Response of Species Diversity of Typical Submerged Macrophyte Communities to Sediment in Yinchuan Plain Wetlands (Postprint)

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Abstract

Understanding the response of submerged macrophyte community species diversity to sediment nitrogen and phosphorus nutrient levels can clarify the functional relationship between the two, which holds direct theoretical and practical significance for studying spatiotemporal changes in wetland vegetation and environment, habitat restoration, pollution control, and planning management in the study area and even similar regions. This study was conducted in the lake and ditch wetlands of the Yinchuan Plain, where field surveys of submerged macrophyte communities were performed and sediment environmental nutrient data were collected. Community classification methods were used to identify three typical submerged macrophyte communities, and sediment nitrogen and phosphorus nutrient levels were graded. Structural equation modeling was then applied to analyze the functional relationships among components of typical submerged macrophyte community species diversity and sediment nitrogen and phosphorus nutrient level grades. The following conclusions were obtained: (1) There are eight common submerged macrophyte species in the lake and ditch wetlands of the Yinchuan Plain. The typical submerged macrophyte communities are the Potamogeton pectinatus community, Myriophyllum spicatum community, and Potamogeton crispus community. The Potamogeton crispus community exhibits high species composition diversity and complexity of species contributions, with uniform species distribution, while the Potamogeton pectinatus community shows clustered or patchy species distribution. (2) The sediment nitrogen and phosphorus nutrient levels in the lake and ditch wetlands of the Yinchuan Plain have three grades (rich, moderate, poor), predominantly moderate and poor grades. (3) The Potamogeton pectinatus community and Myriophyllum spicatum community are primarily distributed in poor and moderate sediment nutrient levels, while the Potamogeton crispus community is primarily distributed in poor, moderate, and rich sediment nutrient levels. (4) Sediment nitrogen and phosphorus nutrient levels have a significant positive effect on the species diversity of the three typical submerged macrophyte communities, promoting an increase in community diversity indices. The diversity of the three typical submerged macrophyte communities is primarily influenced by species evenness. Sediment nitrogen and phosphorus nutrient levels are primarily influenced by phosphorus.

Full Text

Preamble

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Response of Species Diversity of Typical Submerged Plant Communities to Sediment Nutrients in Yinchuan Plain Wetlands

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Abstract

Understanding how species diversity of submerged plant communities responds to nitrogen and phosphorus nutrient levels in sediment can clarify the interactions between these components, which has direct theoretical and practical significance for investigating spatiotemporal changes in wetland vegetation and environment, as well as for habitat restoration, pollution control, and planning management in the study area and similar regions.

This study investigated submerged plant communities in lake and ditch wetlands of the Yinchuan Plain through field surveys and analyzed sediment environmental nutrients. Three typical submerged plant communities were identified using community classification methods, and the nitrogen and phosphorus nutrient levels of the sediment were evaluated. Structural equation modeling was employed to analyze the relationships among species diversity indices of typical submerged plant communities and various components of sediment nitrogen and phosphorus nutrient levels. The following conclusions were obtained: (1) Eight common submerged plant species were identified in the lake and ditch wetlands of Yinchuan Plain. The typical submerged plant communities were *Potamogeton pectinatus* community, *Myriophyllum spicatum* community, and *Potamogeton crispus* community. The *P. crispus* community exhibited high species composition diversity and complex species contributions, with uniform species distribution, while species in the *P. pectinatus* community showed clustered or patchy distribution patterns. (2) Three nutrient levels (rich, moderate, and poor) were identified for sediment nitrogen and phosphorus in the wetlands, with moderate and poor levels being predominant. (3) The *P. pectinatus* and *M. spicatum* communities primarily grew in sediments with poor and moderate nutrient levels, whereas the *P. crispus* community was distributed across poor, moderate, and rich nutrient levels. (4) Sediment nitrogen and phosphorus nutrient levels had significant positive effects on the three typical submerged plant communities, promoting increases in community diversity indices. The diversity of the three typical submerged plant communities was mainly influenced by species evenness, while sediment nitrogen and phosphorus nutrient levels were primarily affected by phosphorus content.

Keywords: submerged plant community; sediment nutrient level; structural equation model; response

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Introduction

Sediment serves as the primary pathway for releasing endogenous pollutants in water bodies, and excessive nutrient levels can lead to over-enrichment of water bodies, constraining the health of wetland ecosystems. Submerged macrophytes are large aquatic plants that root in the substrate and remain submerged below the water surface for extended periods. They can reduce sediment resuspension and decrease endogenous nutrient loading in wetland water bodies, thereby inhibiting nitrogen and phosphorus release in shallow wetland ecosystems. The growth and distribution of submerged macrophytes are closely related to sediment nutrient conditions.

