Postprint of a Study on the Impact of Alpine Meadow Degradation on Soil Electrical Conductivity Changes

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Abstract

Soil electrical conductivity is an important indicator characterizing soil water-soluble salts and can reflect the degree of soil salinization. To investigate the impact of alpine meadow degradation on soil electrical conductivity, this study systematically analyzed the interrelationships between vegetation characteristics and soil characteristics of degraded alpine meadows and soil electrical conductivity, using non-degraded and degraded alpine meadows in the Sanjiangyuan region as research subjects. The results demonstrated that alpine meadow degradation exerts a significant negative effect on soil electrical conductivity, and soil electrical conductivity exhibits a consistent changing trend with the degradation indicators used to evaluate alpine meadows, including vegetation coverage, aboveground biomass, soil organic matter, and soil total nitrogen content. Therefore, it is concluded that degradation of alpine meadows can induce changes in soil electrical conductivity, and soil electrical conductivity, as a metric for soil salinization degree, can also serve as one of the objective indicators for evaluating meadow degradation.

Full Text

The Influence of Alpine Meadow Degradation on Soil Conductivity Change

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Abstract

Soil electrical conductivity is a crucial indicator of water-soluble salts in soil, reflecting the degree of soil salinization. To investigate the impact of alpine meadow degradation on soil electrical conductivity, this study systematically analyzed the relationships between vegetation characteristics, soil properties, and soil conductivity in both undegraded and degraded alpine meadows in the Three-River Headwaters Region. The results demonstrate that alpine meadow degradation exerts a significant negative effect on soil electrical conductivity, which exhibits consistent trends with key degradation indicators including vegetation coverage, aboveground biomass, soil organic matter, and total nitrogen content. Therefore, we conclude that alpine meadow degradation induces changes in soil electrical conductivity, and that soil electrical conductivity, as a measure of soil salinization, can serve as an objective indicator for evaluating meadow degradation.

Keywords: degraded alpine meadow; soil electrical conductivity; vegetation characteristics; soil characteristics

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Introduction

Grassland ecosystems represent one of the most widely distributed vegetation types globally, constituting the second largest green vegetation cover after forests and accounting for approximately 50.9% of terrestrial ecosystem area. Alpine meadow ecosystems dominate the Qinghai-Tibet Plateau, covering about 50% of its area and serving as representative high-altitude ecosystems in central Asia and worldwide. These ecosystems provide vital ecological functions including water conservation, biodiversity protection, and carbon sequestration, forming an irreplaceable ecological barrier for the global biosphere. However, over recent decades, alpine meadows have experienced increasing degradation due to climate warming and drying, human activity disturbances, and the coupling effects between them. This degradation has severely compromised ecosystem structure and function, leading to declining grassland productivity and quality, environmental deterioration, reduced biodiversity and complexity, and diminished or lost self-recovery capacity, ultimately decreasing economic potential and ecological service functions.

Grassland degradation is a complex, long-term process whose most apparent manifestation is vegetation degradation, encompassing changes in community composition, productivity, and spatial structure. Concurrently, soil physicochemical properties undergo fundamental changes, driving soil impoverishment and aridification. Soil electrical conductivity (EC) can indicate changes in major base cation contents such as Na^+, K^+, Ca^{2+}, and Mg^{2+} in soil, serving as an important indicator of water-soluble salts that influences soil nutrient availability, microbial composition, and fertility while reflecting soil salinization degree. Previous studies on alpine meadow degradation have rarely addressed soil conductivity changes and their impacts on vegetation communities and soil characteristics. As degradation intensifies, both aboveground vegetation and soil properties change significantly. How soil conductivity—as an indicator of soil salinization—changes during this process, and whether it follows a declining trend similar to soil physicochemical properties, remains unclear. We therefore propose two hypotheses: (1) alpine meadow degradation significantly affects soil conductivity, and (2) soil conductivity correlates with aboveground vegetation and soil physicochemical properties, showing consistent trends following meadow degradation. This study examines undegraded and degraded alpine meadows in Zhenqin Township, Yushu Prefecture, Qinghai Province, to explore patterns of vegetation community, soil physicochemical properties, and soil conductivity changes during alpine meadow degradation, aiming to reveal vegetation-soil conductivity characteristics, enrich evaluation indicators for degraded alpine meadows, and provide scientific basis for early warning and restoration management.

