RESEARCH ARTICLE

Changes in spatial distribution pattern and ecological characteristics of *Scirpus planiculmis* community driven by hydrology

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Wetlands, as a transitional zone between water bodies and land, are crucial for the ecological environment. However, under the influence of global change and human activities, wetlands are facing serious degradation. Changes in hydrological conditions have had a profound impact on wetland vegetation, especially the *Scirpus planiculmis* community. This study proposed a method that combined field monitoring, experimental manipulation, and ecological index analysis to address wetland vegetation that was significantly affected by changes in hydrological conditions but with unclear mechanisms. This method simulated different water levels, salt, and nitrogen concentrations to deeply analyze the specific mechanism of environmental factors on the growth of *Scirpus planiculmis*. In addition, ecological indicators such as Pielou's evenness index and Cody index were used to quantitatively evaluate community structure characteristics. The results showed that *Scirpus planiculmis* was widely distributed and became the dominant species in the water depth range of 10 - 50 cm. The Simpson and Shannon-Wiener indices reached their peaks at a water depth of 30 cm with values of approximately 0.38 and 0.73, respectively. Water level and nitrogen concentration had a significant impact on the functional traits of *Scirpus planiculmis*, and there was an interactive effect. Nitrogen addition significantly promoted biomass accumulation, and biomass was higher at high nitrogen levels as 200 mgN/kg. Therefore, hydrological drivers could significantly affect the spatial distribution and ecological characteristics of the *Scirpus planiculmis* community. This study provided a scientific basis for wetland ecological protection and restoration.

Keywords: hydrological driven; *Scirpus planiculmis*; spatial distribution; ecological characteristics; community ecology.

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Introduction

Wetlands, as a transitional zone between water bodies and land, have extremely high biological productivity and biodiversity, playing a crucial role in the ecological environment [1, 2]. However, under the dual impacts of global change and human activities, wetlands are facing severe degradation with changes in hydrological conditions having a profound impact on wetland vegetation, especially the *Scirpus planiculmis* community (SPC). The Momoge National Nature Reserve is in the Songnen Plain (Jilin, China) and is a habitat for important endangered species such as white cranes [3, 4]. In recent years, due to human activities such as agricultural irrigation and land reclamation, the hydrological environment of wetlands in this region has undergone drastic changes, leading to serious threats to the distribution and growth status of

SPC. As an important food source for white cranes, the growth and reproductive characteristics of *Scirpus planiculmis* are closely related to the water and salt environment.

In recent years, an increasing number of researchers have directed their attention toward the field of wetland plant research. Ma *et al*. proposed a research method to analyze the impact of the interaction between salt marsh plants on their inter-specific relationships that was influenced by both nitrate supply and soil salinity. This method could effectively reveal the comprehensive effects of environmental driving factors on the dynamics of salt marsh plant communities. However, this research lacked in-depth investigations [5]. Roy *et al*. proposed an experimental principle to compare the spatial distribution of non-excited and excited plants in response to the problem of unclear plant information processing mechanisms with self-made electric probes. The results demonstrated that there was a significant difference in voltage distribution patterns between the two types of plants, and the voltage changes in each layer of excited plants were significant after stimulation [6]. Duguma *et al*. also proposed a method to simulate the species richness of woody plants in southwestern Ethiopia using a generalized linear model to address the impact of land use change on biodiversity. The species richness was the highest in areas with medium altitude and near forest edges, and the "coffee and conservation" scenario was most conducive to the long-term maintenance and enhancement of biodiversity [7]. Thant *et al*. developed a method to collect and classify salt marsh plants using a standard protocol, while measuring environmental factors to address the issue of unknown spatial distribution and activity density of salt marsh plants and found that the animal density of salt marsh plants varied at different temperatures, and their community composition and distribution were influenced by environmental factors such as terrain location index and soil pH [8]. Although all those studies have made some progress in the field of wetland plant ecology, there are still several shortcomings that most studies focus on the impact of specific environmental factors on wetland plants, lacking comprehensive consideration of multi-factor interactions, making it difficult to fully reflect the ecological dynamics in complex environments [9, 10].

This study innovatively combined field monitoring, experimental manipulation, and ecological index analysis to systematically explore the impact of hydrological driving on the spatial distribution and ecological characteristics of SPC. The research simulated different water levels, salt, and nitrogen concentrations to deeply analyze the specific mechanism of environmental factors on the growth of *Scirpus planiculmis* to reveal how hydrological changes drive the dynamic evolution of SPC, providing a scientific basis for wetland ecological protection and restoration. This research comprehensively considered the interaction of multiple factors such as water level, salinity, and nitrogen concentration, providing a more comprehensive perspective for understanding the dynamics of wetland plant communities. By simulating the growth of plants under different hydrological conditions, the ecological adaptation strategies of *Schisandra chinensis* under different water depths and nutritional conditions were revealed. The results of this study could provide a scientific basis for the protection and restoration of wetland ecosystems, while promoting the health and stability of wetland ecosystems.

Materials and methods

Research area

The Momoge National Nature Reserve is located in Zhenlai county, Baicheng City, Jilin Province, China [11, 12]. It is the confluence of the surging Nen River and the gentle Tao'er River with a total area of 144,000 hectares [13, 14]. Rivers crisscross the area, while lakes and depressions are scattered throughout the region. The ecological environment is complex and diverse, mainly including riverbank moss wetlands, *Scirpus planiculmis* wetlands, and alkali salt marshes, which are China national AAAA level tourist attractions [15, 16]. Four survey plots were uniformly set up throughout the entire area using the point quadrant method. The plot area was 1 × 1 m^2, and the straight-line distance between plots was 15 m. Five samples were randomly taken from different plots. Meanwhile, four transects were evenly distributed throughout the entire area. By combining transects and plots, four plots were set from the edge of the lakeside wetland to the open water surface. A total of 400 samples were collected.

