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RESEARCH

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Wind farms reduce grassland plant community diversity and lead to plant community convergence

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Abstract
Climate warming has become a hot issue of common concern all over the world, and wind energy has become an important clean energy source. Wind farms, usually built in wild lands like grassland, may cause damage to the initial ecosystem and biodiversity. However, the impact of wind farms on the functional diversity of plant communities remains a subject with unclear outcomes. In this study, we chose 108 sample plots and identified 10 plant functional traits through a field vegetation survey. We used general linear regression analysis to assess how wind farm influenced vegetation community diversity, focusing on ten distinct plant functional traits. The study revealed that wind farm had significant impacts on grassland plant communities, diminishing diversity and functional traits, which leads to species composition convergence. Additionally, wind farm increased certain functional traits, like height and leaf area, while decreasing phosphorus content. Furthermore, the productivity of these plant communities was reduced by wind farm presence. This study highlights the negative consequences of wind farms in Inner Mongolia on plant diversity, aiming to offer scientific recommendations for the optimal arrangement of wind farms to safeguard biodiversity.

Keywords Inner Mongolia typical grassland, Wind farm, Alpha diversity, Beta diversity, Functional traits

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Introduction

Recent findings highlight an increase in global temperatures by 1–2 degrees Celsius due to the growing greenhouse effect, drawing international focus towards climate change [1]. The issue of climate warming has become the focus of the international community [2]. Electricity and heat production, contributing to approximately 40% of worldwide CO_2 emissions [3], underscores the urgency in advancing sustainable, clean energy solutions [4]. Wind power, recognized for its maturity, scalability, and commercial viability within the renewable sector, emerges as a pivotal clean energy alternative [5].

Wind energy stands as a prominent, sustainable, and clean power generation method, and has rapidly expanded globally in recent years [6, 7]. However, this rapid development has raised concerns about the impact on biodiversity [8, 9]. Recent studies highlight the significant influence of wind farms on both the diversity and structural makeup, pointing to notable changes in both aspects [10]. Research indicates that constructing wind farm can lead to localized increases in temperature and precipitation, potentially enhancing biodiversity in specific regions [11]. However, the results of studies in different regions are inconsistent, with wind farms negatively affecting plant community diversity in some places, if not at all [12]. Variability in outcomes may stem from differences in ecosystem types and geographical locations, necessitating further detailed investigations to elucidate wind farms' impacts on plant communities.

In the field of biodiversity and ecology, analytical approaches utilizing plant functional traits have increasingly gained traction, recognized for their significance in advancing research [13–15]. Functional traits can characterize plant responses and adaptations to environmental change, and they can also be directly involved in specific ecosystem processes, which can have an impact on ecosystem function and diversity [16–18]. Functional diversity within plant communities can be calculated and analyzed through an approach based on functional traits [19], emphasizing the variability in these traits across species [18, 20]. This approach provides enhanced insights into the impacts of wind farms on the functional diversity and structural configuration of plant communities.

Productivity serves as a crucial gauge of ecosystem functionality. Exploring wind farms' effects on plant community productivity offers a holistic view of their ecosystem impacts [21]. Nonetheless, discrepancies exist across different studies and scales, Li et al. [11] observed that large wind farm could enhance local temperatures and precipitation in the Sahara Desert, thereby fostering vegetation growth. Conversely, Di et al. [22] noted a decline in productivity for marine organisms around offshore wind farm. Therefore, comprehensive investigations into how wind farms affect plant community diversity and productivity are vitally important for understanding ecological impacts and guiding policy development.

As a vital component of China's northern grasslands, the Inner Mongolia grassland serves key ecological, economic, and security functions. Notably, this region hosts numerous wind farms, with the highest installed capacity nationwide [23]. Therefore, it is critical to explore how wind farms influence plant communities in Inner Mongolia. While previous studies have focused on plant diversity, the influence on functional diversity remains underexplored. The study delves into how wind farm impact the functional traits and diversity of plant communities within the typical grasslands of Inner Mongolia, utilizing 108 field plots across varying wind farm impact intensities to answer two pivotal scientific questions: (1) How does wind farm influence the alpha and beta diversity of plant communities in the grasslands of Inner Mongolia? (2) how are the functional structures of these plant communities in typical grassland areas of Inner Mongolia affected by the wind farm?

