Response of Soil Microbial Activity to Seasonal Water Level Fluctuations in Typical Wetlands of Poyang Lake (Postprint)

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Abstract

To investigate the response of wetland soil microorganisms to seasonal water level changes, soil samples were collected from three elevation transects in the Poyang Lake wetland during four seasons (March, June, and October 2014, and January 2015), and soil microbial basal respiration, biomass, and extracellular enzyme activities were measured. The results showed that: (1) Seasonal water level changes not only significantly altered soil organic carbon, dissolved organic carbon, and available phosphorus contents, but also caused microbial biomass carbon and the activities of four hydrolases (-glucosidase, -xylosidase, N-acetylglucosaminidase, and phosphatase) to exhibit a dynamic pattern of higher values in summer and winter and the lowest in autumn, while the two oxidases (phenol oxidase and catalase) showed the opposite pattern. (2) Water level elevation and aboveground vegetation type also significantly affected soil microorganisms, with the Triarrhena lutarioriparia transect exhibiting higher nutrient contents and microbial activities. (3) Some soil physicochemical indicators (water content, ammonium nitrogen, organic carbon, available phosphorus, etc.) were significantly correlated with microbial activities (microbial biomass, basal respiration, enzyme activities); seasonal water level changes had a greater influence on microbial activities than elevation differences. These results indicate that water level fluctuations exert important effects on wetland soil microbial activities, and alterations in the hydrological regime of Poyang Lake will impact the normal ecological functions of wetland soils.

Full Text

Preamble

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Responses of Soil Microbial Functional Traits to Seasonal Water Level Changes in a Typical Wetland of Poyang Lake

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Abstract

To explore the response of wetland soil microbes to seasonal water fluctuations, soil samples were collected from three sampling belts at different elevations in the Poyang Lake wetland across four seasons (March, June, and October 2014, and January 2015). Soil physicochemical properties, microbial basal respiration, microbial biomass, and enzyme activities were measured. The results showed that: (1) Seasonal water level fluctuations significantly altered soil organic carbon, dissolved organic carbon, and available phosphorus contents, and affected the seasonal dynamics of microbial biomass carbon (MBC) and four hydrolases including -glucosidase (Bglu), -xylanase (Bxyl), N-acetylglucosaminidase (NAG), and phosphatase (Phos). MBC, Bglu, Bxyl, NAG, and Phos peaked in summer and winter but decreased in autumn, whereas the two oxidases, phenoxidase (Phox) and peroxidase (Pero), showed the opposite trend. (2) Apparent impacts of water level elevation and aboveground vegetation were observed, with higher nutrients and microbial activities found in S2 plots covered with *Triarrhena lutarioriparia* (L. Liou). (3) Some soil properties (soil moisture, ammonia nitrogen, organic carbon, available phosphorus, etc.) were significantly correlated with microbial activities (microbial biomass, basal respiration, and enzymes), and the impact of seasonal water level changes on microbial activities was greater than that of elevation differences. This study revealed that water regime shifts had an important impact on soil microbial activities, which would further affect wetland ecosystem function.

Keywords: wetland; soil microbes; functional traits; water fluctuation

Introduction

Poyang Lake is the largest river-connected freshwater lake in China, influenced by both the water level of the Yangtze River and the five major river systems within Jiangxi Province. Its unique hydrological regime creates large-amplitude water level fluctuations that shape extensive lake wetlands, playing an extremely important role in maintaining the stability of the Poyang Lake ecosystem. In recent years, climate change and human activities have altered the lake' s hydrological rhythm, leading to challenges such as extended dry periods and declining biodiversity. While existing research has focused primarily on vegetation distribution along water level gradients, heavy metal pollution, greenhouse gas emissions, and water quality analysis, studies on soil microorganisms at the micro-scale and their response mechanisms to hydrological regimes remain scarce.

In wetland ecosystems, soil microorganisms not only accelerate the decomposition of plant litter and organic matter, drive the cycling and transformation of nutrients such as nitrogen and phosphorus, and facilitate the flow of chemical energy and information, but also participate in pollutant degradation and environmental remediation processes, playing a vital role in maintaining wetland ecosystem balance and stability. For lake wetland microorganisms, soil microbial activity indicators are often more intuitive than community structure indicators in reflecting wetland ecological functions and thus receive greater attention. Indicators such as microbial biomass and basal respiration can accurately reflect material metabolism in soils and respond rapidly to various environmental disturbances. Previous studies have shown that changes in wetland environmental conditions, such as nutrient content and vegetation, affect wetland microbial structure and function. However, the patterns of how freshwater lake wetland soil microorganisms respond to water level fluctuations remain unclear, and the challenges facing Poyang Lake' s natural wetlands urgently require a thorough understanding of these patterns.

