Seasonal Variation of Zooplankton Functional Groups and Their Influencing Factors in Sanhuanpao Wetland (Postprint)

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Abstract

To investigate the seasonal variations of zooplankton functional groups and the influences of water environmental factors in cold region wetlands, functional groups were classified for freshwater zooplankton. Taking the Sanhuanpao National Nature Reserve, a marsh wetland in the cold northern region, as an example, zooplankton samples were collected from 15 sampling sites during spring (May), summer (July), and autumn (September) of 2014, and the compositional characteristics of zooplankton functional groups were systematically analyzed. The results showed that: the zooplankton functional groups in the Sanhuanpao National Nature Reserve were classified into a total of 7 functional groups; in spring, functional group RF was dominant, accounting for 83.82%; in summer, functional groups RC, PF, RF, and LCC were dominant, accounting for 34.15%, 19.58%, 18.49%, and 10.54%, respectively; in autumn, functional groups RC and RF were dominant, accounting for 71.94% and 17.86%, respectively. The seasonal variation of zooplankton functional groups exhibited the pattern RF → RC+PF+RF+LCC → RC+RF, indicating that functional group RF exerted effective filter-feeding on phytoplankton in spring, and functional group RC exerted strong predation pressure on functional groups PF and RF in summer and autumn. Pearson correlation analysis and RDA multivariate statistical analysis indicated that interspecific competition, chloride ion (Cl-), total nitrogen (TN), total inorganic carbon (IC), and biochemical oxygen demand (BOD5) were the main factors influencing zooplankton functional groups in the Sanhuanpao National Nature Reserve. Except for functional group RF, other functional groups showed significant positive correlations with chloride ion (Cl-), total nitrogen (TN), and total inorganic carbon (IC), and significant negative correlations with biochemical oxygen demand (BOD5). SCF, MCF, MCC, and LCC exhibited extremely significant correlations due to relationships of food competition and predation, whereas RC and RF, PF, which share predatory relationships, did not

show significant correlations. Interspecific competition, phytoplankton bottom-up effects, and nutrients were the main factors influencing the seasonal variation and biomass of zooplankton functional groups in cold region marsh wetlands.

Full Text

Seasonal Dynamics of Zooplankton Functional Groups and Their Relationships with Environmental Factors in the Sanhuanpao Wetland Reserve

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Abstract: This study investigated the seasonal variation of zooplankton functional groups and their responses to environmental factors in a cold-region marsh wetland. Taking the Sanhuanpao National Nature Reserve as a case study, we conducted systematic zooplankton sampling across multiple sites and analyzed the compositional characteristics of zooplankton functional groups. Seven functional groups were identified during the study period. Group RF (Rotifer filter feeders) dominated in spring, accounting for 83.82% of total biomass and playing a crucial role in phytoplankton control. In summer, groups RC (Rotifer carnivores), PF (Protozoan filter feeders), RF, and LCC (Large copepod carnivores) were dominant, with relative biomasses of 34.15%, 19.58%, 18.49%, and 10.54%, respectively. Autumn assemblages were dominated by groups RC and RF, comprising 71.94% and 17.86% of biomass, respectively. Group RC exhibited strong predation pressure, significantly inhibiting PF and RF growth during summer and autumn. Pearson correlation and redundancy analysis (RDA) revealed that interspecific competition, chloride ions (Cl), total nitrogen (TN), total inorganic carbon (IC), and biological oxygen demand (BOD_5) were the primary factors influencing zooplankton functional groups in the Sanhuanpao Wetland Reserve. Cl, TN, and IC showed significant positive correlations with all functional groups except RF, whereas BOD_5 showed significant negative correlations with all groups except RF. Functional groups SCF, MCF, MCC, and LCC exhibited strongly positive interrelationships, while RC showed no significant correlation with PF or RF. Interspecific competition, bottom-up effects from phytoplankton, and nutrient availability were the dominant drivers of seasonal variation and biomass patterns in this cold-region marsh wetland.