1.1 Study Area

The study area is located in Zhenqin Township, Chengduo County, Yushu Prefecture, Qinghai Province, at 33°21 35.04 N, 97°20 37.38 E, with an average elevation of 4,250 m. The region features a cold temperate continental monsoon climate with long cold seasons and short warm seasons, an average annual temperature of -1.6°C, and a frost-free period of approximately 93–126 days. The grassland vegetation is dominated by alpine meadows, with primary native species including *Kobresia pygmaea*, *Kobresia humilis*, and *Stipa purpurea*. The soil type is alpine meadow soil.

1.2 Methods

1.2.1 Sample Plot Establishment In August 2018, one 1,000 m × 1,000 m undegraded alpine meadow plot and one degraded alpine meadow plot were established as study sites in Zhenqin Township, Chengduo County, with approximately 1,000 m distance between plots.

1.2.2 Experimental Design and Sampling Method Within each 1,000 m × 1,000 m plot, a diagonal transect was established. Along each transect, 14 quadrats (0.50 m × 0.50 m) were placed at 175 m intervals, yielding 28 quadrats total [Figure 1: see original paper]. Vegetation community surveys employed the quadrat method, recording plant species, species count, species coverage, total community coverage, and natural species height. Coverage was measured using the pin-point method. Aboveground biomass was determined by clipping plants at ground level, oven-drying at 65°C to constant mass, and weighing to determine dry mass. Soil samples were collected at the center of each quadrat using a soil auger to extract two cores from the 0–15 cm surface layer. Visible plant residues and soil fauna were removed, and samples were sealed in labeled bags for laboratory analysis.

1.2.3 Index Measurement (1) Species Diversity Calculation

Species diversity was assessed using species richness (S), Shannon-Wiener index (H), Simpson index (D), and Pielou' s evenness index (E), calculated as follows:

Important value: IV = (relative coverage + relative height)/2, where IV is important value, C is relative coverage, and H is relative height.

Species richness: S = N, where N is the total number of species per plot.

Simpson dominance index: $D = \Sigma Pi^2$, where Pi is the important value of species i.

Shannon-Wiener diversity index: $H = -\Sigma Pi \ln(Pi)$.

Pielou evenness index: $E = H/\ln(S)$, where H is the diversity index and S is species richness.

(2) Soil Electrical Conductivity Measurement

Soil environmental parameters (temperature, moisture, and electrical conductivity) were measured at 0–15 cm depth in each quadrat using a TDR 350 three-parameter instrument with a 7.50 cm probe, with three replicates per measurement.

(3) Soil Physicochemical Property Measurement

Soil pH was measured using a PHS-3C pH meter at a 2.5:1 water-to-soil ratio. Total nitrogen content was determined using an elemental analyzer. Soil organic matter content was measured using the potassium dichromate oxidation titration method.

1.3 Data Analysis

Data were organized using Excel 2010. T-tests and regression analyses were performed using SPSS 20.0, and figures were generated using Origin software.

2 Results and Analysis

2.1 Vegetation Community Characteristics

2.1.1 Community Characteristics Comparison The most obvious characteristic of meadow degradation is aboveground vegetation change, with more severe degradation corresponding to lower vegetation biomass, species number, and productivity. Vegetation coverage in undegraded meadows was 87.00%, significantly higher than the 55.79% in degraded meadows. T-test analysis revealed significant differences in species number and aboveground biomass between undegraded and degraded meadows (P < 0.05). Degraded meadows showed 13.56% lower species number, 51.54% lower fresh aboveground biomass, and 57.51% lower dry aboveground biomass compared to undegraded meadows .

Table 1. Comparison of vegetation community characteristics

Meadow type	Coverage/%	Fresh aboveground biomass/(g · m^{-2})	Dry aboveground biomass/(g · m^{-2})
Undegraded	87.00±1.06*a*	156.55±52.90*a*	84.73±33.95*a*
Degraded	55.79±16.90*b*	66.51±21.73*b*	41.07±12.48b

Note: Different lowercase letters indicate significant differences (P < 0.05). The same below.

2.1.2 Community Composition Analysis A total of 31 herbaceous species were recorded across all plots, belonging to 12 families. The most species-rich family was Compositae (9 species), followed by Gramineae (5), Cyperaceae (4), Gentianaceae (3), Caryophyllaceae (2), Labiatae (2), Scrophulariaceae (2), Rosaceae (2), Leguminosae (1), Ranunculaceae (1), Caprifoliaceae (1), and Umbelliferae (1).