Method

Overview of the study area

The study focuses on wind farm located in typical grassland areas of Inner Mongolia. The wind farm was built in 2008, positioned at 116°53′E longitude and 43°56′N latitude, adjacent to Xilinhot (Fig. 1). The area's climate is characterized as mid-temperate semi-arid with continental monsoon influences, characterized by an average yearly rainfall of 295 mm, occurring predominantly between June and September, and a mean annual temperature slightly below freezing at -0.1 °C. The elevation ranges from 1210 to 1600 m, and the landscape is predominantly hilly and flat. Vegetation is typical of grasslands, with *Leymus chinensis*, *Stipa krylovii*, and *Cleistogenes squarrosa* being the dominant species.

The average annual wind speed in the wind farm area is 7.57 m/s, with a wind power density of 390.1 W/m^2. There are a total of 33 wind turbines with a distance of 5000 m between them. Each wind turbine has a rated power of 2000 KW, a diameter of 100.5 m, a swept area of 7932 m^2, a rated wind speed of 10 m/s, and a hub height of 80 m.

Flora survey

Randomly select three wind turbines from the wind farm, with each turbine as the center, and extend a sampling line in the same direction outward. There are a total of three sampling lines, which are parallel to each other and run in the downwind direction from northwest to southeast. A 1 m × 1 m plot was selected every 15 m along the line, and 36 sample plots were selected for plant community investigation along each sample line. A total of 108 sample plots were included in the three sample lines. When analyzing the results, three sample plots at the same distance were treated as a parallel, so there were 36 gradients from the wind farm from near to far; In addition, three sample plots with the same gradient were processed as replicates, and based on the average of the three replicates, there were 36 values in the final result (Fig. 2). All sampling work was conducted from August to September 2019, and there were no construction activities, soil overturning or vegetation damage during the 11 years after the wind farm was built.

The plant community survey of the sample plots consisted of two parts, assessing the composition of the plant community and measuring plant functional traits. A detailed list of species occurring in each sample plot was recorded. The above-ground sections of plants were