Keywords: zooplankton; functional groups; Sanhuanpao Wetland Reserve; wetland

1. Introduction

Zooplankton represent secondary productivity in aquatic ecosystems, serving as essential food for fish and shrimp larvae while playing a critical role in controlling phytoplankton populations. As key components of aquatic food webs, zooplankton have become increasingly important subjects of study, particularly as water pollution intensifies, eutrophication worsens, and cyanobacterial blooms become more frequent. Traditional approaches based on systematic taxonomy classify aquatic organisms—including phytoplankton, zoobenthos, and fish—into different taxonomic groups to assess water quality and biodiversity. However, conventional classification fails to capture the ecological functions of aquatic organisms [?]. Ecologists have consequently proposed the functional group concept, which links species traits more closely to environmental conditions [?]. Functional group analysis provides more direct insights into how environmental factors influence ecological processes within aquatic communities, offering greater scientific value for managing aquatic biological resources across different geographic regions. This approach is also crucial for developing and testing community ecology theories, improving understanding of aquatic ecosystem structure and biodiversity [?], and establishing foundations for quantitative ecosystem function modeling, such as energy flow analysis [?].

While functional group classification and analysis have been extensively applied to phytoplankton, zoobenthos, and fish, research on zooplankton functional groups remains limited, particularly regarding cold-region marsh wetlands. Most existing studies focus on marine systems [?], with freshwater ecosystem research lagging behind. The Sanhuanpao National Nature Reserve in Heilongjiang Province represents one of the most important wetlands in the Sanjiang Plain. Its primary conservation targets include inland wetland ecosystems and the rare waterfowl they support, bearing significant responsibility for wetland biodiversity protection and sustainable ecosystem management. Located in the heart of the Sanjiang Plain—specifically in the middle and lower reaches of the Qiqi River in southern Fujin City—the reserve borders Baoqing County to the south and Youyi County to the west. Its southwestern boundary faces the Qiqi River National Nature Reserve across the Qiqi River, while its southeastern edge adjoins the Naoli River National Nature Reserve across the Naoli River. In recent years, agricultural wastewater discharge from the Naoli and Qiqi Rivers has caused significant water quality deterioration and severe eutrophication in parts of the reserve. This study systematically classifies zooplankton functional groups in the Sanhuanpao National Nature Reserve to examine seasonal changes in community structure and biomass and their relationships with environmental factors, providing a scientific basis for integrated wetland management.

2. Materials and Methods

2.1 Sampling Sites

Water samples were collected throughout the Sanhuanpao National Nature Reserve. Sampling stations were established based on the reserve' s core zone, buffer zone, and experimental area designations, as well as surrounding environmental influences. Stations S_{14}-S_{15} were located in the buffer zone of the Daxing management station, while stations S_2-S_6 were situated in the experimental area at the junction of Baoqing, Fujin, and Youyi Counties. Additional stations were positioned in the core area of the Luguan management station (S_9-S_{10}) and the buffer zone of the Zhenxing management station (S_{11}-S_{13}).

2.2 Sampling and Water Chemistry Analysis

Qualitative zooplankton samples were collected using a #25 plankton net towed underwater in a "∞" pattern. Quantitative samples for protozoa and rotifers were obtained with a plexiglass water sampler, fixed with Lugol' s solution (1% final volume), and concentrated to 30 mL after 48 h sedimentation and siphoning. Protozoa were enumerated in 0.1 mL counting chambers under a microscope, while rotifers were counted in 1 mL chambers. Cladocerans and copepods were collected with a plexiglass sampler, filtered through a plankton net, and preserved in 5% formalin solution. All individuals were identified and counted in zooplankton counting chambers [?].

Taxonomic identification followed established references: protozoa according to *New Techniques for Microbial Monitoring* [?]; rotifers according to *Fauna Sinica: Chinese Freshwater Rotifera* [?]; cladocerans according to *Freshwater Cladocera* [?]; and copepods according to *Freshwater Copepoda* [?]. Biomass was calculated using length-weight regression equations: rotifer biomass by volume, and cladoceran and copepod biomass by individual body length [?].