Plant sample collection

(1) *Miscanthus altissima* sample collection

To ensure the collection of complete underground corms of *Miscanthus altissima*, the excavation depth was set at 30 cm. The collected *Miscanthus altissima* corms were neatly packed into woven bags to prevent damage to the samples during transportation. Each woven bag contained about 20 bulbs, and the sampling location and number were marked outside the bag for subsequent identification. After the sample was transported to the laboratory, it was immediately subjected to preliminary processing. The bulbs were thoroughly cleaned to remove any attached soil and impurities and then placed in a well-ventilated environment to dry naturally. To ensure the activity of the sample, temperature and humidity were regularly monitored during storage between 15 - 20℃ and 60 - 70%, respectively. The samples were properly stored in a dry and cool environment, avoiding direct sunlight and humid conditions.

(2) *Scirpus planiculmis* sample collection

Scirpus planiculmis contains rich ecological information in both its aboveground and underground corms such as population density, biomass, reproductive capacity, *etc*. [17, 18]. *Scirpus planiculmis* samples and underground corms were collected from 2023 to 2024. The seasonal monitoring of the flat stem fescue in the Momoge wetland was conducted from October 2023 to May 2024. The detailed changes of water temperature and plant growth status were recorded. After closely observing the germination of flat stemmed fescue and combining ecological and botanical knowledge, the optimal transplanting period was determined as from late May to early June to excavate corms. To avoid damage to the young stems during the germination period of the flat stem fescue, early May was chosen as the best time for digging the bulbs. The depth of sampling was selected as a shallow water area of 0 – 50 cm, and the sample area of flat stem grass grown in the previous year was chosen as the target area for bulb collection [19, 20]. The selected sample strips were marked for accurate identification in subsequent mining. The excavation of patches adopted patch or discontinuous excavation methods to excavate soil in the marked sample area to minimize the damage to wetland ecosystems. Soil treatment involved carefully dumping the excavated soil into the soil collection area and using an agricultural rake to disperse the soil, making it easier to pick up the bulbs. The scattered flat stem grass bulbs in the soil were manually picked up to ensure that valuable bulbs were not lost. The picked corms were neatly packed into woven bags for subsequent transportation and storage in a controlled and monitored environment.

(3) *Platycodon grandifloras* sample collection

The seedlings of *Platycodon grandiflorus* were obtained from Zhenlai County, Baicheng City, Jilin Province, China. Healthy and uniformly sized seedlings were selected and cultured in the cultivation medium provided by Heilongjiang Heitu Agricultural Technology Co., Ltd. (Harbin, Heilongjiang, China). The tubers of *Platycodon grandiflorus* were collected from the same place as the seedlings of *Platycodon grandiflorus*, and tubers with similar weight were selected.

Systematic survey of plant community composition

According to the water level gradient (i.e. low water level, medium water level slow flow zone, and fast flow zone), the study area was divided into three sample areas A, B, and C with water level ranges corresponding to 0 - 20 cm, 20 - 50 cm, and above 50 cm, respectively. During the investigation, detailed water depth, all plant

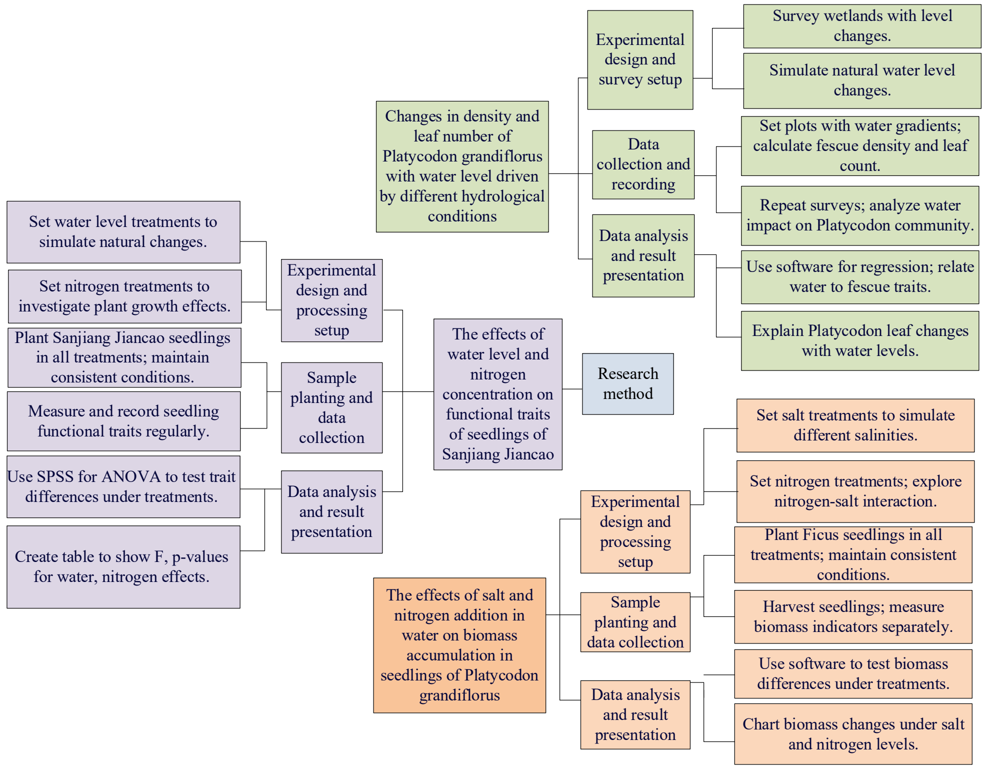


Figure 1. Methods for studying changes in ecological characteristics.

species and their relative abundance for each plot including key indicators such as coverage and plant quantity were recorded. To further analyze the characteristics of community structure, this study used various diversity indices for calculation, which included the Pielou Evenness Index (PEI) obtained from the relative abundance data of various species in the community to evaluate the evenness of species distribution and the Cody index used to measure the heterogeneity or similarity of community species composition across different bands or time series.

