The Relationship Between Species Diversity, Biomass and Groundwater Level: A Case Study of the Hailiutu River Basin (Postprint)

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Abstract

Based on data from 117 vegetation community survey quadrats across three transects, this study investigated the relationships between vegetation species diversity, biomass, and groundwater level in the Hailiutu River basin. The results indicate: 1) Both groundwater level and geomorphological type affect the composition of herbaceous layer plant communities and their dominant species. In floodplain plots, as groundwater level decreases, the succession sequence of dominant herbs is Carex duriuscula, Achnatherum splendens, Iris lactea, Setaria viridis, and Puccinellia distans. In sand slope plots, the succession sequence of dominant herbs is Stipa grandis, Psammochloa villosa, Agriophyllum squarrosum, and Astragalus adsurgens. 2) A groundwater level of 1.5 m represents the most suitable zone for the growth and development of herbaceous plant communities, where species diversity and richness reach their maximum values. In contrast, species diversity and richness of the shrub layer exhibit fluctuating patterns with declining groundwater level. When groundwater depth is less than 5.0 m, species diversity and richness of the herbaceous layer are significantly higher than those of the shrub layer; when groundwater depth exceeds 5.0 m, the species diversity index of the herbaceous layer begins to fall below that of the shrub layer. 3) The correlation between herbaceous plant diversity, richness, and biomass is not strong. In floodplain plots, both above-ground and below-ground biomass of the herbaceous layer reach their maximum values at a groundwater level of 1.8 m, although the plant community structure is relatively simple. In sand slope plots, the maximum above-ground biomass occurs in areas with a groundwater level of 5.0 m, while the maximum below-ground biomass occurs at a groundwater level of 3.5 m. In summary, species diversity, above-ground biomass, and below-ground biomass do not exhibit simple linear relationships with groundwater level; rather, there exists an optimal water level. Both above and below this optimal level, diversity and biomass decrease.

Full Text

Preamble

Relationships Among Plant Species Diversity, Biomass, and the Groundwater Table in the Hailiutu River Basin

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Abstract: Based on data from 117 sampling plots, this study investigated the relationships among plant species diversity, biomass, and the groundwater table in the Hailiutu River basin. The main findings can be summarized as follows: (1) The species composition and dominance of herbaceous plants in the community are greatly affected by both groundwater table and geomorphic type. In flat lands of river beds or lake beaches, a decrease in the groundwater table resulted in a sequential shift in dominant herbaceous plants from *Puccinellia tenuiflora* → *Achnatherum splendens* → *Carex duriuscula* → *Setaria viridis* → *Iris lactea*. However, on sand-dune slopes, dominance shifted sequentially from *Psammochloa villosa* → *Agriophyllum squarrosum* → *Astragalus adsurgens* → *Stipa grandis*. (2) Herbaceous plant community species diversity and richness reached maximum values when the groundwater table was at 1.5 m depth; therefore, the region with a groundwater depth of 1.5 m represents the most suitable area for herbaceous community growth and development. When groundwater depth was less than 5.0 m, species diversity and richness of the herb layer were significantly higher than those of the shrub layer. However, when the groundwater table exceeded 5.0 m, herb layer diversity fell below that of the shrub layer. (3) Correlations among herbaceous plant diversity, richness, and biomass were not significant. In flat lands of river beds or lake beaches, aboveground and belowground biomass of the herb layer peaked at a groundwater table of 1.8 m, though the plant community structure was relatively simple. On sand-dune slopes, aboveground biomass reached its highest value at a groundwater table of 5.0 m, while belowground biomass peaked at 3.5 m. In conclusion, we found no simple linear relationship among plant diversity, plant biomass, and groundwater table. There exists an optimal groundwater table level for both plant diversity and biomass: values higher or lower than this optimum will cause reductions in plant diversity or biomass.

