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UNDERSTANDING THE INTERCONNECTEDNESS OF PLANT DIVERSITY AND SOIL ENVIRONMENT IN CAOHAI LAKESIDE WETLAND, GUIZHOU PROVINCE

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Abstract

Wetland vegetation stands as a pivotal constituent within wetland ecosystems, assuming critical roles in delineating environmental attributes, harnessing energy, and remedying contaminants. Possessing notable productivity, they orchestrate the intricate dance of energy and matter in these ecosystems. The diversity of wetland vegetation, a hallmark of ecological richness, is subject to the sway of multifarious environmental factors, with soil constitution emerging as a linchpin in plant growth and survival. Owing to its role as the material bedrock for plant development, disparities in soil physicochemical properties and parent materials wield profound influence over the distribution patterns and species diversity of wetland flora. In the intricate web of an ecosystem, soil nutrients wield direct influence over the ecological stoichiometry of plants, reciprocally shaping nutrient dynamics. This mutual interplay underscores the imperative of comprehending plant-soil interactions and their coupling characteristics. A study by Zhou Hongyan et al. scrutinized dominant flora in the Poyang Lake region, revealing that soil moisture content, coupled with nitrogen (N) and phosphorus (P) levels, jointly dictated the ecological stoichiometric traits of the vegetation. Meanwhile, research by Zhang et al. delved into the ecological stoichiometric attributes of carbon (C), N, and P in the soil of the Shuangtaizi River Estuary wetland in northeastern China. Their findings unveiled a landscape rife with high spatial heterogeneity in the distribution of ecological stoichiometric ratios, profoundly influenced by a tapestry of factors including plant coverage, community features, topographical undulations, and geomorphological nuances. Furthermore, their insights pointed to phosphorus as the principal limiting factor in the orchestration of plant succession within estuarine wetlands.

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1. Introduction

Wetland vegetation is an essential component of wetland ecosystems, playing significant roles in indicating environmental characteristics, capturing energy, and purifying pollutants. They possess high productivity [1]. The diversity of wetland vegetation is influenced by various environmental factors, with soil being a crucial material foundation for plant growth and an important environmental condition for plant survival. Due to differences in soil physicochemical properties and parent materials, they have significant effects on plant distribution patterns and species diversity [2-3]. Within an ecosystem, soil nutrients directly impact the ecological stoichiometry of plants, and in turn, plants provide feedback on nutrient utilization. Therefore, studying plant-soil coupling characteristics is essential [4]. Zhou Hongyan et al. conducted research on dominant plants in Poyang Lake and found that soil moisture content and nutrient levels of N and P jointly influenced the ecological stoichiometry characteristics of plants [5]. Zhang et al. studied the ecological stoichiometry characteristics of C, N, and P in the soil of Shuangtaizi River Estuary wetland in northeastern China. The results showed that the distribution of ecological stoichiometric ratios exhibited high spatial heterogeneity and was significantly influenced by plant coverage, community characteristics, topography, and geomorphology. They also suggested that phosphorus might be the primary limiting element affecting plant succession in estuarine wetlands [6].

Caohai in Guizhou Province is located in the central part of the Yunnan-Guizhou Plateau and represents a typical wetland ecosystem. Caohai is the largest natural karst rock dissolution lake in Guizhou and one of the three largest freshwater lakes on the plateau in China. It possesses abundant biological resources. However, due to long-term accumulation of nutrient inputs, as well as factors such as farming activities near the lake, the ecological system of Caohai has become increasingly fragile. Additionally, the implementation of fishing bans in recent years has resulted in a severe proliferation of fish biomass and invasive species such as crayfish. Combined with artificial water level rises and accumulated pollution, the aquatic vegetation in Caohai has deteriorated significantly, resulting in turbid water and a transition from an early clearwater macrophyte lake to a eutrophic algal-dominated lake, thereby weakening its ecological service functions and reducing its original economic value.

In this study, we selected 12 regions around Caohai, including Liujiaxiang, as the research objects to explore the regional differences in plant species and diversity in Caohai wetlands. We conducted surveys in nearly all wetland areas within the protected area of Caohai, investigating the species composition of wetland plants (mainly herbaceous plants) and soil environmental factors. Our aim was to understand the spatial differences in plant diversity and community characteristics in Caohai wetlands and analyze the relationship between soil environmental factors and plant diversity, providing a scientific basis for biodiversity conservation and lake ecosystem development in Caohai.

