times 1 \text{ m}^2$ quadrates for vegetation plots. Species names were determined by local botany experts and the average height and coverage of each species were measured.

2.2. Data and analyses

2.2.1. Importance value of plant species

The importance value represents the relative importance of a species in a specific study range, and is calculated for each wetland type using (Zhang 2004; Zhao, Ouyang, Xu, et al. 2010):

$$S_i = (F_i + C_i)/2 \quad (1)$$

where S_i is the importance value for the i th species, and F_i and C_i represent the relative frequency and relative coverage, respectively, of the i th species. For each type of wetland, F_i is obtained by dividing the frequency of the i th species in all plots by the total accumulated frequency of all the species, and C_i is obtained by dividing the accumulated coverage of the i th species by the total accumulated coverage of all the species (Zhao, Ouyang, Zheng, et al. 2010).

2.2.2. Simpson diversity index

The Simpson diversity index is

$$D = 1 - \sum_{i=1}^s P_i^2 \quad (2)$$

where D is the Simpson diversity index; P_i is obtained by dividing the total number of individuals of i th species by the total number of individuals of all the species in that type of wetland (Sun 1992).

2.2.3. Patrick richness index

The Patrick richness index is

$$R = S \quad (3)$$

where R is the Patrick richness index and S is the total number of plant species in that type of wetland (Xie et al. 2012).

2.2.4. Pilou evenness index

The Pilou evenness index is

$$J_{sw} = (-\sum_{i=1}^s P_i \ln P_i) / \ln S \quad (4)$$

where J_{sw} is the Pilou evenness index; P_i is obtained by dividing the total number of individuals of i th species by the total number of individuals of all the species in the investigated wetland type; and S is the total number of species in the type of wetland (Xie et al. 2012).

2.2.5. Determination of dominant species, species origin, life-form and chorological spectra

The dominant species were determined by importance value. In this study, the five most important species were classified as dominant species. The coverage of the species with the highest importance value was analyzed to determine the relationship between the dominant species and vegetation coverage.

The origin of each plant species was determined by reference to their origins specified in the *Flora of China*

(Compilation Committee of the Flora of China 1959–2004) and the *Yunnan Flora* (Kunming Institute of Botany, Chinese Academy of Sciences 1993). The species origin composition was analyzed by the proportional distribution of native and alien species in each type of wetland. The species origin of plants was identified according to their immigration status (Pyšek 1998; Zhao, Ouyang, Zheng, et al. 2010).

The life-form of each species was first determined by reference to the *Flora of China* (Compilation committee of the Flora of China 1959–2004) and the *Yunnan Flora* (Kunming Institute of Botany, Chinese Academy of Sciences 1993). The composition of the life-form was then determined by the proportion of life-forms for each species. For those species with more than one life-form, the most commonly observed life-form for the species under the specific type of wetland was chosen (Zhao, Ouyang, Zheng, et al. 2010).

The chorological spectrum, or areal type and chorological type, refers to the geographical distribution of specific genera in the world (Wen et al. 1995). We determined the specific chorological spectrum for each genus using the method of Wen et al. (1995). The chorological composition of plant species in the wetlands was analyzed by the proportional distribution of each type in the chorological spectrum (Zhao, Ouyang, Zheng, et al. 2010).

2.2.6. Data analysis

We obtained the linear regressions for all indices of species composition to select for significant variables to use in our analysis. Hierarchical partitioning was used to determine the independent and joint contributions for the eight most significant variables. We then constructed a linear model using a multi-variable linear regression based on the three most significant and least collinear variables.

Linear regression and hierarchical partitioning were performed according to Zhao et al. (2012) and Zhao, Chen, et al. (2013). For each linear regression, an approximately normal distribution of the residuals was proved by a QQ-plot of model residuals and boxplot of residuals, and Levene's test was used to test for homogeneity of residual variances (Zhao et al. 2012; Zhao, Zheng, et al. 2013). For hierarchical partitioning, significances of the independent contributions of variables were tested by a randomization routine, which yielded Z-scores for the generated distribution of randomized independent contributions, and a measure of statistical significance (*) based on an upper 0.95 confidence limit (Heikkinen et al. 2005).