Keywords: groundwater level; Hailiutu River basin; plant diversity; biomass

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1. Study Area Overview

The Hailiutu River basin is located at the border between Inner Mongolia Autonomous Region and Shaanxi Province, extending from Bayan Chaidamu Township in Wushen Banner in the north to Hanjiamao in the south, and from Chahanaobao in Wushen Banner in the west to Daduze Third Team in Yulin in the east. The basin covers an area of approximately 2,602 km², with geographical coordinates of 108°56 -109°36 E, 38°01 -38°42 N. The region lies in the transitional zone between the Mu Us Desert and the loess plateau of northern Shaanxi. The overall terrain slopes from north to south, with the highest point at Bayan Aobao Second Team in the northeast of Wushen Banner (1,479.5 m elevation) and the lowest point at the confluence of the Hailiutu River with the Wuding River (982.0 m elevation), resulting in a maximum relative relief of 497.5 m.

The area has a temperate continental monsoon climate characterized by frequent winds and scarce rainfall, representing a semi-arid grassland environment. Annual precipitation ranges from 334.0 to 364.7 mm, while annual average temperature varies between 6.6 and 8.6°C. Annual water surface evaporation reaches 1,883.48–2,186.9 mm, accounting for 65–70% of total precipitation. The basin contains only one river, the Hailiutu River, which originates at Xinmiao Baga in Wushen Banner and flows 120.9 km. The study area includes two aquifers: Quaternary alluvial-diluvial and alluvial-lacustrine pore phreatic water, and Cretaceous Luohe Formation sandstone fracture-pore water.

Geomorphologically, the region is dominated by wind-sand beaches, with sandy loess ridges in the southeastern and western parts and the Hailiutu River valley in the center. Based on genesis and morphology, landforms are classified into river valleys, dunes, and sand ridges. The main plant species include *Artemisia ordosica*, *Salix psammophila*, *Caragana microphylla*, *Salix cheilophila*, *Stipa grandis*, *Hedysarum leave*, *Agriophyllum squarrosum*, *Ixeris denticulata*, and *Astragalus adsurgens*.

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2. Plot Setup and Groundwater Level Investigation

Based on preliminary surveys combined with geomorphic types, we established sampling plots along westward and northward directions in the upper reaches of the basin. In the middle and lower reaches, plots were selected along ridge lines from northwest to southeast based on contour maps. In each zone, plots were chosen at intervals according to naturally occurring different groundwater depth intervals. A total of 117 plots were established, each measuring 10 m × 10 m for shrubs. Within each shrub plot, three 1 m × 1 m herbaceous quadrats were selected along diagonal directions. Since naturally occurring trees are rare in the study area and most are artificially planted, this study focused only on shrubs and herbaceous plants as research objects.

We recorded detailed information on plant species names, frequency, and other indicators in both herbaceous and shrub quadrats, along with environmental factors such as slope, aspect, and soil type. Groundwater level measurement was conducted in two ways: for depths less than 5.0 m, manual drilling methods were used; for depths exceeding 5.0 m, spatial interpolation using the Kriging method was applied. Geographic location information including latitude, longitude, and elevation at plot centers was determined using GPS.

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3. Species Diversity Analysis

Species diversity is generally measured through assessments of species richness and evenness within communities or habitats. The important value index, which evaluates the role of plant populations in the community, was used to assess species diversity in the survey plots. The important value of each plant species in the quadrats was calculated individually, considering factors such as relative density, relative frequency, and relative coverage. Species dominance was measured using relative important values, which are influenced by the combined effects of relative density, relative frequency, and relative coverage. The mean value of species diversity across quadrats within each plot was used.

The selected diversity indices and calculation methods were as follows:

- **Shannon-Wiener Diversity Index (H):** $H = -\sum_{i=1}^{S} P_i \log P_i$
- **Margalef Richness Index (dMa):** $dMa = \frac{S-1}{\log N}$
- **Pielou Evenness Index (JSW):** $JSW = \frac{H}{\log S}$
- **Berger-Parker Dominance Index (I):** $I = \frac{N_{max}}{N}$

Where P_i is the relative important value of species i, S is the total number of species in the quadrat, N_i is the important value of species i, N_{max} is the important value of the dominant species, and N is the sum of important values of all species in the quadrat.