In undegraded meadows, the community was dominated by *Kobresia pygmaea* (dominance value: 0.53), with sub-dominant species *Stipa purpurea* (0.24), *Aster diplostephioides* (0.14), and *Ajania tenuifolia* (0.09). Main companion species included *Gentiana straminea*, *Saussurea superba*, and *Leymus secalinus*. In degraded meadows, *Kobresia pygmaea* remained dominant but with reduced dominance (0.42), accompanied by sub-dominants *Thalictrum alpinum* (0.19), *Stipa purpurea* (0.18), and *Gentiana straminea* (0.19). Main companion species included *Potentilla multifida*, *Lancea tibetica*, and *Heracleum millefolium* .

Table 2. Community composition and important values of different degraded meadows (Mean±SD)

Species	Undegraded	Degraded
Kobresia pygmaea	0.53$±0.13|0.42±0.09||∗ *Stipapurpurea* ∗ |0.24±0.07|0.18±0.03||∗ *Asterdiplostephioides*∗ |0.14±0.08|0.09±0.00||∗ *Ajaniatenuifolia*∗ |0.09±0.01|0.08±0.00||∗ *Gentianastraminea*∗ |0.08±0.00|0.19±0.03||∗ *Saussureasuperba*∗ |0.08±0.00|0.06±0.02||∗ *Leymussecalinus*∗ |0.08±0.02|0.05±0.00||∗ *Thalictrumalpinum*∗ |0.05±0.02|0.19±0.15||∗ *Potentillamultifida*∗ |0.04±0.01|0.11±0.00||∗ *Lanceatibetica* ∗ |0.06±0.01|0.13±$0.07	

The results indicate that degradation reduces the dominance of key species *Kobresia pygmaea* and *Stipa purpurea*, while increasing the importance values of leguminous plants, particularly the degradation indicator species *Oxytropis ochrocephala*. Thus, meadow degradation alters community structure, primarily manifested in changes to dominant species.

2.1.3 Plant Community Species Diversity Analysis Diversity measures the uniformity and abundance of species distribution within a community, reflecting species' adaptation to the environment and resource utilization capacity. Degraded and undegraded meadows showed significant differences in diversity indices ($P < 0.05$). Simpson, Shannon-Wiener, and Pielou' s indices increased by 56.19%, 10.12%, and 52.57% in degraded meadows, respectively [Figure 2: see original paper]. The increased diversity following degradation primarily results from reduced competitiveness of dominant species, creating opportunities for invasion by less competitive species and increasing their importance values.

Figure 2. α-diversity index of different degraded alpine meadows

2.2 Soil Characteristics

2.2.1 Soil Physicochemical Properties Undegraded and degraded meadows showed significant differences in soil total nitrogen, organic matter, and pH ($P < 0.05$). Degraded meadows exhibited 23.20% lower total nitrogen, 17.91% lower organic matter, and 38.71% higher pH compared to undegraded meadows

. The increased pH in degraded meadows results from reduced vegetation cover, enhanced water evaporation, and accumulation of soil alkalis at the surface.

Table 3. Soil chemical composition in different degraded alpine meadows

Meadow type	Total nitrogen/$(g \cdot kg^{-1})$	Organic matter/$(g \cdot kg^{-1})$	pH
Undegraded	10.67±1.98a	72.64±8.23a	6.31±0.12b
Degraded	6.54±1.71b	55.79±16.90b	7.44±0.37a

2.2.2 Soil Parameter Comparison Soil temperature, moisture, and electrical conductivity at 0–15 cm depth differed significantly between meadow types ($P < 0.05$). Degraded meadows showed 55.12% lower temperature, 70.37% lower electrical conductivity, and 17.11% higher moisture compared to undegraded meadows .

Table 4. Soil values in different degraded alpine meadows

Meadow type	Soil temperature/°C	Soil moisture/%	Soil electrical conductivity/$(S \cdot cm^{-1})$
Undegraded	20.29±2.16a	20.40±6.29b	0.27±0.10a
Degraded	13.08±4.39b	24.61±4.00a	0.08±0.08b

2.3 Correlation Analysis Between Soil Electrical Conductivity and Vegetation/Soil Characteristics

2.3.1 Correlation Between Soil Electrical Conductivity and Vegetation Characteristics Regression analysis revealed linear relationships between soil electrical conductivity and vegetation coverage, species number, fresh biomass, and dry biomass in degraded alpine meadows. Soil electrical conductivity showed extremely significant positive correlations with vegetation coverage ($P < 0.001$), fresh aboveground biomass ($P < 0.001$), and dry aboveground biomass ($P < 0.001$), and a positive correlation with species number [Figure 3: see original paper].