3. Results

3.1. Species diversity

During the investigation of the degraded Napahai Plateau wetlands, 71 plant species belonging to 47 genera and 24 families were recorded, of which 61 (86%) were native

Figure 1. Patrick richness of wetland vegetation in Napahai during different growth seasons.

species. Only one species, i.e. *Lotus corniculatus* var. *japonicus*, was reported to be invasive. The most common life-forms were perennial (66.2%) and annual (32.8%) herbs, with only one shrub species found.

As a result of the high altitude, the growing season for plants in the Napahai Plateau was relatively short. In April, when plants start to grow, species richness was relatively low, and Patrick richness values were between 2.0 and 7.1. After several months of growth, the Patrick richness value peaked in July, and then declined in September (Figure 1). Comparing the four types of wetland, Patrick richness and Simpson diversity were the highest in wet meadow and the lowest in riverine wetland. In human-disturbed wet meadow, Patrick richness and Simpson Diversity both decreased significantly compared with non-disturbed wet meadow (Figures 1 and 2). Pielou evenness did not exhibit significant variation between the different seasons for all habitats (Figure 3).

3.2. Dominant plant species

The dominant species varied between the different types of wetland and in different growth seasons. The most important dominant species of riverine wetland included *Eleocharis liouana*, *Hippuris vulgaris*, *Batrachium bungei* and *Potamogeton distinctus*; in wet meadow, they were *Carex* sp., *Carex nubigena*, *Potentilla anserina*, *Poa nubigena*, *Plantago asiatica* and *Blysmus sinocompressus*; in seasonally flooded wetland they were *B. sinocompressus*, *H. vulgaris*, *Carex* sp. and *Juncus prismatocarpus*; and in human-disturbed wet meadow they were *P. anserina*, *P. asiatica*, *B. sinocompressus*, *Polygonum sibiricum* and *Poa annua* (Table 1).

Figure 2. Simpson diversity of wetland vegetation in Napahai during different growth seasons.

Figure 3. Pilon evenness of wetland vegetation in Napahai during different growth seasons.

The dominant species of riverine wetland were different from those of other wetland types, and continually dominant species were rare in this type of wetland. Species in human-disturbed wet meadow were relatively similar to wet meadow, because many of the dominant species were common for both of these wetland types. However, human disturbance led to less variation in dominant species in different growing seasons. Four of the five

most important species did not vary during different seasons in disturbed wet meadow. But, in non-disturbed wet meadow, only two of the five most important species were the same species between different growth seasons.

3.3. Chorological spectra

The most common chorological type in Napahai was Cosmopolitan. The cumulative percentages of genera of the 'Cosmopolitan' spectrum ranged from 48.2% to 66.7% for different wetlands in different seasons (Figure 4). Other chorological types with higher proportions of genera were 'North Temperate' and 'Old World Temperate', which were both occupied by more than 5% of genera in most wetland types. Most of the other chorological types only appeared in specific wetland(s) and/or in a specific season(s). For example, 'East Asia' and 'Tropical Australasia' spectra were only recorded in the riverine wetland, with a cumulative percentage of genera of 5.9–14.3%; 'Tropical Asia' and 'Tropical Australasia' spectra were only occasionally found in human-disturbed wet meadow in July; plants of the 'Endemic to China' spectrum only appeared in wet meadow, but not in human-disturbed wet meadow; plants of the 'Eurasia and South Africa disjuncted' and 'Sino-Himalaya' spectra were only recorded in wet meadow and human-disturbed wet meadow, with cumulative genera of 4.8–5.3%.

3.4. The relationship between species composition variables and vegetation coverage

After ln-transformation of species composition indices, the relationship between vegetation coverage and species composition was analyzed by Pearson linear regressions. Ten of the 16 species composition variables were significantly related to vegetation coverage (Table 2). The six insignificant variables were indices of chorological types with a rather low percentage of genera, which contributed a relatively low amount of the variation in chorological spectra. The other four indices of chorological types with a higher percentage of cumulative genera all have significant relationships with vegetation coverage. The highest adjusted R -square values appeared in regressions for Patrick richness, Simpson diversity and the coverage of the most important dominant species. Both the indices of life-form exhibited significant relationships with vegetation coverage.