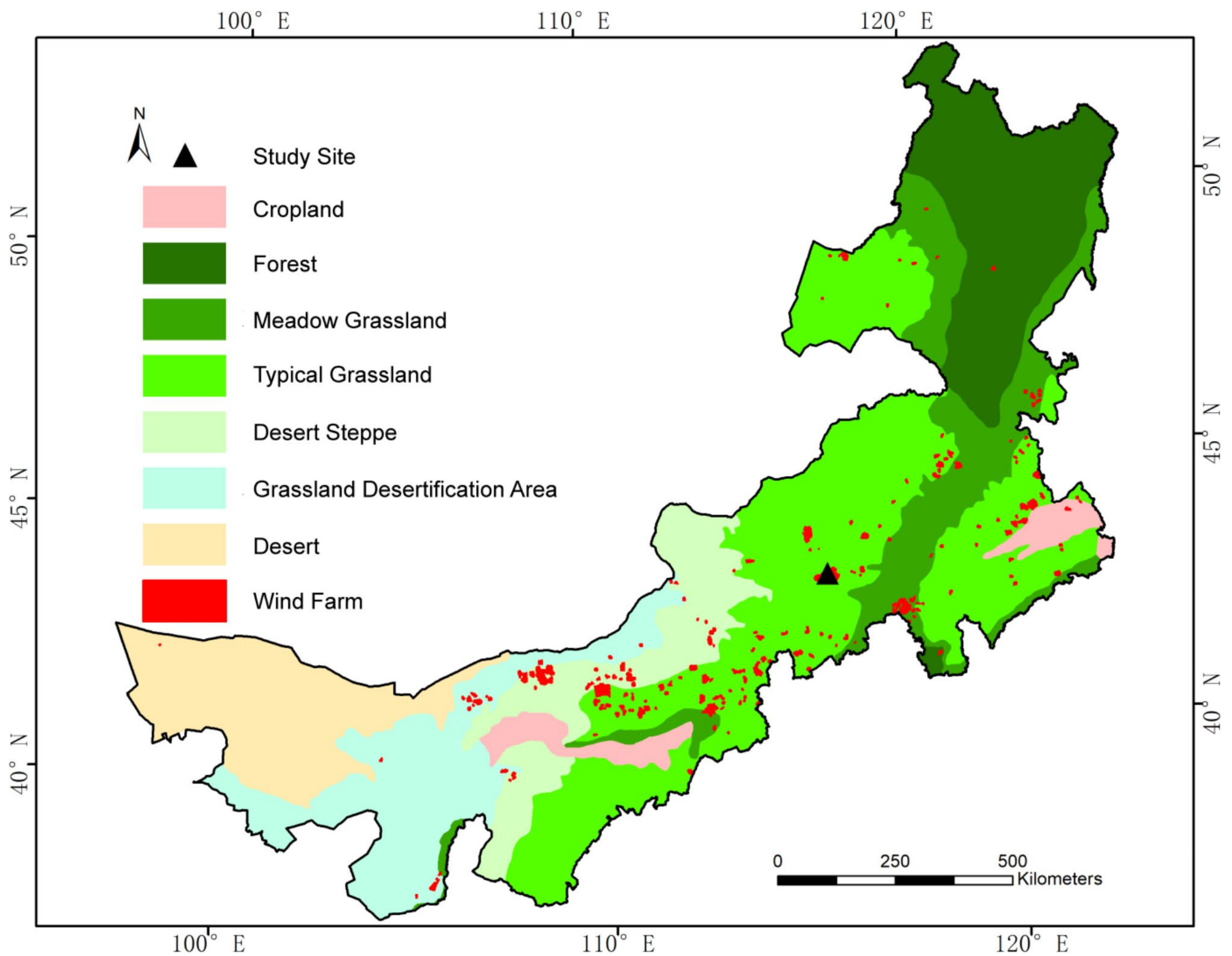

Fig. 1 Map of inner Mongolia zonal grassland type and study site

harvested at ground level, dried in a laboratory at 80 °C until reaching a consistent weight, and then weighed. This process provided the dry weight data for each species, enabling the calculation of the community's aboveground biomass, which served as a measure of its productivity.

In this research, ten critical plant functional traits were identified: plant height, leaf area, and various leaf content metrics including dry mass, specific area, dry matter, nitrogen, phosphorus, carbon, and ratios of carbon-nitrogen and nitrogen-phosphorus. The methodology for measuring these traits adhered to global standards set forth by Cornelissen et al. [24]. For every species documented in the study area, fifteen healthy, pest-free specimens were chosen for trait analysis. Plant height (cm) was determined by measuring its natural vertical height from the vertical ground. Three healthy and intact leaves were collected from each plant for the determination of leaf functional traits. Leaf area (cm^2) was measured using a Li 3000 hand-held leaf area meter. The saturated fresh weight (g) of the leaves was determined by placing the freshly collected leaves between moist filter paper, sealing them in a plastic bag placing them in the dark at 5 ℃ for 12 h, and then drying them in an oven at 60 ℃ until they reached a constant weight for leaf dry weight measurement (g). The specific leaf area (specific leaf area = leaf area/leaf dry weight, $cm^2 \cdot g^{-1}$) and leaf dry matter content (leaf dry matter content = leaf dry weight/leaf saturated fresh weight, $mg \cdot g^{-1}$) were calculated according to the formula. Leaf carbon content (%) and nitrogen content (%) were determined by Vario EL III elemental analyzed, and leaf phosphorus content ($mg \cdot g^{-1}$) was determined using molybdenum antimony colorimetric spectrophotometry.

Calculation of diversity and community weight

For alpha diversity, this study quantified species richness by counting the number of species present in each sample plot, the Shannon index to represent species diversity, the FRic index to represent functional richness, and the