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4. Biomass Measurement

Aboveground biomass was measured using the harvest method: plants within quadrats were clipped at ground level, and aboveground parts were collected after removing adhering soil, gravel, and other impurities, then brought to the laboratory and dried to constant weight in a constant-temperature oven. Belowground biomass was sampled using soil cores. Each small quadrat was divided into layers of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm for root collection.

Root samples were washed, separated by layer, placed in cloth bags, and dried to constant weight in an oven. All biomass measurements were based on dry weight.

Statistical analysis was performed using SPSS 17.0, with one-way ANOVA and multiple comparisons used to analyze aboveground and belowground biomass in relation to groundwater level data. All figures were created using Origin 8.5.

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2. Results

1. Plant Community Species Composition and Groundwater Level

Survey results from the plots indicated a total of 83 plant species, including 12 shrubs and semi-shrubs, and 71 herbaceous plants. Among these, Poaceae, Asteraceae, and Leguminosae were the dominant families. As groundwater level decreased, the number of plant species showed a gradual declining trend. At groundwater depths of 0.5, 1.0, 1.8, 3.0, 6.0, and 11.0 m, the numbers of species were 29, 28, 20, 16, 10, and 9, respectively.

The herbaceous layer species list and their important values are shown in [TABLE:N]. At a groundwater level of 0.5 m on beaches around lakes, the dominant species was *Carex duriuscula* (important value: 0.89), with main associated species including *Puccinellia tenuiflora*, *Achnatherum splendens*, *Setaria viridis*, and *Limonium* spp. At 1.0 m in sandy slopes, *Stipa grandis* dominated (0.61), accompanied by *Imperata cylindrica* and *Ixeris denticulata*. At 1.8 m, *Iris lactea* became dominant (0.50) in local areas, with psammophytes such as *Agriophyllum squarrosum* and *Psammochloa villosa* beginning to appear. At 3.0 m, *Achnatherum splendens* showed enhanced competitiveness and became dominant (0.98) on interdune lowlands, with *Imperata cylindrica* and *Astragalus adsurgens* as main companions. At 6.0 m, common species like *Stipa grandis* and *Setaria viridis* gradually gave way to *Agriophyllum squarrosum* as the dominant species (0.72) on beaches, accompanied by *Puccinellia tenuiflora* and *Taraxacum* spp. At the lowest groundwater level of 11.0 m on sand ridges, psammophytes *Agriophyllum squarrosum* (0.48) dominated, with only 11 herbaceous species present.

2. Plant Community Species Diversity and Groundwater Level

Since different landform types significantly affect vegetation community composition, this study categorized sample plots into three geomorphic types: beach land (including river beaches, lake beaches, and beaches around lakes), sand slopes (including dune and sand ridge slopes), and interdune lowlands.

Changes in herbaceous community diversity indices with groundwater depth are shown in [Figure 2: see original paper]. In interdune lowland plots, Shannon-Wiener diversity and Margalef richness indices showed a trend of initial increase followed by decrease with declining groundwater level, peaking at 1.5

m (Shannon-Wiener: 2.239 ± 0.04; Margalef: 2.023 ± 0.069). Pielou evenness index gradually decreased with groundwater level, reaching its minimum at 1.5 m (0.573 ± 0.05), while Berger-Parker dominance index gradually increased (0.242 ± 0.002).

In beach land plots, Shannon-Wiener diversity ranged 2.135-2.314 at groundwater depths of 0-1.5 m, decreasing to 1.843-1.957 at 1.8-3.0 m. Margalef richness showed similar patterns, ranging 2.191-2.237 at 0-1.5 m and 1.487-1.606 at 1.8-3.0 m. Evenness and dominance indices showed little overall change with groundwater level, varying between 0.800-0.932 and 0.290-0.445, respectively. Richness indices gradually decreased with declining groundwater level, reaching their maximum at 3.0 m.