The Yinchuan Plain features flat terrain and, due to the passage of the Yellow River and long-term irrigation practices, has developed an extensive ditch system and numerous small drainage lakes, supporting diverse and widely distributed submerged plant communities. However, most previous research has focused on responses of submerged plants to water environmental factors, while studies on how submerged plants in Yinchuan Plain wetlands respond to sediment nitrogen and phosphorus nutrient levels are lacking. Therefore, this study selected three typical submerged plant communities from lake and ditch wetlands in the Yinchuan Plain to address the following scientific questions: (1) How do typical submerged plant communities respond to sediment nitrogen and phosphorus nutrient levels? (2) How do the relationships among various components of plant community species diversity and sediment nitrogen and phosphorus nutrient levels change? Since submerged macrophytes are rooted in sediment and absorb nitrogen, phosphorus, and other nutrients for growth and development, interactive relationships exist between submerged macrophytes and sediment nutrient content. This research will provide scientific basis for understanding spatiotemporal changes in wetland vegetation and environment, habitat restoration, pollution control, and planning management in the Yinchuan Plain and similar regions.

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1. Materials and Methods

1.1 Study Area Overview

The study area is located in the Yinchuan Plain in northern Ningxia [Figure 1: see original paper]. The geographical coordinates are 37°50 ~39°23 N, 104°17 ~107°39 E. The region has a temperate continental arid to semi-arid climate, with average annual precipitation of approximately 200 mm. Winters are cold and dry, while summers are hot with little rainfall. The average annual temperature is 9 °C. The Yellow River flows through the plain from Qingtongxia to Mahuangou, with a channel length of 190 km. The flat terrain and historical Yellow River irrigation have created an extensive ditch network and numerous small drainage lakes, resulting in diverse and widely distributed submerged plant communities.

1.2 Research Methods

Sampling was conducted using random methods combined with quadrat and transect methods during July-August 2022 [Figure 2: see original paper]. Transects were established approximately parallel to lake and ditch shorelines, with quadrats placed along transects according to community variations. A comprehensive survey was conducted on submerged plant communities in 48 lakes and ditch wetlands in the Yinchuan Plain. Quadrats of 1 m × 1 m were established, with three replicates per site, totaling 147 quadrats. Non-submerged plant quadrats were excluded, and characteristic indicators including species name, coverage, density, and height were recorded.

Sediment samples were collected from 0–20 cm depth within quadrats using a soil auger, sealed in plastic bags, labeled, and transported to the laboratory for physicochemical analysis. For each site, three replicates were collected. Available phosphorus (AP) and alkali-hydrolyzable nitrogen (AN) were measured using the hydrochloric acid-ammonium fluoride method and the alkali diffusion method, respectively.

1.2.1 Community Species Diversity Indices Plant community species diversity indices were used to comprehensively reflect community characteristics. The indices included the Patrick index, Margalef index, Shannon-Wiener index, and Pielou index, calculated as follows:

$$\text{Margalef} = \frac{S-1}{\ln N}$$

$$\text{Pielou} = \frac{H'}{\ln S}$$

$$\text{Shannon-Weiner} = -\sum_{i=1}^{S} P_i \ln P_i$$

$$\text{Patrick} = S$$

where N is the total number of plant individuals in the quadrat, S is the number of species in the quadrat, and Pi is the relative importance value of the ith plant species, calculated as Pi = (relative height + relative coverage + relative density)/3. Community frequency was calculated as: (number of occurrences of a community / total number of communities) × 100%.

1.2.2 Sediment Nitrogen and Phosphorus Nutrient Level Evaluation The evaluation method for sediment nitrogen and phosphorus nutrient levels followed the "National Second Soil Census Nutrient Classification Standard," while drawing on appropriate evaluation indicators selected by previous researchers and considering the characteristics of lake and ditch wetlands in the Yinchuan Plain. Alkali-hydrolyzable nitrogen and available phosphorus were used as evaluation factors to construct a regional sediment nutrient quality assessment system .

The evaluation process involved: (1) Standardization of sediment nutrient indicators using the single-factor index method, and (2) Calculation of the Nemerow index. The classification standards for sediment nitrogen and phosphorus levels were based on the National Second Soil Census nutrient classification standard data .

1.3 Data Processing and Analysis

Data were organized and analyzed using Excel 2010 for statistical description, SPSS for correlation analysis and principal component analysis, Amos for structural equation modeling, and Origin 2018 for graphical representation.