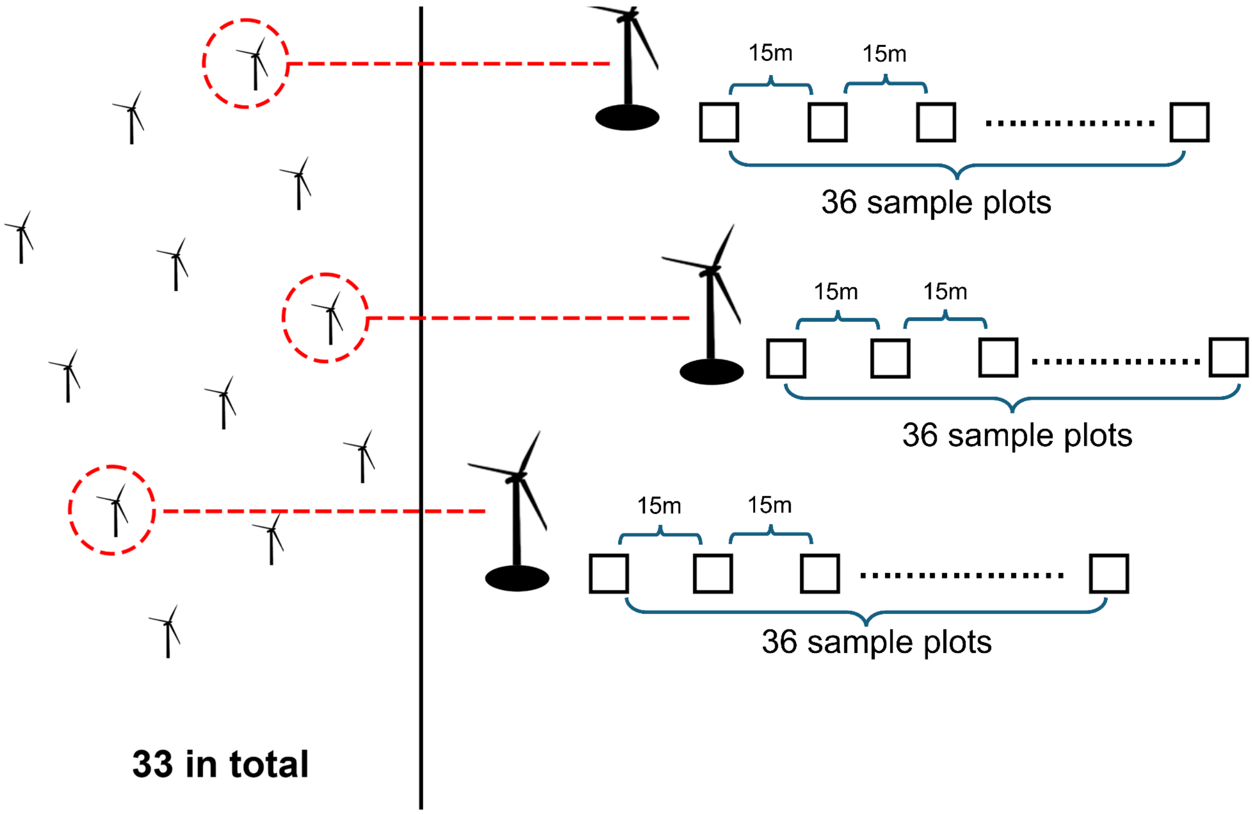

Fig. 2 Sample plot setting diagram

commonly used RaoQ quadratic entropy index to represent functional diversity [25]. This study used the relative dry weight of species as the abundance for diversity calculation. The formula is:

$$Species\ richness = N$$

$$Shannon\ index = -\sum{}_{i=1}^{N} Pi \bullet log_2 \bullet Pi \tag{1}$$

$$RaoQ = \sum{}_{i=1}^{N} \sum{}_{j>1}^{N} d_{ij} \bullet Pi \bullet Pj \tag{2}$$

$$FRic = Convex\ Hull\ Volume \tag{3}$$

where N represents the total species count in the sample plot, d_{ij} denotes the Euclidean distance between the functional traits of species i and j, while P_i and P_j signify the community weights of species i and j, respectively, calculated using their relative dry weights (dry weight of each species / total dry weight). *Convex Hull Volume* represents the multidimensional "volume" or "range" occupied by species communities in functional space, reflecting the functional diversity of species communities and the breadth of their occupation of functional space.

For beta-scale diversity, this study used the pairwise-site algorithm proposed by Baselga [26]. Based on the Jaccard dissimilarity index, we calculated the beta diversity among communities and the corresponding turnover and nestedness components. The calculation of Jaccard coefficients for the species dimension was based on a 0–1 matrix of species occurrences, and the calculation of Jaccard coefficients for the functional trait dimension was based on a matrix of Euclidean distances for functional traits between species. This research focuses on analyzing the impact of wind farms on plant community beta diversity, therefore, the sample site furthest from the wind farm was analyzed here as a control sample site. The formula is:

$$Beta_{Overall} = Beta_{Turnover} + Beta_{Nestedness} \tag{4}$$

$$Beta_{Overall} = \frac{b+c}{a+b+c} \tag{5}$$

$$Beta_{Turnover} = \frac{2min(b,c)}{a+2min(b,c)} \tag{6}$$

$$Beta_{Nestedness} = \frac{|b-c|}{a+b+c} \times \frac{a}{a+2min(b,c)} \tag{7}$$

where $Beta_{Overall}$ is the total beta diversity between the two samples. $Beta_{Turnover}$ and $Beta_{Nestedness}$ respectively quantify the species turnover and nestedness components within beta diversity. For the species dimension, a denotes species common to both sample sites, while b and c are unique to each, indicating site-specific species presence. For the functional trait dimension, a refers to the Euclidean distance measuring the dissimilarity in functional traits of species common to both plots, whereas b and c indicate the dissimilarity distances for species unique to each plot.