Spatial distribution pattern changes of the community of *Platycodon grandiflorus*

Multiple ecological indices were employed for quantitative evaluation. The Lloyd's clustering index (m/m) was calculated with the “m” as the actual observed average nearest neighbor distance that was the expected distance under random distribution and used to accurately measure the aggregation degree the plants. The Average Crowding Degree (ACD) combined with population density and other data was further calculated using Green's crowding index to reveal the crowding situation of individuals within the population. The multiple sampling points were set up in the three zones of A, B, and C, and regular population surveys were conducted. Detailed records of the distribution and quantity of the plants provided a solid foundation for index calculation. In addition, this study also focused on the trend of species diversity index changes with water depth, which calculated the Simpson index and Shannon-Wiener index of each sample plot and combined them with the water depth gradient setting to ensure that there was sufficient sample plot data to support analysis in each water depth interval.

The changes in ecological characteristics of SPC under hydrological driving

The effects of water level and nitrogen concentration on SPC functional traits were examined. The treatments combined with different water levels of 0, 10, 20, 30 cm and nitrogen concentrations of 0, 50, 100, 200 mM were applied to simulate water level changes and nitrogen supply in natural environments. The same number of SPCs was planted in each treatment combination, ensuring consistent growth conditions of light and temperature. By regularly measuring functional traits such as plant height, number of branches, number of corms, root biomass, rhizome biomass, and corm biomass, the effects of different treatments on seedling growth were comprehensively evaluated (Figure 1). The significance of differences in functional trait indicators was tested using analysis of variance for each treatment combination

The effects of water salinity and nitrogen addition on biomass accumulation of *Schisandra chinensis* seedlings

Scirpus planiculmis seedlings were planted under various treatments combined with different salt concentrations of 0, 25, 50, 100 mg/L and nitrogen additions of 0, 50, 100, 200 mgN/kg. The biomasses of leaves, stems, roots, and rhizomes were measured, and the significance of differences between treatments was tested through analysis of variance or regression analysis.

The changes in *Scirpus planiculmis* density and leaf number under different hydrological conditions

The representative wetland areas were selected and subjected to two hydrological conditions, including periodic flooding and long-term flooding. The *Scirpus planiculmis* density and leaf number were regularly examined under different water level gradients of 0, 10, 20 cm. The regression analysis was applied to establish regression equations between water level, density, and leaf number.

Statistical analysis

SPSS 26.0 (IBM, Armonk, New York, USA) was employed for the statistical analysis of this research. Analysis of variance (ANOVA) and regression analysis were performed to determine the differences among different treatment groups. *P* value less than 0.05 was defined as statistically significant difference.

Results and discussion

Changes in the composition of plant communities

This study first investigated the changes in plant community composition in the study area. Zone A was in a low water level or slow water flow area, while zone B was in a moderate water level or moderate water flow velocity area that was the most suitable environment for the growth of *Scirpus planiculmis* as it was not threatened by severe flooding and could receive sufficient nutrients and light. Zone C was a high-water level or fast water flow area. Under such environmental conditions, *Scirpus planiculmis* might be limited by significant flooding pressure and insufficient oxygen supply, which could affect its growth and distribution. The compositional changes of plant communities in the study area under hydrological gradients demonstrated that, in the water depth of 0 - 10 cm, *Scirpus planiculmis* appeared as a sub-dominant species in zone C, forming a community with other plants such as *Suaeda salsa* and reed, which indicated that, although *Scirpus planiculmis* had a certain distribution in this shallow water area, it was not the dominant species. As the water depth increased to 10 - 30 cm, *Scirpus planiculmis* became a dominant or sub dominant species in both sample zones A and B, especially in sample zone A, where it formed the main community together with dinoflagellates. The results demonstrated its strong adaptability and competitiveness within this water depth range. When the water depth reached 30 - 50 cm, *Scirpus planiculmis* appeared in all three transects and was the dominant species or main constituent species in transects A and C, which indicated that the distribution of *Scirpus planiculmis* was more widespread and important in this water depth range. Especially in sample zone C, *Scirpus planiculmis* and other species such as the three rivers sugarcane grass

Table 1. Changes in plant community composition in the study areas under the hydrological gradients.