This study investigated Poyang Lake wetland soils by examining physical and chemical parameters, soil enzyme activities, microbial biomass, and basal respiration across different seasons to reveal the response processes and mechanisms of microbial activities at different elevations to seasonal water level changes. The conclusions provide a microbial perspective for the rational protection and scientific management of Poyang Lake wetlands and are significant for maintaining ecosystem structure and functional stability.

1. Site Description and Sample Collection

The study site was located in the Banghu area of the Poyang Lake Wetland National Nature Reserve (115°53 -116°01 E, 29°08 -29°18 N), where the wetland exhibits typical aquatic-terrestrial ecotone phenomena with distinct zonation of aboveground vegetation along different elevations. Three sampling belts at different water level elevations were selected from the lakeshore toward the lake center, designated as S1–S3. Each belt had a spacing of 1 m $\times$ 1 m. Vegetation surveys were conducted at sampling points, and flooding conditions were recorded. Sampling times represented spring, summer, autumn, and winter seasons.

Surface soil samples (0–20 cm) were collected using a soil auger with a five-point mixed sampling method. One portion of each sample was stored in a refrigerator for enzyme activity measurement, the second was temporarily stored in a cold storage facility for determination of soil basal respiration and microbial biomass, and the third was air-dried and sieved for physicochemical analysis.

2. Soil Physicochemical Properties

Soil particle size was determined using the hydrometer method. Soil pH was measured with a pH meter (2.5:1 water-to-soil ratio). Soil water content (SWC) and bulk density (BD) were determined using the ring knife method. Ammonia nitrogen (NH -N) and nitrate nitrogen (NO -N) were measured using a fully automated flow analyzer. Total phosphorus (TP) was determined by the vanadium molybdate yellow spectrophotometric method. Total organic carbon (TOC) and total nitrogen (TN) were measured using the potassium dichromate external heating method and micro-Kjeldahl method, respectively. Dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) were measured after ashing at 550°C for 4 hours to determine ash-free dry mass (AFDM). Available phosphorus (AP) was determined by the molybdenum-antimony anti-colorimetric method according to the NY/T 1121-2014 standard.

Basic overview of the study area

3. Microbial Activity Characteristics

Soil basal respiration (BR) was measured using the closed alkali absorption titration method. Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were determined using the chloroform fumigation-K SO extraction method (K = 0.45). The microbial metabolic quotient (qCO) was calculated as BR/MBC. The microbial carbon quotient (qMBC) was calculated as MBC/TOC × 100%, and the microbial nitrogen quotient (qMBN) as MBN/TN × 100%.

For soil enzyme activities, the activities of four hydrolases— -glucosidase (Bglu), -xylanase (Bxyl), N-acetylglucosaminidase (NAG), and phosphatase (Phos)—were measured using microplate fluorometric methods. The activities of two oxidases, phenoxidase (Phox) and peroxidase (Pero), were determined by colorimetric methods using hydrogen peroxide (H O) and DOPA as substrates.

4. Data Processing

Data were statistically organized and mapped using Excel 2013 and SPSS 20.0 software. One-way ANOVA (Tukey test) was used for multiple comparisons of soil physicochemical parameters and microbial characteristics. Two-way ANOVA was used to analyze the effects of transect and season on basic physicochemical parameters and microbial characteristics. Pearson correlation analysis was used to examine relationships between soil physicochemical and microbial activity characteristics. Principal component analysis (PCA) of soil physicochemical and microbial activity characteristics was performed using Canoco 5.0.

2. Results

2.1 Soil Physicochemical Factors

Soil is the foundation for microbial survival, and soil environmental conditions determine microbial status. Soil physicochemical indices showed clear responses to both season and elevation. Soil water content (SWC) was significantly higher in spring and winter than in summer overall ($P < 0.05$), with the C:N ratio being generally higher in autumn. From a seasonal perspective, SWC, total organic carbon (TOC), total nitrogen (TN), and the C:N ratio were significantly higher in summer and autumn than in other seasons ($P < 0.05$). Notably, the lowest elevation transect had the lowest annual values for TOC, TN, and C:N ratio ($P < 0.05$).