The functional structure of the community was tabulated using community-level weighted trait means (CWM) which is calculated as:

$$CWM = \sum {}_{i=1}^{N} Pi \times Trait_i \tag{8}$$

Where CWM reflects the average community weight per functional trait, with N symbolizing the total species count in a plot. Pi represents the relative dry weight of species i within the community, and $Trait_i$ denotes the functional trait value of species i.

Diversity indices and community weight means were computed using R version 4.0.3. The Shannon Wiener index utilized the "diversity" function from the vegan package, while the FRic, RaoQ, and CWM indices were determined using the "dbFD" function from the FD package. Species dimension beta diversity, along with its turnover and nestedness components, were assessed using the "beta.pair" function in the betapart package. Similarly, functional trait beta diversity and its respective turnover and nestedness components were evaluated using the "functional.beta.pair" function from the same package.

Data analysis

In this analysis, the distance of sampled sites to wind turbines was utilized as a proxy for the intensity of wind farm effects, positing that greater distances indicate diminished influence. This spatial metric was then incorporated into statistical models to quantify the wind farm's impact on plant community dynamics.

To investigate the changes in dominant species at different distances, we divided the 36 plots under each plot into 6 groups, with 6 plots in each group. We analyzed the important values of each plant in each group, which were calculated based on the proportion of dry weight of each plant in the entire plot. The table only shows the three species with the highest important values.

To examine the influence of wind farm on grassland plant communities' diversity and productivity, general linear regression was employed. This analysis focused on how the distance from wind turbines affects various indices: alpha diversity (Species richness, Shannon index, FRic index, and RaoQ quadratic entropy index), beta diversity (Jaccard dissimilarity index), and productivity (Above-ground biomass).

To assess the effect of wind farm on the functional structure of grassland plant communities, general linear regression was used to analyze the direction, magnitude, and significance of the effect of distance from wind turbines on the community weight means (CWM) of 10 specific plant functional traits: height, leaf area, dry mass, specific area, nitrogen, phosphorus, and carbon contents, along with carbon-nitrogen ratio, nitrogen-phosphorus ratio, and dry matter content of the leaf. All the above data have passed the normality test (Table. S1).

Results

Effects of the wind farm on grassland plants composition and alpha diversity

There are significant differences in species composition in different areas of the three transects, with *Artemisia scoparia* and *Salsola collina* showing higher importance values in the initial and middle plot ranges. In the middle plot range, the importance value of *Stipa capillata* begins to increase, while in the final 31–36 plot range, *Leymus chinensis* shows a significant advantage (Table 1).

Species richness, species diversity, functional richness, and functional diversity of plant communities showed a significant increase with rising distance from the wind turbines (Fig. 3). Wind farm had a stronger effect on species richness (Fig. 3a) and species diversity (Fig. 3b) than on functional richness (Fig. 3c) and functional diversity (Fig. 3d).

Effects of the wind farm on grassland plants beta diversity

Species and functional beta diversity showed a decreasing trend with rising distance from the wind turbines (Fig. 4a, b). For species beta diversity, this decrease was mainly from the turnover of species between sample sites (Fig. 4c, e), while for functional beta diversity, this decrease was mainly from the nestedness of functional traits (Fig. 4d, f). Wind farm had no significant effect on the turnover component of functional beta diversity (Fig. 4d).

Effects of the wind farm on grassland plants functional traits

Wind farm significantly affected the community-level weighted trait means (CWM) of plant communities' functional traits (Fig. 5). Except for phosphorus content, nitrogen content and carbon-nitrogen ratio, the CWM of other functional traits showed a significant decrease with rising distance from the wind turbines (Fig. 5a, b,c, d,f, h,j). The CWM for phosphorus content showed a significant increasing trend with rising distance from the wind farm (Fig. 5e). There was no significant effect of the wind