Water depth (cm)	Transect	Subdominant Species	Dominant Species	Community Composition
0 - 10	A	Reed (*Phragmites australis*)	*Suaeda salsa*	*Suaeda salsa*
	B	Reed (*Phragmites australis*)	*Suaeda salsa*	*Suaeda salsa*, Reed (*Phragmites australis*)
	C	*Scirpus planiculmis*	*Suaeda salsa*	*Suaeda salsa, Scirpus planiculmis*, Reed (*Phragmites australis*), *Chenopodium glaucum, Echinochloa crus-galli*
10 - 30	A	*Ceratophyllum demersum*	*Scirpus Planiculmis*	*Scirpus planiculmis, Ceratophyllum demersum, Typha angustifolia*
	B	Reed (*Phragmites australis*)	*Scirpus Planiculmis*	*Scirpus planiculmis*, Reed (*Phragmites australis*), *Potamogeton natans*, *Ceratophyllum demersum*
	C	*Scirpus planiculmis*	*Eleocharis tuberosa*	*Eleocharis tuberosa, Scirpus planiculmis*, Reed (*Phragmites australis*), *Scirpus triqueter, Ceratophyllum demersum*
30 - 50	A	*Utricularia aurea*	*Scirpus Planiculmis*	*Scirpus planiculmis*, *Utricularia aurea*, Reed (*Phragmites australis*)
	B	*Salvinia natans*	Reed (*Phragmites australis*)	Reed (*Phragmites australis*), *Scirpus planiculmis*, *Salvinia natans*, *Utricularia aurea*, *Ceratophyllum demersum*
	C	*Scirpus planiculmis*	*Scirpus triqueter*	*Scirpus planiculmis*, *Scirpus triqueter*, *Echinochloa crus-galli*, *Spirodela polyrhiza*
50 - 80	A	*Scirpus planiculmis*	Reed (*Phragmites australis*)	*Scirpus planiculmis*, Reed (*Phragmites australis*)
	B	Reed (*Phragmites australis*)	*Typha angustifolia*	*Typha angustifolia*, Reed (*Phragmites australis*), *Scirpus validus*, *Scirpus planiculmis*
	C	*Scirpus planiculmis*	Reed (*Phragmites australis*)	Reed (*Phragmites australis*), *Scirpus planiculmis*

jointly formed a community, indicating that it could also form a stable community structure in areas with deeper water depth. However, in the area with a water depth of 50 - 80 cm, *Scirpus planiculmis* was still distributed in sample areas B and C, but was no longer the dominant species, which suggested that its adaptability might gradually decrease with further increase in water depth (Table 1). Overall, the spatial distribution pattern of *Scirpus planiculmis* was significantly influenced by hydrological conditions. It was widely distributed and important within a water depth range of 10 - 50 cm and was an important component of the plant community in lakeside wetlands. The appearance of the flat-stemmed *Scirpus* as a subdominant species in sample zone C indicated that, although it had certain growth ability in shallow water areas, its competitiveness was relatively weak. This might be because the water level in the shallow water area was relatively shallow, and the soil moisture conditions were various greatly. Meanwhile, it might be under competitive pressure from other surrounding plants such as *Suaeda glauca* and reeds, which limited its status as a dominant species. *Scirpus planiculmis* gradually became the dominant or subdominant species in zones A and B, especially in zone A, where it formed the main community together with *Elodea*. This water depth range might be the most suitable growth environment for *Scirpus planiculmis*. A moderate water depth could ensure that its root system had sufficient water supply, while not affecting oxygen acquisition due to excessively high-water levels. Further, the light conditions in this area were relatively good, which was conducive to the progress of photosynthesis, thereby promoting its growth and reproduction and giving it an advantage in competition with other plants. With the increase of water depth, the root system of *Scirpus planiculmis* could better adapt to the underwater environment. Meanwhile, its growth characteristics and physiological mechanisms enabled it to maintain a certain level of competitiveness under such water depth conditions.

Community changes under the influence of different water levels during the growing season

The community changes under the influence of different water levels during the growing season showed that the index of each water level

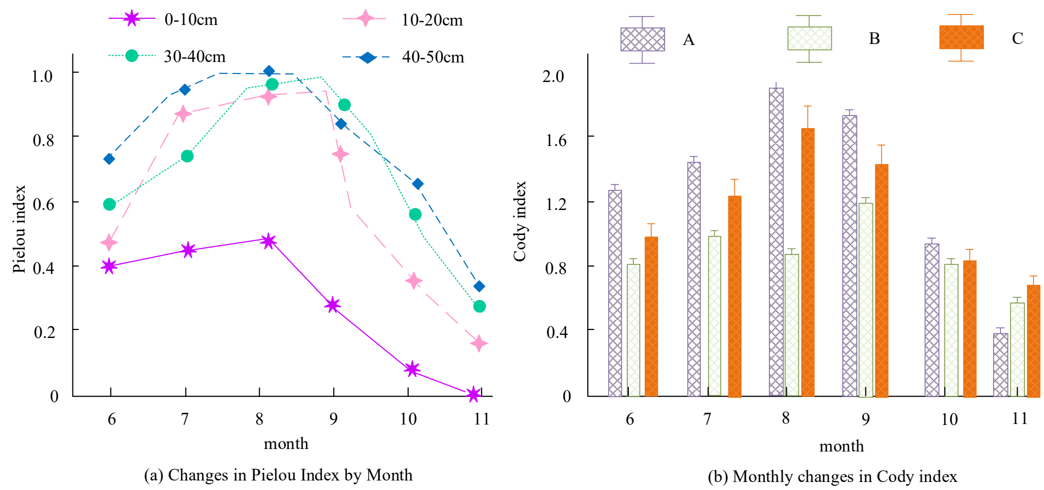


Figure 2. Changes in community PEI and Cody index under the influence of different water levels during the growth season.

interval fluctuated between June and November in the PEI variation chart. Specifically, the index of 0 - 10 cm water level was consistently low, approaching zero in November, while the index of 10 -20 cm water level gradually increased from June to September with a peak of about 0.8 and the index changes of water levels at 30 - 40 cm and 40 - 50 cm were relatively large, reaching their highest in September at 1.0 and 0.8, respectively, and then rapidly decreasing (Figure 2a). In the variation chart of the Cody index, there were significant differences in the index among different treatment groups. The index of sample A was relatively high between July and September with a peak of about 2.0 and then decreased slightly. The index of sample band B remained relatively stable throughout the entire growing season, ranging from approximately 1.2 to 0.8. The index of sample C reached its highest point in August around 1.6 and gradually decreased thereafter (Figure 2b). The results demonstrated that different water levels and treatment groups had a significant impact on the evenness and species composition of the community. PEI first increased and then decreased with significant differences between different water levels. The Cody index showed significant differences in species composition among the treatment groups during the growing season, providing a scientific basis for ecological restoration and management.