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2. Results

2.1 Common Submerged Plants in Yinchuan Plain Wetlands

Based on surveys of thriving submerged plant communities in 48 lakes and ditch wetlands in the Yinchuan Plain, eight submerged plant species were recorded . After excluding rare species with frequency <5% (such as *Potamogeton natans*), the remaining seven species were: *Potamogeton pectinatus*, *Najas marina*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton crispus*, *Najas minor*, *Potamogeton perfoliatus*, and *Utricularia vulgaris*. These belong to five families, with three species of Potamogetonaceae, two species of Najadaceae, and one species each of Ceratophyllaceae, Haloragaceae, and Lentibulariaceae.

Using community classification methods and field vegetation survey data, communities were named based on the species with the highest abundance, coverage, and biomass in each quadrat. Seven submerged plant communities were identified: *P. pectinatus* (frequency: 28.67%), *N. marina* (22.38%), *M. spicatum* (18.18%), *C. demersum* (12.59%), *P. crispus* (6.29%), *N. minor* (5.59%), and *P. perfoliatus* (4.19%). The typical submerged plant communities were *P. pectinatus*, *M. spicatum*, and *P. crispus*.

2.2 Species Diversity of Three Typical Communities

The species diversity status of submerged plant communities in Yinchuan Plain wetlands was characterized using the Shannon-Wiener index [Figure 3: see original paper]. The three submerged plant communities showed significant differences in Margalef community richness index ($P < 0.05$), but no significant differences in Shannon-Wiener, Patrick, or Pielou indices. The *P. pectinatus* community had relatively low species diversity indices, the *P. crispus* community had relatively high indices, and the *M. spicatum* community fell between them.

2.3 Sediment Nitrogen and Phosphorus Nutrient Levels

Sediment is a multi-factor, multi-level complex system. This study used limited but key environmental indicators (alkali-hydrolyzable nitrogen and available phosphorus) to evaluate sediment nutrient levels. Analysis data for available phosphorus (AP) and alkali-hydrolyzable nitrogen (AN) from the study area were processed using the evaluation formulas and compared with the National Second Soil Census classification standards. The results showed that among the 147 sampling sites, three nutrient levels existed: rich (23 sites), moderate (71 sites), and poor (53 sites), with moderate and poor levels being predominant.

2.4 Response of Three Typical Communities to Sediment Nutrients

The response of the three typical submerged plant communities to sediment nutrients is shown in [Figure 4: see original paper]. The *P. pectinatus* and *M. spicatum* communities primarily occurred in poor and moderate nutrient level sediments, while the *P. crispus* community was distributed across poor, moderate, and rich nutrient level sediments. The responses to the main indicators (AN and AP) used to construct the nutrient level system are shown in [Figure 5: see original paper]. The *P. pectinatus* and *M. spicatum* communities responded to AN and AP indicators at poor and moderate levels, whereas the *P. crispus* community responded across poor, moderate, and rich levels.

2.5 Structural Equation Model Analysis

2.5.1 *Potamogeton pectinatus* Community Community species diversity indices reflect plant community characteristics. Based on correlation analysis, a structural equation model was established linking species diversity indices and sediment nitrogen-phosphorus nutrient level indicators. The results [Figure

6: see original paper] showed significant relationships between the *P. pectinatus* community and species diversity indices, with the highest correlation coefficient for the Pielou index (0.71). Sediment nitrogen-phosphorus nutrient levels showed significant relationships with AN and AP, with the highest correlation coefficient for AP (0.85). Sediment nutrient levels had a significant positive effect on the *P. pectinatus* community, with a path coefficient of 0.58.

2.5.2 *Myriophyllum spicatum* Community The structural equation model for the *M. spicatum* community and sediment nutrient levels [Figure 7: see original paper] showed significant relationships with species diversity indices, with the highest correlation coefficient for the Pielou index (0.69). Sediment nutrient levels showed significant relationships with AN and AP, with the highest correlation coefficient for AP (0.86). Sediment nutrient levels had a significant positive effect on the *M. spicatum* community, with a path coefficient of 0.61.

2.5.3 *Potamogeton crispus* Community The structural equation model for the *P. crispus* community and sediment nutrient levels [Figure 8: see original paper] showed significant relationships with species diversity indices, with the highest correlation coefficient for the Pielou index (0.73). Sediment nutrient levels showed significant relationships with AN and AP, with the highest correlation coefficient for AP (0.84). Sediment nutrient levels had a significant positive effect on the *P. crispus* community, with a path coefficient of 0.63.