Figure 3. Relationship between soil conductivity and vegetation characteristics in degraded alpine meadow

2.3.2 Correlation Between Soil Electrical Conductivity and Soil Characteristics Soil electrical conductivity exhibited linear relationships with total nitrogen, organic matter, pH, soil temperature, and soil moisture. Extremely significant positive correlations were found with total nitrogen ($P < 0.01$), organic matter ($P < 0.001$), and soil temperature ($P < 0.001$), while extremely significant negative correlations were observed with pH ($P < 0.001$) and soil moisture ($P < 0.001$) [Figure 4: see original paper].

Figure 4. Relationship between soil electrical conductivity and soil physicochemical properties in degraded alpine meadow

3 Discussion

3.1 Impact of Degraded Alpine Meadow Vegetation Characteristics on Soil Electrical Conductivity

Alpine meadow degradation involves not only vegetation deterioration but also soil degradation, ultimately leading to entire ecosystem degradation that disrupts grassland ecosystem balance and drives reverse succession. Severe degradation simplifies community structure, reduces vegetation productivity and forage quality, decreases desirable forage species, lowers vegetation coverage, and reduces community diversity, richness, and evenness. Our results showing reduced vegetation coverage and aboveground biomass following degradation align with previous findings. Electrical conductivity serves as a crucial indicator for assessing soil salinization, a primary characteristic of grassland degradation. The strong correlations and consistent trends between soil electrical conductivity and vegetation characteristics in degraded meadows demonstrate that degradation reduces not only vegetation coverage and biomass but also soil electrical conductivity content, indicating that meadow degradation negatively impacts soil electrical conductivity. Previous research indicates that degraded grassland vegetation shows increased accumulation of mineral elements, which both results from and accelerates grassland degradation. The increased mineral nutrient storage in degraded plants inevitably alters soil mineral element content, leading to soil degradation. The declining trend of soil electrical conductivity during alpine meadow degradation can cause changes in soil texture, which is essential for vegetation growth.

3.2 Impact of Degraded Alpine Meadow Soil Characteristics on Soil Electrical Conductivity

Soil serves as the primary habitat for biological activity in grassland ecosystems, with its properties directly affecting plant growth, development, and succession. Total nitrogen and organic matter decrease with meadow degradation, consistent with previous studies. This occurs because reduced vegetation weakens or halts nitrogen fixation, while degradation accelerates decomposition of biological residues, converting organic nitrogen to inorganic nitrogen that is lost through water erosion. Decreased organic matter results from reduced aboveground biomass and subsequent litter input. Grassland degradation leads to progressive aridification and salinization due to reduced vegetation cover enhancing water evaporation and accumulating soil alkalis at the surface, consistent with our findings. While previous studies reported decreased soil moisture with degradation, our results showed increased moisture, likely due to thicker thatch layers and sampling during Yushu' s rainy season.

Soil electrical conductivity serves as a quantitative indicator of salt accumulation. Research shows that soil inorganic nitrogen correlates extremely significantly with soil electrical conductivity. In this study, total nitrogen correlated positively with soil electrical conductivity, though not significantly, possibly because organic nitrogen constitutes a large proportion of total nitrogen. Studies on saline-alkali soils demonstrate significant relationships between moisture and electrical conductivity, with 雨季 values lower than 旱季. Our results show a significant negative correlation between soil electrical conductivity and soil moisture, as increased moisture dilutes soluble salt ion concentrations. The extremely significant positive correlation between soil temperature and electrical conductivity aligns with previous research, as lower temperatures slow ion migration. The extremely significant negative correlation between soil electrical conductivity and pH matches findings from other saline soil studies. The extremely significant positive correlation between soil electrical conductivity and organic matter indicates that both parameters decline with grassland degradation, consistent with research showing decreased salt ions following crop planting and organic matter reduction.

4 Conclusion

This study on the influence of alpine meadow degradation on soil electrical conductivity demonstrates that degradation significantly negatively affects soil electrical conductivity. Analysis of relationships between soil electrical conductivity and vegetation/soil characteristics in degraded alpine meadows revealed strong correlations with vegetation coverage, aboveground biomass, soil organic matter content, total nitrogen content, and soil temperature. These parameters, which serve as indicators of alpine meadow degradation, show consistent trends with soil electrical conductivity, suggesting that soil electrical conductivity can characterize alpine meadow degradation and serve as an evaluation index. These findings enrich grassland degradation assessment indicators and provide data support for degraded alpine meadow early warning and restoration.

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