In sand slope plots, Shannon-Wiener diversity and Margalef richness indices decreased sharply with groundwater level, peaking at 1.0 m (1.877 ± 0.145 and 1.634 ± 0.300, respectively). When groundwater level exceeded 15.0 m, only *Agriophyllum squarrosum* could survive. The dominance index maximum occurred at 3.5 m groundwater depth.

3. Relationship Between Species Diversity of Different Growth Forms

Following Whittaker' s classification system, this study focused on two main growth forms: shrubs and herbaceous plants. [Figure 3: see original paper] shows changes in species diversity and richness of shrub and herb layers across different groundwater levels in the study area. Shrub layer diversity and richness fluctuated with declining groundwater level, while herb layer diversity and richness showed a decreasing trend. For the shrub layer, Shannon-Wiener index peaked at 2.0 m (1.534), and Margalef index peaked at 15.0 m (1.442).

When groundwater depth was less than 5.0 m, herb layer diversity was significantly higher than shrub layer diversity, but this gap narrowed as groundwater level declined. At groundwater depths greater than 5.0 m, herb layer diversity indices began to fall below those of the shrub layer. At 15.0 m, herb layer Shannon-Wiener and Margalef indices dropped to 0.5, while shrub layer maintained relatively high values, with herb layer indices being only 0.3 times those of the shrub layer.

4. Biomass and Groundwater Level

Variance analysis of aboveground biomass of herbaceous communities in relation to groundwater level across the three main geomorphic types is shown in [Figure 4: see original paper]. In interdune lowland plots, aboveground biomass peaked at 1.5 m groundwater depth (715.30 ± 25.46 g/m^2), showing no significant difference from biomass at 1.8 m (324.3 ± 35.2 g/m^2). However, when groundwater level fell below 6.0 m, aboveground biomass significantly decreased to 129.8 ± 12.9 g/m^2 ($P < 0.05$). In beach land plots, aboveground biomass peaked at 1.8 m (603.46 ± 71.39 g/m^2), significantly higher than at 3.0 m (381.16 ± 61.57 g/m^2, $P < 0.05$). In sand slope plots, aboveground biomass peaked at 5.0 m

(431.01 ± 7.97 g/m²), with *Agriophyllum squarrosum* showing optimal growth (comprising 80.7% of biomass). Minimum aboveground biomass occurred at 15.0 m (83.34 ± 28.91 g/m²), a 65.8% reduction from the maximum.

[Figure 5: see original paper] shows the relationship between belowground biomass of herbaceous communities and groundwater level. In interdune lowland plots, belowground biomass peaked at 1.5 m (781.67 ± 50.54 g/m²), decreasing significantly when groundwater level fell below 1.5 m (297.37 ± 57.76 g/m² at 6.0 m, $P < 0.05$). In beach land plots, belowground biomass peaked at 1.8 m (90.1 ± 7.5 g/m²), with significantly lower values at other depths. In sand slope plots, belowground biomass peaked at 3.5 m (163.92 ± 16.16 g/m²), showing no significant dependence on groundwater level when it fell below 9.0 m.

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3. Discussion

The response of desert plant communities to groundwater level is reflected in the spatial transition of dominant populations along groundwater gradients. Herbaceous community appearance is typically characterized by dominant species and species composition, making dominant species replacement a marker of community change. Analysis of community composition and important values shows that both groundwater depth and geomorphic type affect herbaceous community composition and important values. On beach lands at 0.5, 1.8, and 3.0 m groundwater depths, dominant species were sequentially *Carex duriuscula* and *Achnatherum splendens*, *Iris lactea* and *Achnatherum splendens*, and *Setaria viridis* and *Puccinellia tenuiflora*, respectively. In sand slopes at 1.0, 6.0, and 11.0 m, dominant species were sequentially *Stipa grandis*, *Agriophyllum squarrosum* and *Astragalus adsurgens*, and *Agriophyllum squarrosum*. This reflects that different plants have distinct strategies and characteristics for water utilization and environmental adaptation. Species like *Astragalus adsurgens* and *Agriophyllum squarrosum* have wide adaptation ranges and occur across all groundwater depths.