Table 1 The important values of plants in the three transects

Plot range	Transect1	Transect2	Transect3
1–6	*Artemisia scoparia*: 0.29 *Salsola collina*: 0.22 *Cleistogenes squarrosa*: 0.11	*Artemisia scoparia*: 0.30 *Leymus chinensis*: 0.22 *Stipa capillata*: 0.09	*Artemisia scoparia*: 0.25 *Leymus chinensis*: 0.23 *Cleistogenes squarrosa*: 0.10
7–12	*Salsola collina*: 0.40 *Artemisia scoparia*: 0.17 *Allium bidentatum*: 0.07	*Salsola collina*: 0.26 *Stipa capillata*: 0.19 *Artemisia scoparia*: 0.18	*Salsola collina*: 0.46 *Stipa capillata*: 0.14 *Artemisia scoparia*: 0.11
13–18	*Cleistogenes squarrosa*: 0.26 *Salsola collina*: 0.20 *Artemisia scoparia*: 0.18	*Artemisia scoparia*: 0.27 *Stipa capillata*: 0.25 *Salsola collina*: 0.15	*Stipa capillata*: 0.23 *Salsola collina*: 0.21 *Artemisia scoparia*: 0.17
19–24	*Salsola collina*: 0.31 *Artemisia scoparia*: 0.28 *Stipa capillata*: 0.17	*Artemisia scoparia*: 0.29 *Stipa capillata*: 0.26 *Salsola collina*: 0.23	*Stipa capillata*: 0.33 *Artemisia scoparia*: 0.20 *Salsola collina*: 0.16
25–30	*Stipa capillata*: 0.26 *Leymus chinensis*: 0.25 *Cleistogenes serotina*: 0.17	*Stipa capillata*: 0.34 *Leymus chinensis*: 0.23 *Cleistogenes squarrosa*: 0.15	*Artemisia scoparia*: 0.23 *Leymus chinensis*: 0.22 *Stipa capillata*: 0.17
31–36	*Leymus chinensis*: 0.70 *Artemisia scoparia*: 0.13 *Cleistogenes squarrosa*: 0.05	*Leymus chinensis*: 0.80 *Cleistogenes squarrosa*: 0.08 *Artemisia scoparia*: 0.06	*Leymus chinensis*: 0.67 *Artemisia scoparia*: 0.11 *Cleistogenes squarrosa*: 0.04

farm on the CWM for nitrogen content and carbon-nitrogen ratio (Fig. 5g, i).

Effects of the wind farm on grassland plants community productivity

Wind farm had a significant effect on plant community productivity, with a p-value of 0.02. As the distance between wind turbines increase, community productivity often increases significantly (Fig. 6).

Discussion

Wind farms reduce the grassland plant diversity

Wind farms' impacts on plant diversity display significant variability, influenced by regional and environmental conditions. Wang et al. [9] observed that in humid regions like Hubei, China, factors such as terrain slope and local vegetation significantly affect plant diversity. Girmay et al. [27] pointed out the crucial role of soil fertility in arid regions like Ethiopia. The interaction between wind farms and plant diversity is complex, and dependent on a myriad of factors including vegetation composition [28, 29], soil properties, and terrain leading to varied impacts across different ecosystems. While the influence of wind farms differs by ecosystem and region [30], prevailing research indicates a notable decline in species diversity within grassland areas due to wind farms. Boutin et al. [31] reported that wind farms alter community structures and ecosystem functions, leading to decreased functional diversity and richness. The study also indicated that wind farms significantly compromise the functional richness and diversity of plant communities.

This result might be due to the fact that wind farms affected the micro-environment of plant communities. Previous studies have found that wind farm disturbance led to an overall decrease in soil nutrients (including water content, organic composition, total phosphorus, total nitrogen, etc.) (Fig. 7). Therefore, as the intensity of wind farm impacts increases, plant communities will be subjected to increased environmental screening, leading to the convergence of functional traits among species [32, 33], which in turn resulted in the reduction of the functional diversity of the community. On the other hand, functional diversity reflects the range and differentiation of functional traits within a community, serving as an indicator of ecological niche breadth and the extent of differentiation among species [34, 35]. The higher the functional diversity of plant communities, the more ecological niche space they provide, and the higher the degree of ecological niche differentiation among species, which in turn can sustain more species coexistence. Hence, with escalating impacts from wind farms, the ecological niches within plant communities may become constrained, potentially leading to diminished biodiversity.

Wind farms lead to plant community convergence

Beta diversity, as an important bridge between local (alpha) and regional diversity (gamma), is important for identifying patterns of biodiversity loss and for regional biodiversity conservation [36]. In a previous study, Ji et al. [21] found that wind farms altered species composition in the community but did not significantly affect beta diversity. Our research revealed significant impacts of wind farms on the species composition and beta diversity, showcasing substantial alterations in ecological structures.