2. Materials and Methods

2.1. Study Area

Caohai is located in Weining County, Guizhou Province, in the central part of the Yunnan-Guizhou Plateau (26°47′35″~26°52′10″N, 104°9′23″~104°20′10″E). The protected area covers a total area of approximately 120 km2 and is the largest natural freshwater lake on the plateau in Guizhou Province [7]. Caohai belongs to the headwaters of the second-level tributary of the Jinsha River, the Luoze River. The normal storage area of Caohai is 19.8 km^2, with a normal water level of 2171.7 m and a maximum depth of 5 m. During the flood season, the water level can reach 2172.0 m, corresponding to a water area of 226.05 km^2, while during the dry season, the water level drops to 2171.2 m, corresponding to a water area of 15.0 km2. The main water sources of the protected area are the Da Zhong River, Maojiahaizi River, Qingshui Gully, Dongshan River, and Baima River, with the Da Zhong River and Maojiahaizi River contributing the largest inflow into the lake [8].

2.2. Sample Collection and Data Acquisition

The sampling and survey areas are shown in Figure 1. Plant surveys were conducted at various locations, including Jiangjiawan Matou (JJ), Dengjiayuanzi (DJ), Xihai Matou (XH), Baima Wetland (BM), Wangjiayuanzi (WY), Wenjiatun (WT), Huyelin (Bird Watching Tower) (HY), Loulaoshan (LL), Wujia Yantou (WJ), Zoujiayuanzi (ZJ), Liujiaxiang (LJ), and Yangguanshan (YG). The sample plots were established using a GPS toolbox at regular intervals. The plant survey followed the methods described in reference [9] and employed a combination of plot and quadrat sampling. A total of 152 herbaceous quadrats were surveyed. In some plots, surface soil samples (0~10cm) were randomly collected and brought back to the laboratory for processing and analysis. Handheld instruments were used to measure soil water content (WS), temperature (W), pH, oxidation-reduction potential (ORP), and compaction (PSI) within the quadrats on a monthly basis.

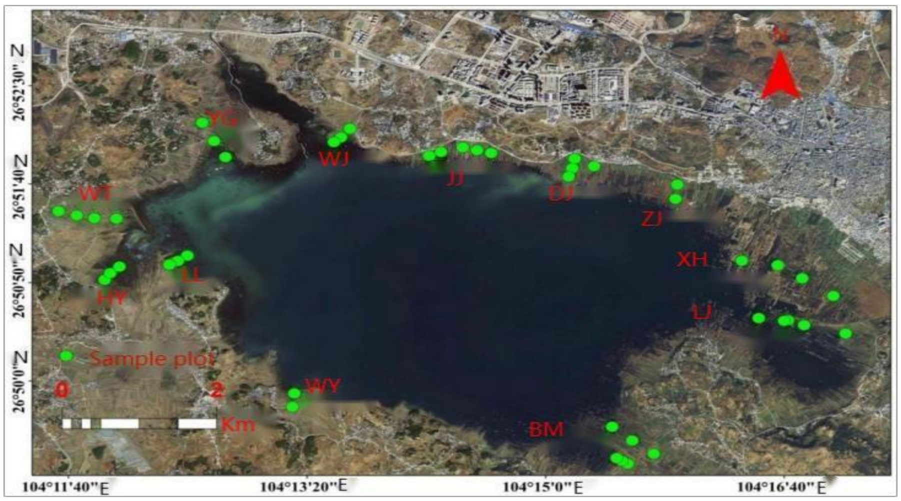

Figure 1: Distribution map of Caohai sample

2.3. Data Analysis

2.3.1. Measurement of Plant Diversity

S

$D=1-\sum Pi^2$

Simpson Index: i=1

Shannon-Wiener Index: $H=-\sum_{i=1}^{S} P_i \ln P^i$

Pielou's Evenness Index: $E=H/\ln S$

In the equation, S represents the number of species occurring in the sample plot. Pi=Ni/N, where Ni is the number of individuals of the i-th species, and N represents the total number of individuals of all species. Fi represents the frequency of occurrence of the i-th species across all sample plots [9].

2.3.2. Plant and Soil Chemical Factor Determination

The determination of total organic carbon (P-TOC) in soil was performed using the potassium dichromate oxidation method with high-temperature external heating and volumetric analysis. The determination of total nitrogen (P-TN) was conducted using the Kjeldahl method, and the determination of total phosphorus (P-TP) was carried out using the SMT method [7].