Changes in aggregation index and ACD of flat stem swallow grass population

The changes in the population aggregation index (PAI) and ACD of *Platycodon grandiflorus* over the course of a year demonstrated that sample A was in a low water level or slow water flow area and its PAI of the flat stem fescue was relatively low with small fluctuations and a peak value between approximately 0.6 - 0.7, indicating limited aggregation of the flat stem fescue in this environment. Meanwhile, its overall ACD was also relatively low, fluctuating between 1 - 2, indicating that congestion was not significant. The B-spline was in a moderate water level or moderate water flow velocity area, which might be the most suitable environment for the growth of the flat stem swallow grass and the PAI was significantly high with significant fluctuations occurring multiple times, especially reaching a maximum value close to 1.0 in summer, indicating that the flat-stemmed fescue had formed a high degree of aggregation in this environment. Meanwhile, the ACD was also at a high level in most months with a peak close to 6 in summer, further confirming the suitability of this region for the growth of the flat stemmed swallow grass. The C-band was in a higher water level or faster water flow area. Although its PAI and ACD also fluctuated, they were generally lower than that of the B-band with the peak of PAI approximately between 0.8 - 0.9 and ACD

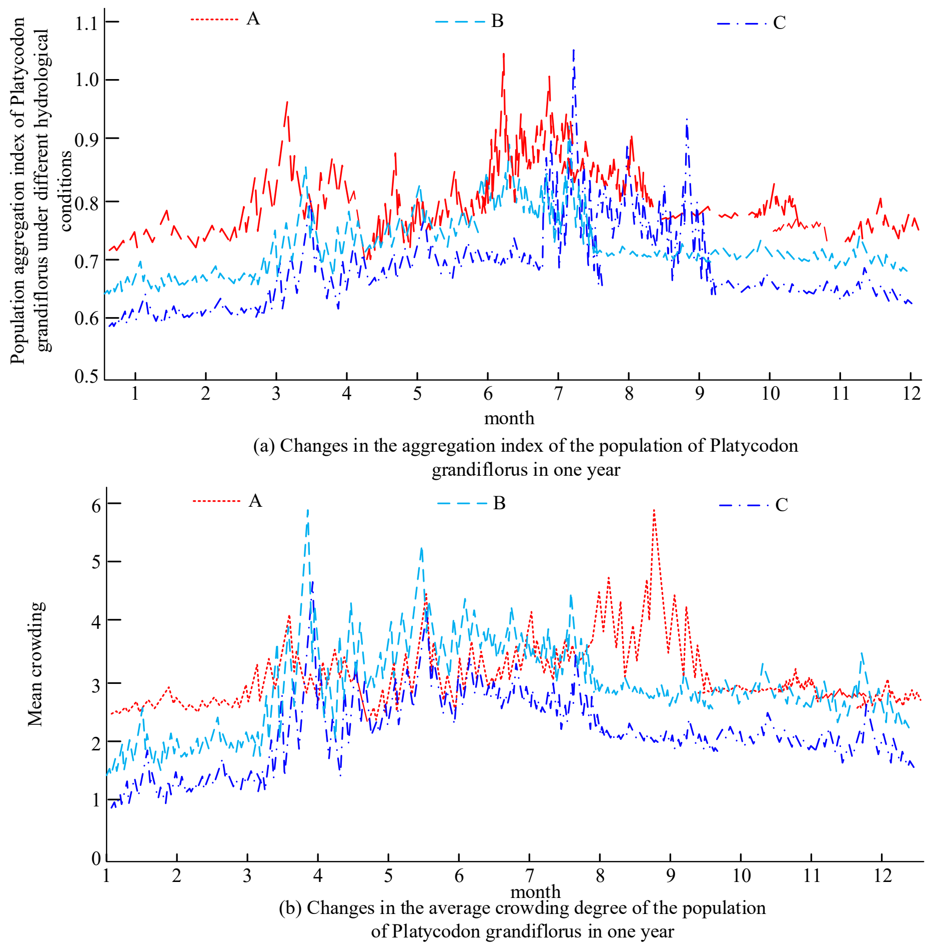


Figure 3. Changes in PAI and ACD of *F. planus* during a year.

between 2 – 4 (Figure 3). The results suggested that, under higher water levels or faster water flow conditions, the growth of the flat stemmed swallow grass was somewhat restricted, and the degree of aggregation and crowding was relatively low.