Based on the species beta-diversity perspective, wind farms affect the species composition of plant communities mainly through species turnover processes. The result suggested that plant communities, when disturbed

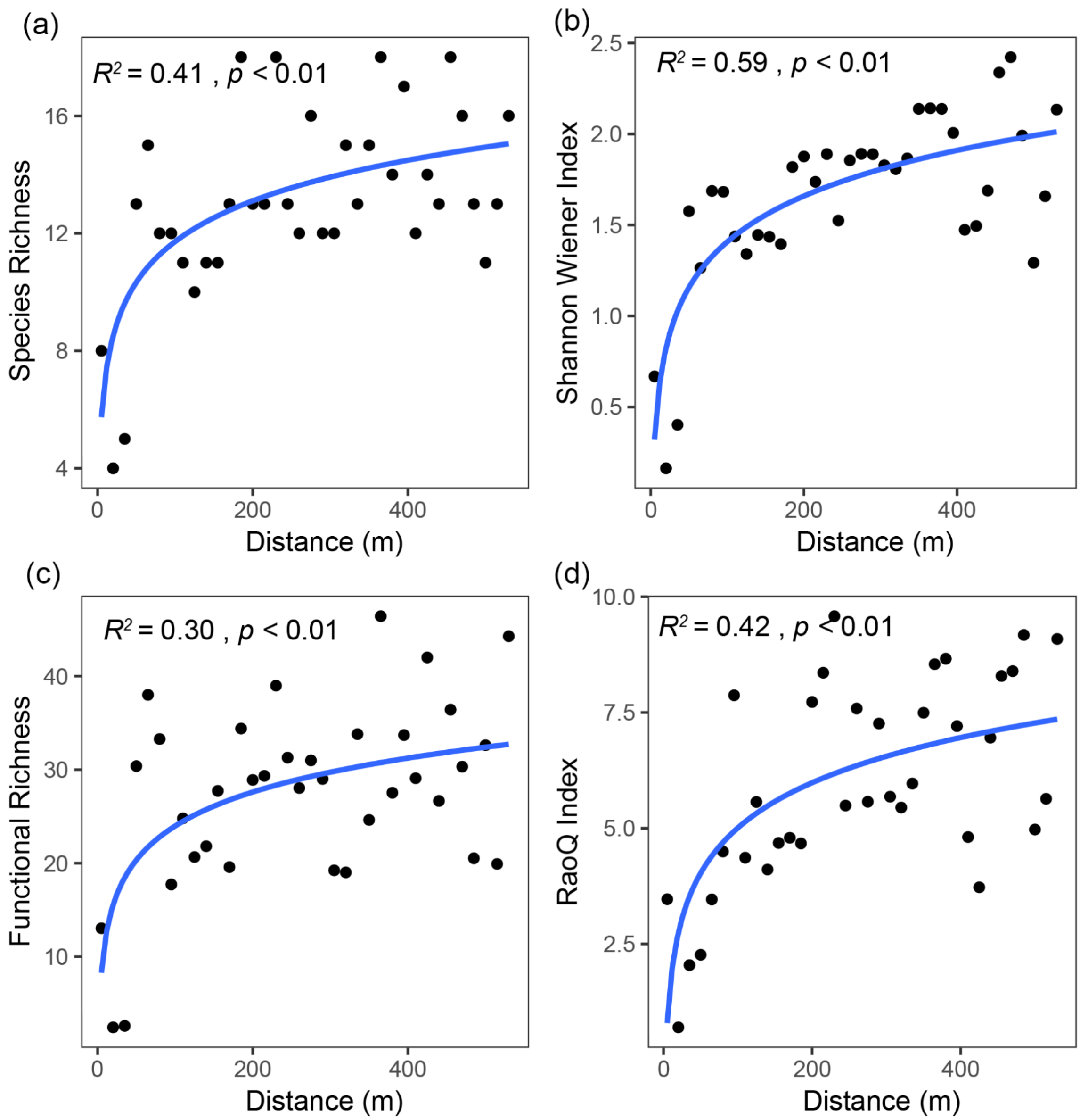

Fig. 3 Wind farms' impact on alpha diversity within plant communities. (**a**) The correlation between species richness and distance from turbines. (**b**) The correlation between the Shannon Wiener index and distance from turbines. (**c**) The correlation between functional richness and distance from turbines. (**d**) The correlation between RaoQ index and distance from turbines

by wind farms, will lose some previously existing species and some new species will appear. Urziceanu et al. [10] also found that due to the influence of wind turbines, some rare and endemic species can decrease or even disappear, and the turnover rate of disturbed land caused by wind turbines is lower than that of other undisturbed land. Wind farms affected the species composition of plant communities' beta-diversity index (i.e., beta diversity) by the process of functional nestedness. This result suggested a difference in the process of wind farm influence on the two dimensions of beta diversity, which may be due to the fact that although new species appeared in the plant community after disturbance by wind farm impacts, these new species were similar in terms of functional traits, and all of them had functional traits adapted to wind farm disturbance [37]. Therefore, as the effects of wind farm impacts increase, species with these functional traits will enter the community and thus showed a nested pattern in functional traits.