2.4. Data Processing

ArcGIS 10.6 was used to import the sampling point coordinates and related data to create a sampling map of Caohai. Excel 2003 was utilized for the organization of environmental data, and Origin 2021 was employed for correlation analysis. Canoco 5 was used for redundancy analysis (RDA).

3. Results and Analysis

3.1. Wetland Plant Species Composition

In this survey, a total of 166 species belonging to 124 genera, 45 families, and 6 orders of aquatic plants (including aquatic, submerged, emergent, floating-leaved, and floating plants) were found in the protected area. Among them, the highest number of species was observed in wetland plants. The families with 10 or more species were Asteraceae (26 species), Poaceae (25 species), Cyperaceae (14 species), and Polygonaceae (12 species), accounting for approximately 46.39% of the total plant species. The genus with the highest number of species was Persicaria, which included 10 species. Other genera with multiple species included Cyperus (4 species), Schoenoplectus Palla (3 species), Oenanthe L (3 species), Ranunculus L. (3 species), Equisetum est a (3 species), and Carex L. (3 species). There were 20 genera that contained two species, accounting for approximately 24.10% of the total species. The majority of genera consisted of only one species, totaling 97 genera and representing approximately 58.43% of the total species.

3.2. Differences in Plant Diversity among Different Sampling Sites

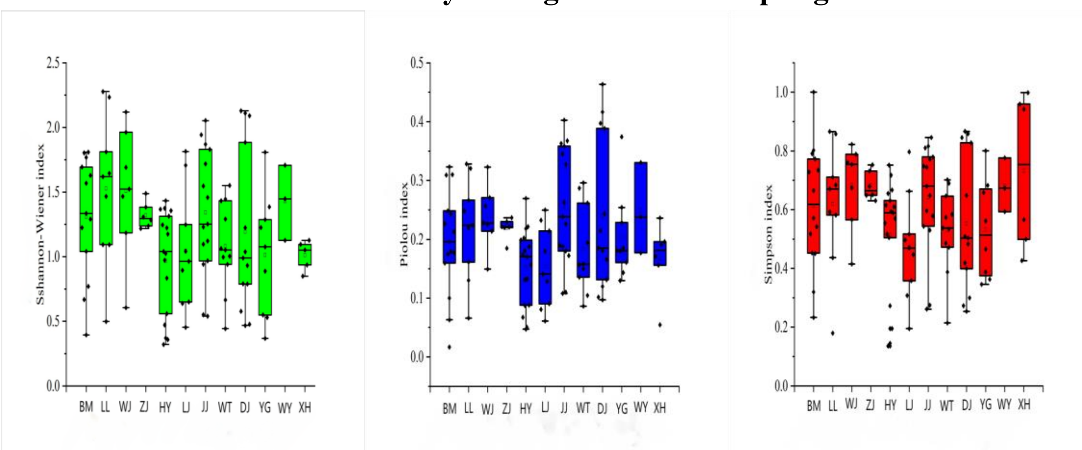

Figure 2: Diversity of wetland plants in different sampling sites

In the 12 sampling sites investigated in this study (Figure 2), the Shannon-Wiener index was the highest in Louluo Mountain, with an average plot value of 1.526; the lowest Shannon-Wiener index was found in Xihai Wharf, with an average plot value of 0.865. The Shannon-Wiener index average plot values were ranked in descending order as follows: Louluo Mountain > Wujiayantou > Wangjiayuanzi > Jiangjiawan > Zoujiayuanzi > Baima Wetland > Dengjiayuanzi > Wenjiatun > Yangguan Mountain > Guanniao Platform > Xihai Wharf. The highest Simpson index was found in Xihai Wharf, with an average plot value of 0.732; the lowest Simpson index was in Liujiacun, with an average plot value of 0.472. The Simpson index average plot values were ranked in descending order as follows: Xihai Wharf > Wujiayantou > Zoujiayuanzi > Wangjiayuanzi > Jiangjiawan > Louluo Mountain > Baima Wetland > Dengjiayuanzi > Yangguan Mountain > Wenjiatun > Guanniao Platform > Liujiacun. The highest Pielou evenness index was found in Jiangjiawan, with an average plot value of 0.256. The lowest Pielou evenness index was in Guanniao Platform, with an average plot value of 0.152. The Pielou evenness index average plot values were ranked in descending order as follows: Jiangjiawan > Wangjiayuanzi > Dengjiayuanzi > Wujiayantou > Zoujiayuanzi > Louluo Mountain > Yangguan Mountain > Baima Wetland > Wenjiatun > Xihai Wharf > Liujiacun > Guanniao Platform.