Studies on herbaceous community species diversity and richness show that plant community growth is primarily influenced by groundwater depth. Diversity and richness increase with declining groundwater level, peaking at 1.5 m, which scholars have defined as the critical water level for ecotones. When groundwater depth exceeds 1.5 m, diversity indices gradually decrease, plant species become fewer, and community structure simplifies, indicating strong dependence of plant growth on groundwater depth. Groundwater is the most important water source for vegetation survival in this region.

Research on relationships between different growth forms shows that when groundwater depth is less than 5.0 m, herb layer diversity and richness are significantly higher than shrub layer values, but this difference diminishes as groundwater level declines. When groundwater depth exceeds 5.0 m, herb layer diversity falls below shrub layer diversity. Previous studies indicate that at depths greater than 5.0 m, capillary water replenishment to surface soils decreases, creating drought conditions that prevent shallow-rooted herbs from surviving, while deep-rooted shrubs can extend their roots to obtain water.

Analysis of aboveground and belowground biomass relationships with groundwater depth across three geomorphic types shows that in interdune lowland plots, both aboveground and belowground biomass peaked at 1.5 m groundwater depth, where plant diversity and richness were also highest, indicating optimal population growth and development. In beach land plots, aboveground and belowground biomass simultaneously peaked at 1.8 m, where species diversity and richness were lowest, mainly because species like *Iris lactea* and *Achnatherum splendens* with large cover and crown width had obvious competitive advantages, resulting in simple community structure. In sand slope plots, maximum aboveground biomass occurred at 5.0 m, while maximum belowground biomass occurred at 3.5 m. When groundwater level fell below 9.0 m, neither aboveground nor belowground biomass showed significant dependence on groundwater level.

These analyses demonstrate that the relationship between groundwater depth and plant diversity, richness, and biomass is not a simple statistical linear relationship but rather a complex system involving interactions among groundwater, soil, and vegetation.

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4. Conclusion

Both groundwater depth and geomorphic type affect herbaceous community composition and important values. In beach land plots, as groundwater level declines, the replacement direction of dominant herbs is *Carex duriuscula* → *Achnatherum splendens* → *Setaria viridis*, while in sand slope plots, the replacement direction is *Stipa grandis* → *Agriophyllum squarrosum* → *Astragalus adsurgens*. Herbaceous plant growth shows strong dependence on groundwater level, with 1.5 m being the optimal depth for herbaceous community growth and development, where species diversity and richness reach their maximum. Beyond this depth, herbaceous growth becomes limited.

Herbaceous communities have an optimal groundwater depth range, while shrub community species diversity and richness show fluctuating patterns with declining groundwater level. When groundwater depth is less than 5.0 m, herb layer diversity and richness are significantly higher than shrub layer values, but when groundwater depth exceeds 5.0 m, herb layer diversity indices begin to fall below those of the shrub layer. No significant correlation exists between herbaceous plant diversity, richness, and biomass.

In interdune lowland plots, aboveground and belowground biomass peaked at 1.5 m groundwater depth, where population growth and development were optimal. In beach land plots, aboveground and belowground biomass simultaneously peaked at 1.8 m, but the plant community structure was relatively simple. In sand slope plots, maximum aboveground and belowground biomass occurred at different groundwater depths (5.0 m and 3.5 m, respectively), and when groundwater level fell below 9.0 m, biomass showed no obvious dependence on groundwater level.

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