3.5. Relative effects of individual variables

After linear regression for all of the individual variables, a hierarchical partitioning was performed to analyze the independent and joint contributions of the eight most significant variables (Figure 5). As a result, all of the eight variables had significant independent contributions to the variation in vegetation coverage. Among the selected variables, Patrick richness exhibited the highest independent

Table 1. Dominant species in different wetlands of Napahai during different growing seasons.

	Riverine wetland	Wet meadow	Seasonally flooded wetland	Disturbed wet meadow
April	<i>Eleocharis liouana</i>	<i>Carex</i> sp.	<i>Blysmus sinocompressus</i>	<i>Potentilla anserina</i>
	<i>Hippuris vulgaris</i>	<i>Carex nubigena</i>	<i>Hippuris vulgaris</i>	<i>Plantago asiatica</i>
	<i>Zizania latifolia</i>	<i>Potentilla anserina</i>	<i>Eleocharis liouana</i>	<i>Blysmus sinocompressus</i>
	<i>Batrachium bungei</i>	<i>Poa nubigena</i>	<i>Scirpus validus</i>	<i>Polygonum sibiricum</i>
July	<i>Blysmus sinocompressus</i>	<i>Ranunculus napahaiensis</i>	<i>Cardamine gracilis</i>	<i>Hippuris vulgaris</i>
	<i>Eleocharis liouana</i>	<i>Carex</i> sp.	<i>Carex</i> sp.	<i>Potentilla anserina</i>
	<i>Potamogeton distinctus</i>	<i>Plantago asiatica</i>	<i>Hippuris vulgaris</i>	<i>Blysmus sinocompressus</i>
	<i>Poa nubigena</i>	<i>Blysmus sinocompressus</i>	<i>Blysmus sinocompressus</i>	<i>Plantago asiatica</i>
September	<i>Hippuris vulgaris</i>	<i>Potentilla anserina</i>	<i>Menyanthes trifoliata</i>	<i>Poa annua</i>
	<i>Bidens cernua</i>	<i>Carex nubigena</i>	<i>Juncus prismatocarpus</i>	<i>Polygonum sibiricum</i>
	<i>Potamogeton distinctus</i>	<i>Poa nubigena</i>	<i>Juncus bufonius</i>	<i>Potentilla anserina</i>
	<i>Eleocharis liouana</i>	<i>Carex</i> sp.	<i>Hippuris vulgaris</i>	<i>Blysmus sinocompressus</i>
	<i>Lemna minor</i>	<i>Plantago asiatica</i>	<i>Utricularia exoleta</i>	<i>Poa annua</i>
	<i>Batrachium bungei</i>	<i>Blysmus sinocompressus</i>	<i>Carex</i> sp.	<i>Plantago asiatica</i>
	<i>Hippuris vulgaris</i>	<i>Potentilla anserina</i>	<i>Juncus prismatocarpus</i>	<i>Polygonum sibiricum</i>

Figure 4. Chorological spectra composition of different types of wetlands in Napahai.

Table 2. Relationship between species composition indices and vegetation coverage for Napahai wetlands based on results from linear regressions.

	Adjusted <i>R</i> -square	<i>p</i> -Value
Old world temperate spectrum	0.0852	<0.001
North temperate spectrum	0.1015	<0.001
Perennial herb species ratio	0.1234	<0.001
Pilou evenness index	0.1505	<0.001
Coverage of the most important dominant species	0.261	<0.001
Annual herb species ratio	0.2726	<0.001
Simpson diversity index	0.3792	<0.001
Patrick richness index	0.6429	<0.001
Sino-Himalaya spectrum	0.022	0.044
Pantropic spectrum	0.038	0.011

Notes: To improve the comparability and the linearity of relationships between predictor variables and trend of green space coverage, all the predictor variables were ln-transformed.

and joint contribution to the variance of vegetation coverage at 25.9% and 38.7%, respectively. Simpson diversity was the second highest in independent and joint contributions, contributing 13.2% and 25.2%, respectively (Figure 5). Another index with a higher independent contribution was the coverage of the most important dominant

species (8.7%). Between the two indices of life-forms, 'annual herb' had relatively higher contributions, with an independent contribution of 7.3% and a joint contribution of 20.4%. 'Old World Temperate' and 'North Temperate' spectra were the chorological types with the highest contributions.