3.3. Correlation Analysis of Soil Environmental Factors

As shown in Figure 3, the correlation analysis of wetland soil environmental factors and their ecological stoichiometry ratios (C, N, P) revealed the following relationships. Soil moisture content showed a significant

negative correlation with temperature, bulk density (P < 0.01), and TP content (P < 0.05), while it exhibited a significant positive correlation with soil TN content (P < 0.05), soil C:P ratio (P < 0.01), and N:P ratio (P < 0.001). Soil temperature was significantly negatively correlated with pH (P < 0.05), while soil pH showed a significant positive correlation with TP (P < 0.05). Soil TOC exhibited significant positive correlations with TN (P < 0.001), C:N ratio (P < 0.001), C:P ratio (P <
0.001), and N:P ratio (P < 0.01). Soil TN was significantly positively correlated with C:P ratio (P <
0.001) and N:P ratio (P < 0.001). Soil TP showed a significant positive correlation with C:N ratio (P < 0.01), but a highly significant negative correlation with C:P ratio and N:P ratio (P < 0.001). C:N ratio exhibited a significant positive correlation with C:P ratio, while C:P ratio showed a highly significant positive correlation with N:P ratio (P < 0.001).

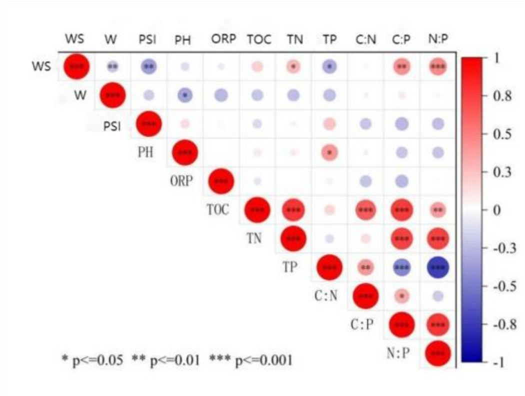

Figure 3: Correlation analysis of soil environmental factors and ecological stoichiometric ratio **3.4. Relationship between Plant Diversity and Soil Environmental Factors**

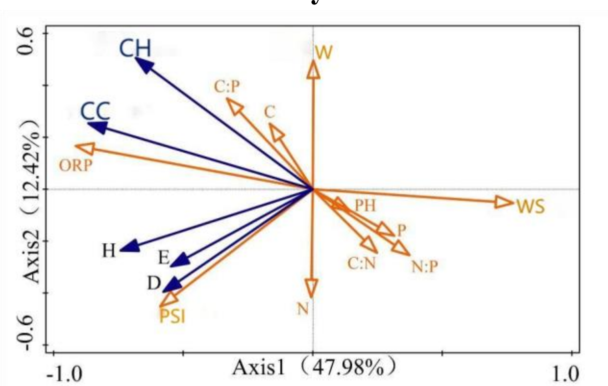

Figure 4: RDA analysis of wetland plant diversity and soil environmental factors

From the RDA ordination diagram (Figure 4), it can be observed that the first two ordination axes explain a total variation of 60.4%, indicating a relatively high explanatory power. The first ordination axis is positively correlated with soil moisture content, TP, N:P ratio, and pH, while it is negatively correlated with ORP and bulk density. The remaining factors show weaker correlations with the ordination axes. Plant diversity indices H, D, and E are positively correlated with soil bulk density and ORP, while they exhibit negative correlations with moisture content and temperature. Community height (CH) and canopy coverage (CC) are positively correlated with soil ORP and C:P ratio, and negatively correlated with moisture content, TP, N:P ratio, and C:N ratio. Additionally, in the RDA analysis, environmental factors are constrained to linear combinations on the axes, and the importance of each factor on an axis is measured by its correlation coefficient (F) with the axis. The Monte Carlo test reveals that at a significance level of P < 0.05, the soil environmental factors significantly influencing the characteristics of wetland plant community diversity are ORP (40.5%, F = 23.2, P = 0.002), bulk density (6.7%, F = 4.2, P = 0.012), and temperature (5.4%, F = 3.6, P = 0.022). This indicates that the main environmental factors influencing the characteristics of plant community diversity in Caohai wetland are ORP, bulk density, and temperature.