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3. Discussion

3.1 Typical Submerged Plant Communities

The common submerged plants in Yinchuan Plain lake and ditch wetlands include *P. pectinatus*, *N. marina*, *M. spicatum*, *C. demersum*, *P. crispus*, *N. minor*, *P. perfoliatus*, and *U. vulgaris*, belonging to five families. The typical communities are *P. pectinatus*, *M. spicatum*, and *P. crispus*. The *P. crispus* community exhibits high species composition diversity and complexity, with uniform species distribution. In contrast, the *P. pectinatus* community, composed mainly of *P. pectinatus*, *C. demersum*, *N. marina*, *N. minor*, and *U. vulgaris*, shows clustered or patchy distribution patterns with lower species diversity and complexity.

3.2 Sediment Nutrient Level Classification

Sediment nutrient distribution is influenced by multiple factors including plant community type and soil physicochemical properties. Some sampling sites were adjacent to fish ponds and farmland where water flow enriched nutrients, and the static wetland conditions facilitated nutrient assimilation and accumulation in sediment. The primary nutrient sources are decomposition of plant organic residues and humification. The Yinchuan Plain wetlands have rich plant community types with high productivity, and nutrients from decaying plants are returned to the sediment. Using AN and AP to construct the nutrient level system revealed three levels (rich, moderate, poor), predominantly moderate and poor, possibly because some sites have not been disturbed by human activities, maintaining healthy ecosystems with high resource utilization efficiency and lower nutrient levels.

3.3 Community Distribution Patterns

The *P. pectinatus* and *M. spicatum* communities primarily occurred in poor and moderate nutrient level sediments, while the *P. crispus* community was distributed across all three levels. This reflects that AP is the main indicator affecting sediment nutrient evaluation. The AP concentration ranges for poor, moderate, and rich levels were 1.29–10.96 $mg \cdot kg^{-1}$, 2.99–16.63 $mg \cdot kg^{-1}$, and 5.59–62.45 $mg \cdot kg^{-1}$, respectively, while AN ranges were 14.03–53.76 $mg \cdot kg^{-1}$, 26.53–92.74 $mg \cdot kg^{-1}$, and >92.74 $mg \cdot kg^{-1}$. The *P. pectinatus* and *M. spicatum* communities responded to these indicators at poor and moderate levels, whereas the *P. crispus* community responded across all three levels.

3.4 Structural Equation Model Analysis

All three typical submerged plant communities have well-developed root systems that absorb nutrients from sediment for growth, metabolism, and activity. Sediment nutrient concentration is a key factor affecting community development. Studies have shown that when sediment nutrient content exceeds water column concentrations, submerged macrophytes primarily absorb nutrients through their roots. Therefore, sediment nitrogen-phosphorus levels have significant positive effects on all three communities.

Community species diversity indices integrate multiple observational metrics (height, abundance, frequency, coverage) and reflect species quantity characteristics and complex community-environment relationships. The three typical communities showed significant relationships with species diversity indices, with the highest correlation coefficients for the Pielou index, indicating that community diversity in Yinchuan Plain wetlands is mainly influenced by species evenness. Sediment nutrient levels showed significant relationships with AN and AP, with the highest correlation coefficient for AP, demonstrating that phosphorus is the primary factor affecting sediment nutrient status.

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4. Conclusions

1) The common submerged plants in Yinchuan Plain lake and ditch wetlands are *Potamogeton pectinatus*, *Najas marina*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton crispus*, *Najas minor*, *Potamogeton*

perfoliatus, and *Utricularia vulgaris*. The typical submerged plant communities are *P. pectinatus*, *M. spicatum*, and *P. crispus* communities. The *P. crispus* community exhibits high species composition diversity and complex species contributions with uniform distribution, while the *P. pectinatus* community shows clustered or patchy distribution.

2) Three nutrient levels (rich, moderate, and poor) exist for sediment nitrogen and phosphorus in Yinchuan Plain wetlands, with moderate and poor levels being predominant.

3) The *P. pectinatus* and *M. spicatum* communities primarily grow in sediments with poor and moderate nutrient levels, while the *P. crispus* community is distributed across poor, moderate, and rich nutrient levels.

4) Sediment nitrogen and phosphorus nutrient levels have significant positive effects on the three typical submerged plant communities, promoting increased community diversity indices. The diversity of these communities is mainly influenced by species evenness, while sediment nutrient levels are primarily affected by phosphorus content.

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