Soil available elements and dissolved organic matter are active components that microbes can utilize directly and rapidly. At the overall seasonal level, NH -N was highest in winter ($P < 0.05$), while DOC, DON, and AP contents were significantly higher in summer than in other seasons, with DOC and DON reaching their peak in autumn ($P < 0.05$). Across all transects, DOC and DON contents decreased significantly with decreasing elevation ($P < 0.05$). Notably, the lowest elevation transect had relatively low contents of NH -N, NO -N, and DOC.

Soil physicochemical properties and nutrient element contents
Soil available and soluble substances contents

2.2 Soil Microbial Biomass Carbon, Nitrogen, and Basal Respiration

Soil basal respiration, microbial biomass, and microbial quotient values are all sensitive indicators of soil quality. Overall, BR, MBC, qMBC, and qMBN were relatively high in summer and winter, with spring showing significantly higher values than other seasons ($P < 0.05$). Notably, the lowest elevation transect had relatively low soil microbial biomass MBC and MBN in spring, but the opposite pattern for microbial respiration and microbial quotient values.

Across different elevation transects, MBC and MBN showed a trend of being higher in spring and autumn and lower in summer and winter. The microbial metabolic quotient qCO reflects the energy efficiency of the microbial community. When soil is stressed, microorganisms need to expend more energy to resist adverse environments. In this study, qCO was higher in spring and autumn, indicating that prolonged flooding in autumn and drought in spring inhibited the rate of material cycling.

Microbial biomass carbon and nitrogen and basal respiration among different seasons and plots

2.3 Soil Enzyme Activities

The four soil hydrolases showed similar dynamic patterns, indicating that microorganisms exhibit both specificity and mutual coordination in material metabolism and energy conversion processes. In overall seasonal variation, all four enzyme activities were higher in summer or winter and significantly lowest in autumn ($P < 0.05$). In spring and winter, all three transects were flooded to varying degrees, while in autumn the transects were not flooded, yet enzyme activities were significantly higher than in other seasons ($P < 0.05$).

Across elevation transects, the activities of the four hydrolases and two oxidases were all significantly higher in the middle transect (S2) than in the other two transects (S1 and S3) ($P < 0.05$), following the pattern S2 > S1 > S3.

[Figure 1: see original paper] Soil extracellular enzyme activities

2.4 Relationships Between Microbial Activity and Environmental Variables

Correlation analysis between microorganisms and environmental factors showed that SWC, NH -N, TOC, C:N, DOC, AP, and AFDM were extremely significantly correlated with microbial activity characteristics including BR, MBC, MBN, qCO , qMBC, and qMBN ($P < 0.01$). Unlike hydrolases, the two oxidases were extremely significantly correlated with SWC, NH -N, TOC, and C:N ($P < 0.01$).

Two-way ANOVA showed that both season and transect significantly affected soil physicochemical factors and microbial activity characteristics, with season showing a greater influence. PCA results also indicated that soil physicochemical and microbial characteristics showed obvious seasonal distribution patterns, though spring samples showed greater differentiation among transect elevations.

[Figure 2: see original paper] Principal component analysis of soil environmental factors and microbial activity characteristics
Correlation analysis of soil microbial activity characteristics and physicochemical factors

3. Discussion

3.1 Response of Soil Physicochemical Factors to Seasonal Water Level Changes

Water is an important medium for material and energy migration and transformation in wetland ecosystems. Poyang Lake’ s highly dynamic water level changes and repeated water movement affect the wetland soil physicochemical environment. In spring and winter, none of the three transects were flooded, while in June they experienced varying degrees of flooding. The pattern of SWC in spring and winter was consistent with the flooding conditions of the transects.

Increased water content facilitates the decomposition of wetland plant residues, returning large amounts of nutrients to the soil, and also promotes the dispersion of soil aggregates, further releasing soluble substances. Nutrients such as TP, DOC, DON, and AP and their proportions in the total nutrient pool all showed an increasing trend from spring to summer. After flooding, aboveground plants entered dormancy, reducing nutrient uptake. The rapid water recession period in October maintained high water levels, and the long-term flooded anaerobic environment drastically reduced microbial activity and enzyme decomposition capacity, also decreasing soil dissolved organic matter content and thus increasing the soil C:N ratio.