4. Discussion

The survey identified a total of 166 plant species in Lake Caohai wetland, belonging to 6 classes, 45 families, and 124 genera. This species richness is higher than the study by Liu et al. on the aquatic plants in the Lake Taihu wetland (64 species, 33 families, 51 genera) [10], but lower than the 386 species reported in Dianchi Lake, including both aquatic and wetland plants [11]. This indicates that the plant species richness in Lake Caohai wetland is at a relatively abundant level. The study also found differences in dominant species populations among different sampling sites in Lake Caohai, as well as variations in species richness, community biomass, and species diversity. In particular, the Shannon-Wiener index was highest in the Loulaoshan site, which also had the highest number of species. This can be attributed to the unique topographical features of Loulaoshan, as it has higher terrain, experiences less influence from fluctuating water levels, and has relatively abundant groundwater, which is favorable for plant growth. Similar results were reported by Zhang et al. in their analysis of alpha diversity of typical karst plant communities around the FAST project, where the Shannon-Wiener index was significantly higher in higher-altitude areas compared to lower-altitude areas [12].

The significant negative correlation ($P<0.01$) between soil moisture content and temperature in Lake Caohai wetland is consistent with the findings of Wu et al. in their study on soil moisture content and temperature across different land use types [13]. The correlation analysis also revealed significant correlations ($P<0.01$) between soil moisture content and the C:P and N:P ratios, suggesting that soil moisture content can influence the spatial distribution of soil nutrients, and adequate and suitable soil moisture content promotes soil organic matter accumulation [14]. The study found a significant negative correlation ($P<0.01$) between soil bulk density and soil moisture content, which is consistent with previous research findings [15]. There is a significant correlation ($P<0.001$) between S-TOC and S-TN, indicating that the main sources of carbon (C) and nitrogen (N) in Lake Caohai wetland are consistent. This is in line with the findings of Yang et al. in their study of wetlands in the Yellow River basin in Baotou [16]. Additionally, soil TN is significantly correlated with C:P and N:P ratios ($P<0.001$), but not with C:N ratio. This may be due to the consistent response of soil total organic carbon (TOC) and TN to environmental changes in Lake Caohai wetland, with parallel data weakening the correlation between soil TN and C:N ratio. However, there is a significant correlation ($P<0.01$) between soil TP and C:N ratio, indicating that the nutrient cycling of plants and soil is likely influenced by N deficiency. The C:N:P ratios in the wetland soil can serve as important indicators for predicting nutrient limitations and organic matter decomposition rates [17]. The average C:N ratio in Lake Caohai wetland is 13.96, the C:P ratio is 55.75, and the N:P ratio is 4.15, which is slightly lower than the values reported by D for a karst rocky desertification area in northwestern Guangxi (C:N ratio of 14.49, C:P ratio of 61.33, N:P ratio of 4.23) [18], but slightly higher than the N:P ratio (3.54) reported for a karst rocky desertification area in southwestern Guizhou [19]. This indicates that soil ecological stoichiometry can vary in different research areas, possibly due to differences in soil use types.

Soil environmental factors influence the community structure and functional characteristics of plants, and variations in soil environments can lead to changes in species diversity. Huang et al. conducted an RDA analysis of soil factors and plant diversity in three wetlands in Guangzhou, revealing that soil factors such as TOC, TN, TP, and pH had significant impacts on wetland plant diversity [20]. Ma et al. found that soil TOC, salinity, pH, moisture content, and TN content significantly influenced plant diversity indices [21]. In this study, the main environmental factors influencing plant diversity and community characteristics in Lake Caohai wetland were found to be ORP, bulk density, and temperature, indicating that the environmental factors influencing plant diversity can vary at different geographical scales.

5. Conclusion

(1) Lake Caohai wetland has a total of 166 plant species, belonging to 6 classes, 45 families, and 124 genera. The families with the highest number of species are Asteraceae (26 species) and Poaceae (25 species).

(2) The Louluoshan site has the highest Shannon-Wiener index and the highest number of species, while the Xihaimatou site has the highest Simpson index, and the Jiangjiawan site has the highest Pielou evenness index.

(3) The main soil environmental factors influencing plant diversity and community characteristics in Lake Caohai wetland are oxidation-reduction potential (ORP), bulk density, and temperature.

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