Changes in Simpson index and Shannon-Wiener index of *Platycodon grandiflorus* community under different water depth conditions

The changes in Simpson index and Shannon-Wiener index of SPC in the study area under different water depth conditions showed that the Simpson index first increased and then slightly decreased with increasing water depth. When the water depth increased from 0 to 10 cm, the Simpson index increased from about 0.16 to about 0.21. When the water depth ranged from 10 to 30 cm, the index continued to rise to a maximum value of about 0.38 at 30 cm. Subsequently, when the water depth increased to 60 cm, the index slightly decreased to about 0.29 (Figure 4a). The results indicated that the Simpson index reached its highest at a water depth of around 30 cm, reflecting a relatively low state of species diversity. The trend of the Shannon-Wiener index was similar to the Simpson index with higher overall values. When the water depth increased from 0 to 20 cm, the index increased from about 0.39 to about 0.62. When the water depth was between 20 and 30 cm, the highest value reached about 0.73. When the water depth continued to increase to 60 cm, the index decreased to about 0.54 (Figure 4b), which indicated that, at a water depth of around 30 cm, the Shannon-Wiener index also reached

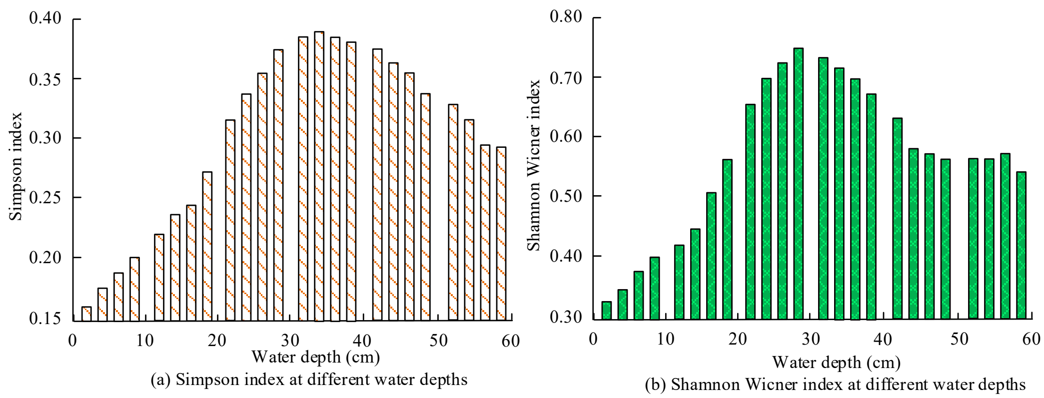


Figure 4. Changes in Simpson index and Shannon-Wiener index of the community in the study area under different water depths.

its peak, indicating a state of high species diversity. The index of each water level interval fluctuated greatly during the growing season, and there were significant differences between different water levels, which might be because, under different water level conditions, the composition and structure of plant communities changed, resulting in different relative abundances of various species. In areas with lower water levels, the distribution of species was not uniform enough, which might be due to the relatively simple environmental conditions. In the moderate water level area, the competition among species and resource allocation were relatively balanced, resulting in a higher evenness index. With the further change of water level, the community structure changed again, and the evenness also changed accordingly. The differences in species composition between the treatment groups were significant during the growing season, which indicated that factors such as water level and sample bands had a significant impact on the species composition of the community. The environmental factors such as hydrological conditions and soil properties in different zones varied, resulting in different distributions and compositions of species within different zones. During the growing season, as environmental conditions changed such as seasonal fluctuations in water levels and changes in light intensity, *etc*., the competitive relationship between species and ecological niches also changed, leading to dynamic changes in species composition and significant seasonal differences in the Cody index.

Effects of water level and nitrogen concentration on the community function of *Scirpus planiculmis* driven by hydrology

After exploring the spatial distribution pattern of SPC, the impact of different hydrological conditions including water level changes, water salinity, nitrogen addition, *etc*. on the growth, reproduction, and ecological adaptability of *Scirpus planiculmis* wetland plants was further explored. The key ecological indicators such as density changes, biomass accumulation, and leaf expansion under cyclic and long-term flooding conditions of *Scirpus planiculmis* were observed and analyzed to reveal the mechanism of community dynamic changes driven by hydrology. The effects of water level and nitrogen concentration on SPC functional trait indicators showed that water level and nitrogen concentration had a significant impact on the functional trait indicators of SPC, and the interaction between the two was also significant on certain indicators. The results demonstrated that water level had a highly significant impact on all functional trait indicators (P < 0.001), indicating that water level was a key factor in SPC growth. For the height of plant, the F value was as high as 170.859, indicating significant differences in plant height under different water level treatments, which might be due to the

Table 2. The effects of water level and nitrogen concentration on the community of *Platycodon grandiflorus*.

Parameters	Water level		Water level x nitrogen concentration		Nitrogen concentration (mM)	
	F value	*P* value	F value	*P* value	F value	*P* value
Plant height (cm)	170.859	< 0.001***	0.831	0.523	3.786	0.042*
Number of branches	48.729	< 0.001***	10.678	< 0.001***	0.548	0.588
Number of corms	85.940	< 0.001***	20.601	< 0.001***	3.862	0.040*
Root biomass (g)	37.808	< 0.001***	2.528	0.077	0.977	0.395
Root and stem biomass (g)	10.649	< 0.001***	3.201	0.038*	0.093	0.911
Biomass of corms (g)	36.725	< 0.001***	6.039	0.003**	0.239	0.790
Underground biomass (g)	63.215	< 0.001***	5.682	0.004**	1.542	0.241
Aboveground biomass (g)	11.041	< 0.001***	3.304	0.034*	1.461	0.258
Total biomass (g)	47.883	< 0.001***	5.033	0.007**	3.786	0.042*

direct impact of water level changes on plant light, oxygen uptake, and root respiration, which in turn affected overall growth and development. The nitrogen concentration had a significant effect on plant height and bulb number ($P < 0.05$) but had no significant effect on other indicators. Nitrogen is an important nutrient element for plant growth, and its promoting effect on plant height and bulb number may be related to its involvement in the synthesis of biomolecules such as proteins and nucleic acids in the plant body. However, nitrogen concentration had no significant effect on indicators such as branch number and root biomass, which might be related to the limited ability of plants to absorb and utilize nitrogen, or the nitrogen concentration range set in the experiment did not reach the response threshold of plants (Table 2).