Water chemistry parameters were measured using standard methods. Temperature (WT), pH, dissolved oxygen (DO), conductivity (COND), and turbidity (TURBID) were determined in situ using a YSI-6600 multiparameter water quality analyzer. Transparency (SD) was measured with a Secchi disk. Total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (CODMn), biological oxygen demand (BOD_5), total carbon (TC), total organic carbon (TOC), total inorganic carbon (IC), and chloride ions (Cl) were analyzed according to *Standard Methods for Water and Wastewater Monitoring* [?].

2.3 Functional Group Classification

Based on previous research and considering zooplankton body size, feeding habits, and interspecific interactions, freshwater zooplankton can be classified into ten functional groups: protozoan filter feeders, protozoan predators, rotifer filter feeders, rotifer predators, small copepod/cladoceran filter feeders, small copepod/cladoceran predators, medium copepod/cladoceran filter feeders, medium copepod/cladoceran predators, large copepod/cladoceran filter feeders, and large copepod/cladoceran predators [?]. However, the Sanhuanpao survey did not detect protozoan predators or large copepod/cladoceran filter feeders, resulting in seven functional groups being recognized (Table 1).

[FIGURE:1] Sampling sites for zooplankton in the Sanhuanpao Wetland Reserve

Classification of freshwater zooplankton functional groups

2.4 Data Analysis

Zooplankton functional group biomass was calculated for each sampling site. Differences among sites were assessed using Bray-Curtis similarity coefficients [?]. Species and environmental data were $\log_{10}$(x+1) transformed to approximate normal distributions. Pearson correlation analysis examined relationships between functional groups and water chemistry parameters. Canonical correspondence analysis (CCA) was performed using Canoco for Windows 4.5 to investigate relationships between functional group composition and environmental variables.

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3. Results

3.1 Water Environment Characteristics

Seasonal variations in water environmental factors are presented in Table 2. Significant seasonal differences were observed for most parameters except conductivity. Spring exhibited lower transparency (SD), turbidity (NTU), and total nitrogen (TN) compared to other seasons, but higher biological oxygen demand (BOD_5), total organic carbon (TOC), and total inorganic carbon (IC). Summer showed elevated total nitrogen (TN), total phosphorus (TP), total carbon (TC), and chemical oxygen demand (CODMn), while autumn had lower water temperature (WT) and total phosphorus (TP).

Seasonal averages of environmental variables in the Sanhuanpao Wetland Reserve

3.2 Seasonal Distribution of Zooplankton Functional Groups

Analysis of seasonal biomass patterns revealed that the Sanhuanpao Wetland Reserve zooplankton community comprised seven functional groups. Spring communities were dominated by RF (83.82% of total biomass). Summer assemblages were codominated by RC, PF, RF, and LCC, contributing 34.15%, 19.58%, 18.49%, and 10.54% of biomass, respectively. Autumn communities were dominated by RC and RF, accounting for 71.94% and 17.86% of biomass, respectively. The seasonal succession pattern can be expressed as: RF $\rightarrow$ RC+PF+RF+LCC $\rightarrow$ RC+RF.