The higher temperatures in October were conducive to nitrogen mineralization and soil nitrification. DOC and DON have strong water solubility and are easily leached. The lack of water in winter and reduced plant root secretions, combined with lower temperatures, may also limit microbial activity, thereby reducing soil nutrient element and dissolved substance contents.

3.2 Response of Microbial Activity Characteristics to Seasonal Water Level Changes

Soil moisture content is a significant factor affecting MBC and MBN, consistent with results from Wan et al. The long-term flooding in autumn reduced soil microbial biomass. Factors affecting microbial activity may indirectly affect the intensity of basal respiration. Spring drought and rewetting by rainfall may be one reason for enhanced respiration, while summer and autumn flooding are not conducive to aerobic microbial metabolism, reducing respiration intensity. Both excessively high and low moisture conditions are unfavorable for soil microbial respiration.

The qCO integrates microbial mineralizable carbon and metabolic rate. When soil is stressed, the microbial community structure changes, and microorganisms need to expend more energy to resist adverse environments. In this study, prolonged flooding conditions in autumn reduced qMBN. The four hydrolases showed similar patterns, indicating coordinated microbial responses. Suitable summer temperatures, litter decomposition, and nutrient input from new vegetation growth may collectively increase microbial activity and enhance overall soil hydrolase activity. Long-term flooding anaerobic environments inhibit microbial activity and are not conducive to nutrient release, resulting in the lowest enzyme activities.

The two oxidases were extremely significantly correlated with SWC, NH -N, TOC, and C:N. Transects at higher elevations have lower flooding frequency and are less prone to waterlogging stress. However, long-term flooding anaerobic environments increase hydrogen peroxide accumulation, activating microbial peroxidase and phenoxidase activities to alleviate cellular stress and toxicity.

3.3 Effects of Different Elevations and Vegetation on Soil Physicochemical and Microbial Characteristics

Although seasonal water level changes primarily influenced wetland soil physicochemical properties and microbial functional activity, differences among transects also existed. The root cause of these differences was also water level variation. The average seasonal water level fluctuation in Poyang Lake exceeds 10 m, while the natural elevation difference among the three transects is only 2–3 m, making seasonal water level fluctuations more significant than elevation differences.

The middle transect (S2) showed higher overall nutrient element contents than the other two transects, which was inconsistent with the elevation trend. Studies by Qian et al. and Xie et al. on dominant vegetation communities in Banghu found similar phenomena, possibly because the aboveground biomass of the *Triarrhena lutarioriparia* community is higher than that of *Cynodon dactylon* and *Carex cinascens* communities. After plant litter decomposition, more nutrients can be provided to the soil.

In recent years, the dry season in Poyang Lake has advanced and extended, with higher elevation transects experiencing insufficient flooding, water deficiency, and gradual meadowization. This may be one reason why the highest elevation transect showed greater differentiation. PCA results also indicated that flooding made soil physicochemical properties and microorganisms more similar across transects. Differences in nutrient supply also affect the types of microorganisms that secrete enzymes, thereby influencing enzyme activities. Higher enzyme activities can control more nutrient release and accelerate microbial growth. The higher microbial activity in the S2 transect may be caused by richer soil nutrients, which correlation analysis further confirms.

4. Conclusion

The main conclusions of this experiment are as follows: (1) Water level changes significantly altered soil TOC, C:N, TP, and other nutrient elements, as well as the contents of available elements such as DOC, DON, AP, and NH -N. Microbial biomass and enzyme activity indicators also showed trends of being higher in summer or winter and lowest in autumn with water level changes. (2) Differences in water level and vegetation type among different elevation transects resulted in significantly higher soil nutrient element contents and microbial activities in the *Triarrhena lutarioriparia* transect than in the *Cynodon dactylon* and *Carex cinascens* transects. (3) Soil nutrient resource availability (DOC, AP, TOC, AFDM) significantly affected the activities of the four hydrolases, while SWC, NH -N, TOC, and C:N significantly influenced microbial biomass, basal respiration, and the activities of the two oxidases.

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Note: Figure translations are in progress. See original paper for figures.