Effects of salt and nitrogen addition in water bodies on biomass accumulation of *Scirpus planiculmis* seedlings

The effects of water salinity and nitrogen addition on the biomass accumulation of *Scirpus planiculmis* seedlings showed that, at a nitrogen addition level of 0 mgN/kg, the leaf biomass reached the highest at a salt content of 50, approximately 2.47 g/pot, but significantly decreased to approximately 1.2 g/pot at a salt content of 100. The biomass of the stem also showed a similar trend, reaching the highest value of 3.21 g/pot at a salt content of 50. The biomass of roots demonstrated relatively small changes but slightly increased with the addition of 200 mgN/kg nitrogen and 50% salt content, reaching a maximum value of about 1.2 g/pot. The overall change in biomass of rhizomes was not significant but slightly decreased with high nitrogen addition of 200 mgN/kg, especially reaching its lowest value at a salt content of 25, which was about a negative value that indicated data recording or processing errors and should be ignored or further verified in actual analysis. Overall, nitrogen addition significantly affected the biomass accumulation of *Scirpus planiculmis* with generally higher biomass in all parts at high nitrogen addition levels of 200 mgN/kg. The effect of salt content on biomass varied by location with leaves and stems being more sensitive to salt changes, while roots and rhizomes were relatively stable (Figure 5). These specific values provided important foundational data for understanding the ecological adaptation mechanisms of wetland plants to salinity and nitrogen and contributed to further in-depth research on the growth strategies and adaptability of *Scirpus planiculmis* under different environmental conditions.

The relationship between population density and water level driven by different hydrological conditions

The relationship between population density and water level under different hydrological conditions demonstrated the relationship between *Scirpus planiculmis* density and water level under different hydrological conditions. Under the driving force of periodic flooding, the *Scirpus planiculmis* density was negatively

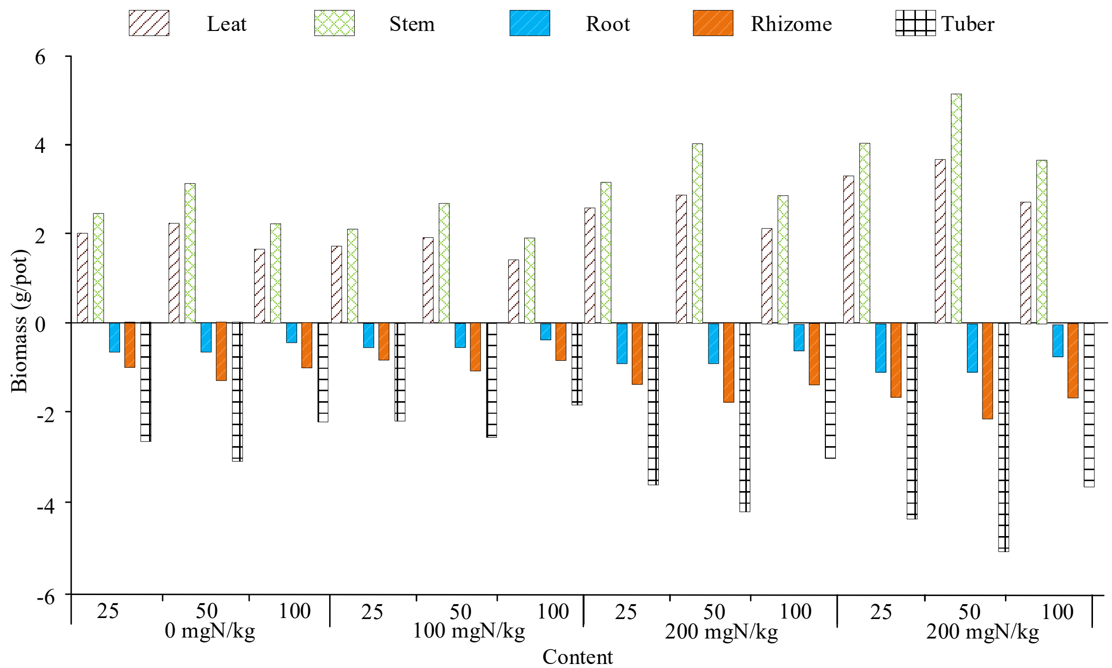


Figure 5. The effect of water salt and nitrogen addition on seedling biomass accumulation.