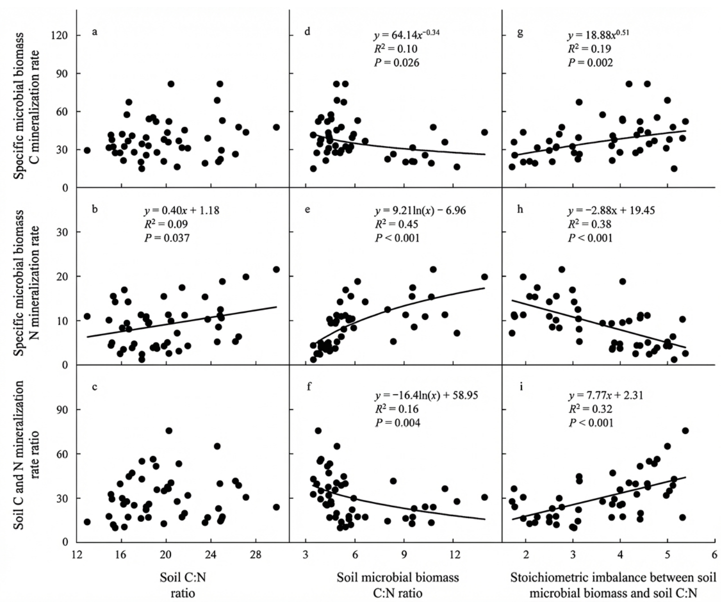

Figure 1: Figure 2

MDS ordination of zooplankton functional group biomass in the Sanhuanpao Wetland Reserve

Zooplankton functional groups identified in the Sanhuanpao Wetland Reserve

3.3 Relationships Between Functional Groups and Environmental Factors

Pearson correlation analysis revealed that most zooplankton functional groups showed no significant relationships with water environmental factors, except for positive correlations with chloride ions and conductivity. Among functional groups, SCF, MCF, and MCC exhibited extremely significant positive correlations with each other, while RC showed no significant correlation with PF or RF. Predatory relationships between RF and PF displayed highly significant correlations.

RDA results indicated that the first two axes explained 27.0% of cumulative variance in functional group composition. The first axis (eigenvalue = 0.245) was most strongly correlated with conductivity (0.6188) and total carbon (0.6457) as positive factors, and transparency (-0.4660) as a negative factor. The second axis was primarily associated with total inorganic carbon (-0.5643) and total nitrogen (0.5731). All functional groups except RF showed positive correlations with Cl, TN, COND, and TC, and negative correlations with BOD_5 and SD.

Horizontal distribution of phytoplankton functional group biomass

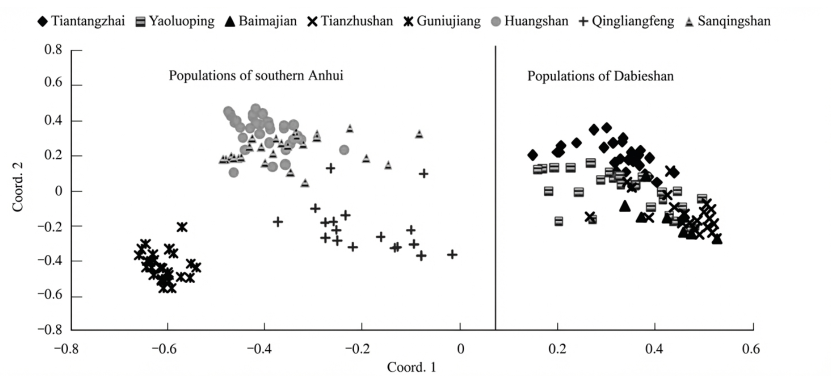

Figure 2: Figure 3

[FIGURE:4] Seasonal mean relative biomass of main zooplankton functional groups in the Sanhuanpao Wetland Reserve

[FIGURE:5] RDA biplot of functional groups and environmental factors

Pearson correlations among zooplankton functional group biomasses (n = 45)

Pearson correlations between zooplankton functional groups and environmental variables (n = 45)

RDA results: eigenvalues and species-environment correlations

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4. Discussion

4.1 Seasonal Variation of Zooplankton Functional Groups

Research on zooplankton seasonal dynamics has primarily focused on tropical and temperate lakes and rivers [?], with relatively few studies in cold-region wetlands [?]. Seasonal patterns in these systems are influenced by water temperature, phytoplankton bottom-up effects, fish predation top-down effects, and interspecific competition [?]. In tropical regions, temperature has minimal effect on zooplankton, with fish predation being the primary determinant of community structure [?]. In temperate zones, temperature and nutrients are the main environmental drivers, with cladocerans and copepods showing positive correlations with water temperature [?]. Eutrophication often leads to zooplankton miniaturization, with nutrient-rich waters dominated by small rotifers [?] and cladocerans [?] year-round.