Figure 5. Contributions to the variance of vegetation coverage by the eight most significant variables.
Notes: ‘*’ denotes that the effect of this variable is significant at $p < 0.05$. All the variables were ln-transformed.

Table 3. Results of multi-linear regression of vegetation coverage.

Model	Label for variables	Un-standardized coefficients	Standardized coefficients	Collinearity statistics	
		B-value	Beta	VIF (variance inflation factor)	Sig.
(Constant)		36.2586			<0.001
Patrick diversity index	b_1	43.5497	0.7022	0.6563	<0.001
Annual herb percentage	b_2	2.5227	0.1260	0.6722	0.030
Old world temperate percentage	b_3	4.0128	0.1928	0.9680	<0.001

3.6. Multi-linear regression for a model of vegetation coverage

Based on joint contributions of different combinations of variables calculated by hierarchical participation, a model was constructed using the three most significant and least collinear variables, as follows:

$$y = -36.259 + 43.550b_1 + 2.523b_2 + 4.013b_3 \quad (5)$$

where y is the vegetation coverage, b_1 is Patrick Diversity Index, b_2 is Annual Herb Percentage and b_3 is Old World Temperate Percentage. As revealed by the regression, higher species diversity, higher coverage of annual herbs and more genera of Old World Temperate spectra might lead to higher vegetation coverage.

This model explained 68.2% of the variance in vegetation coverage. According to the results of the multi-linear regression, the modeling of vegetation coverage was desirable, because all coefficients were significant. The R -value of 0.83 indicated a strong relationship between the variables and vegetation coverage, and the squared R -value was 0.69, meaning that more than half the variation in

vegetation coverage was explained by the model. The VIF (variance inflation factor) values were all smaller than 2, so the multi-collinearity was quite low and the standard error of the regression coefficients could not be significantly inflated (Table 3).

4. Discussion

In our research, three main indices of plant species composition explained 68.2% of the variation in vegetation coverage, and demonstrated the significant relationship between vegetation coverage and species composition (Caliman et al. 2010; Cardinale et al. 2012). Plant species richness had the highest contribution, highlighting the importance of plant species diversity as previously reported (Zedler et al. 2001; Long et al. 2006, 2009). Based on these findings, improving biodiversity is one of the main targets of vegetation restoration. However, other indices of species composition were also significantly influenced by vegetation coverage; thus, conducting a thorough investigation relating to species composition is important when assessing and preparing vegetation restoration (Carvalho et al. 2013).

When selecting plant species for vegetation restoration, the origin and adaptability of each species are not the only considerations; species that disappeared should receive special attention. In this case study, species such as *Atomia. anacrusis*, *Lancea tibetica*, *L. corniculatus* var. *japonicus*, *Sparganium simplex*, *Veronica serpyllifolia*, *B. bungei* and *Halenia elliptica* need special attention, and conditions need to be optimized to support the development of these species during vegetation restoration. Recovery of the plant community structure requires balancing the proportions of dominant species. Increasing the density of some dominant species that were in decline in this study, such as *Carex* sp., *C. nubigena* and *P. nubigena*, and others, might be helpful during vegetation restoration.

The relationship between species composition and vegetation coverage related to human disturbances are dynamic and complex. To restore a destroyed ecosystem or to increase vegetation coverage, more attention should be focused on the composition of species, including species diversity. Human disturbance influenced not only vegetation coverage but also species composition in these wetlands, and so measures need to be taken to control human disturbance (DeFries & Townshend 1994; Burgos & Maass 2004; Morawitz et al. 2006). The role of human disturbance in vegetation coverage differs depending on the type of land, so more investigations of the relationship between human disturbance and vegetation coverage are needed. Research studies into the effect and interactions of other factors (water resources, slope, land use, soil and climate) on vegetation coverage should be integrated to understanding the total impact. Field surveys provide important basic data, so in-depth and long-term field investigations are encouraged.

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