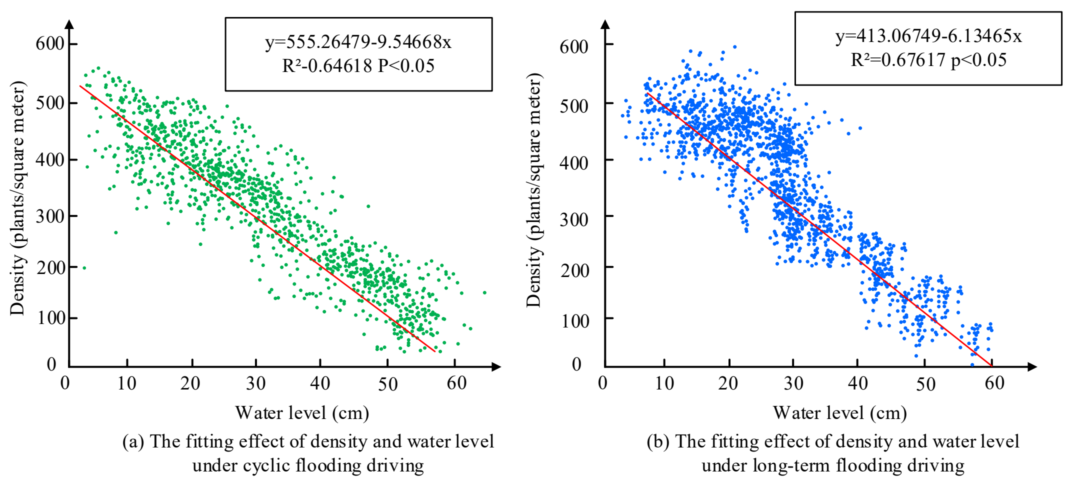


Figure 6. Changes of the density with water level driven by different hydrological conditions.

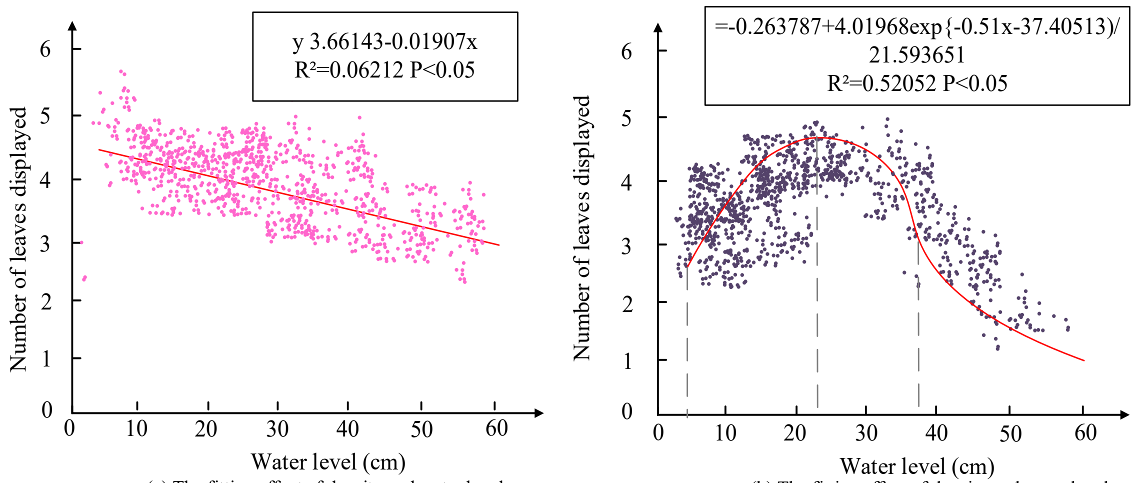
correlated with water level with the regression equation as follows.

$$Y = 555.26479 - 9.54668X$$

The results showed that R^2 was 0.64618 and $P < 0.05$, which indicated that for every 1 cm increased in water level, the density decreased by approximately 9.55 plants/m^2. Under long-term flooding, the relationship was also negative with the regression equation as below.

$$Y = 413.06749 - 6.13465X$$

The resulted R^2 was 0.67617 and $P < 0.05$, which meant that for every 1 cm increased in water level, the density decreased by about 6.13 plants/m^2 (Figure 6). The model driven by long-



(a) The fitting effect of density and water level under cyclic flooding driving

(b) The fitting effect of density and water level under long-term flooding driving

Figure 7. Change of leaf spread number of flat straw sugarcane grass with water level driven by different hydrological situation.

term flooding had a higher fit and stronger relationship. *Scirpus planiculmis* as an aquatic plant was significantly influenced by changes in water level on its growth. The increase in water level might lead to soil hypoxia, affecting the respiration of plant roots and thus inhibiting their growth. In addition, the rise in water level might increase the submergence time of plants, affect photosynthesis, and further limit their growth and reproduction.

Relationship between the number of spread leaves of the flat stemmed sugarcane grass and water level under periodic flooding and long-term flooding conditions

The relationship between the number of expanded leaves and water level of flat stemmed sugarcane grass under periodic flooding and long-term flooding showed that, under periodic flooding conditions, as the water level increased from 0 to 60 cm, the number of expanded leaves showed a decreasing trend with a fitted line slope of -0.01907 and an R^2 value of 0.06212 (Figure 7a). This indicated that the fitting effect was average but statistically significant (P < 0.05), suggesting that an increase in water level had a negative impact on the number of expanded leaves. Under long-term flooding conditions, the relationship between the number of expanded leaves and water level exhibited nonlinear characteristics with a fitted line slope of -0.263787 and an R^2 value of 0.52052, indicating a good fitting effect. Especially in the water level range of 20 - 40 cm, the number of expanded leaves remained relatively high, indicating that plants had a certain degree of adaptability to specific flooding levels (Figure 7b). Periodic flooding might cause plants to frequently experience flooding and drying, affecting stable growth and leading to a decrease in leaf expansion. Although long-term flooding had a small initial impact, long-term high-water levels might create an oxygen-deficient environment, inhibit root function, and affect overall growth. Nonlinear changes reflected the adaptation of plants to specific waterlogging, but their adaptability weakened under extreme conditions. This study revealed a significant impact of hydrological driving on the ecological characteristics of SPC, particularly in the water depth range of 10 - 50 cm, where *Scirpus planiculmis* exhibited the strongest adaptability and competitiveness. However, this study mainly focused on the Momoge wetland, which had strong geographical limitations. In the future, the research scope needs to be expanded to verify the universality of the results.

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