From a taxonomic perspective, zooplankton seasonal variation in the Sanhuanpao National Nature Reserve appears modest, with rotifers dominating all seasons. However, functional group analysis reveals significant seasonal shifts: RF dominance in spring, codominance of RC, PF, RF, and LCC in summer, and

RC+RF dominance in autumn. The spring RF dominance is composed of low-temperature tolerant, filter-feeding species such as *Polyarthra trigla* and *Keratella cochlearis*. The summer peak in RF represents the primary phytoplankton-filtering functional group, while autumn RC dominance by *Strombidium gyrans* —a bacterivorous and detritivorous species inhabiting oligotrophic waters [?]—suggests relatively better water quality at those sampling sites.

4.2 Functional Group Interactions and Environmental Relationships

Phytoplankton bottom-up effects, fish predation top-down effects, and interspecific competition are primary factors influencing zooplankton growth and functional group distribution. In subtropical regions, fish predation dominates, whereas temperature and nutrients are key in temperate zones. For cold-region wetlands like Sanhuanpao, temperature is not the primary factor; instead, BOD_5 and IC emerge as the main environmental drivers.

Although the reserve experiences minimal direct anthropogenic disturbance from tourism, agricultural wastewater from upstream Qiqi and Naoli Rivers significantly elevates Cl and TN concentrations during summer and autumn. Increased Cl and TN promote phytoplankton growth, which indirectly affects zooplankton through bottom-up effects. Inorganic carbon also influences phytoplankton, thereby indirectly impacting zooplankton. Carbon is a fundamental element for phytoplankton, and phytoplankton carbon fixation plays a critical but underappreciated role in global carbon cycling [?]. In Sanhuanpao, IC is a major factor affecting phytoplankton functional groups, and phytoplankton represent the most important carbon source for zooplankton [?].

BOD_5, reflecting organic pollution from aerobic microorganisms, showed significant negative correlations with most functional groups. Values exceeding 1 mg/L indicate organic contamination [?], and Sanhuanpao' s annual BOD_5 of 4 mg/L suggests moderate organic pollution. The RF functional group showed no significant correlation with BOD_5, likely because these rotifers can filter-feed on bacteria and detritus [?] and tolerate low-oxygen conditions.

RDA results showed that the first two axes explained 27.0% of functional group variation, similar to findings from tropical water bodies (11%) [?] and eutrophic reservoirs (34.6%) [?]. This suggests that besides water environmental factors, other processes such as interspecific competition significantly influence functional group structure. While many Chinese studies emphasize water environmental factors [?], they often overlook zooplankton interactions. Pearson analysis revealed that although PF, RF, and RC showed no significant intercorrelations, the predatory relationship between RF and PF was highly significant. In contrast, SCF, MCF, and MCC showed extremely significant positive correlations, indicating weak competitive interactions among these groups. These patterns align with findings from tropical eutrophic reservoirs where rotifers and cladocerans showed no significant correlation [?].

5. Conclusion

This study classified freshwater zooplankton into seven functional groups based on body size, feeding habits, and interspecific interactions. The Sanhuanpao Wetland Reserve supported seven functional groups, with RF dominating in spring, RC+PF+RF+LCC codominating in summer, and RC+RF dominating in autumn. These seasonal shifts represent the most characteristic pattern for this wetland ecosystem.

The primary factors influencing Sanhuanpao' s zooplankton functional groups were interspecific interactions and water environmental conditions. RF showed no significant correlation with other functional groups or environmental factors, whereas other groups exhibited significant positive correlations with Cl, TN, and IC, and negative correlations with BOD_5. Interspecific competition and predation relationships were highly significant, particularly between the predatory groups RF and PF, while SCF, MCF, and MCC showed weak competitive relationships.

This research provides a valuable framework for functional group classification in freshwater ecosystems, particularly for cold-region marsh wetlands, and offers scientific guidance for wetland ecosystem management and conservation.

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