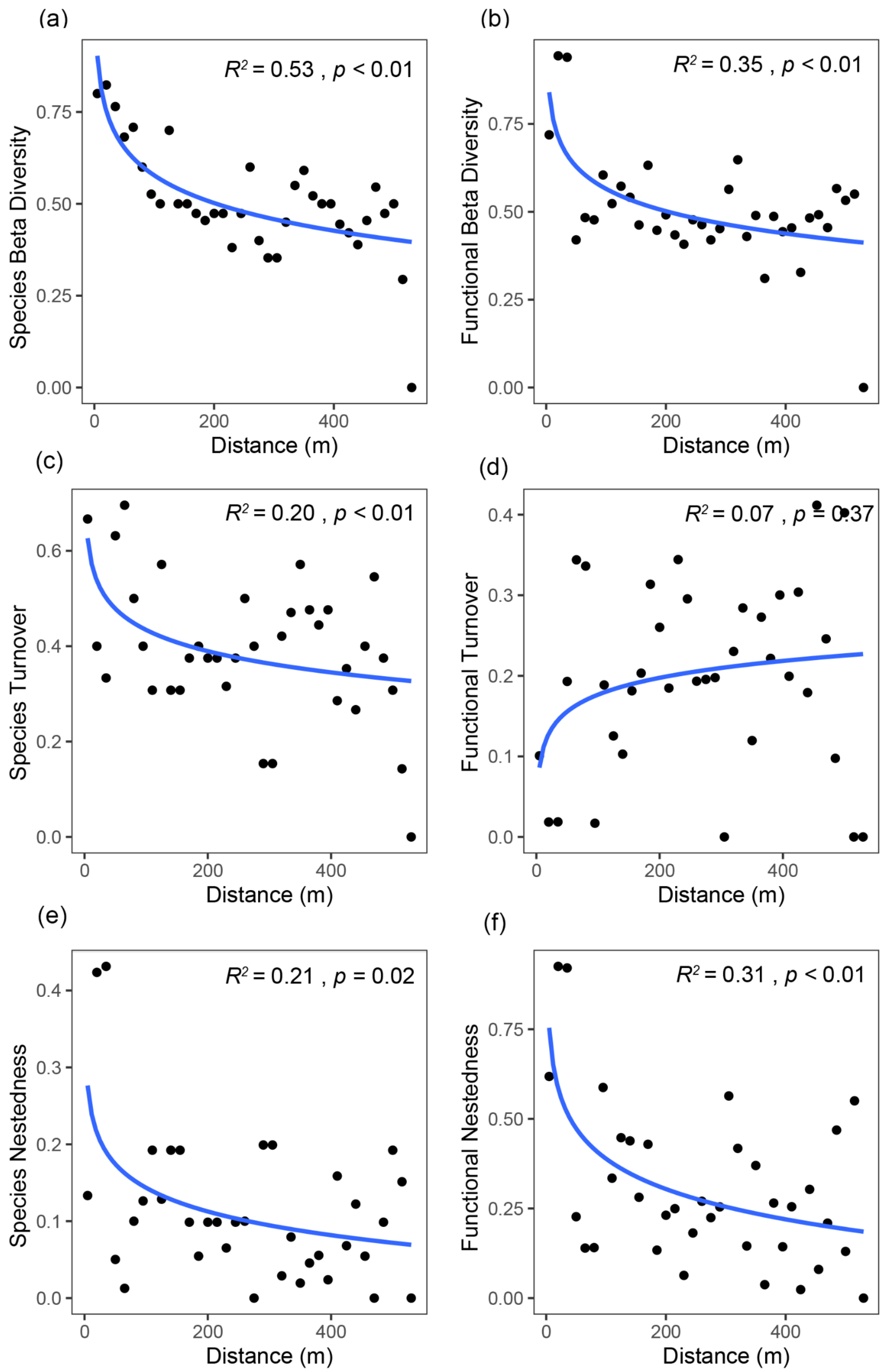

Fig. 4 Wind farms' impact on plant community beta diversity and turnover and nested components. (**a**) The correlation between species beta diversity and distance from turbines. (**b**) The correlation between functional beta diversity and distance from turbines. (**c**) The correlation between species turnover and distance from turbines. (**d**) The correlation between functional turnover and distance from turbines. (**e**) The correlation between species nestedness and distance from turbines. (**f**) The correlation between functional nestedness and distance from turbines

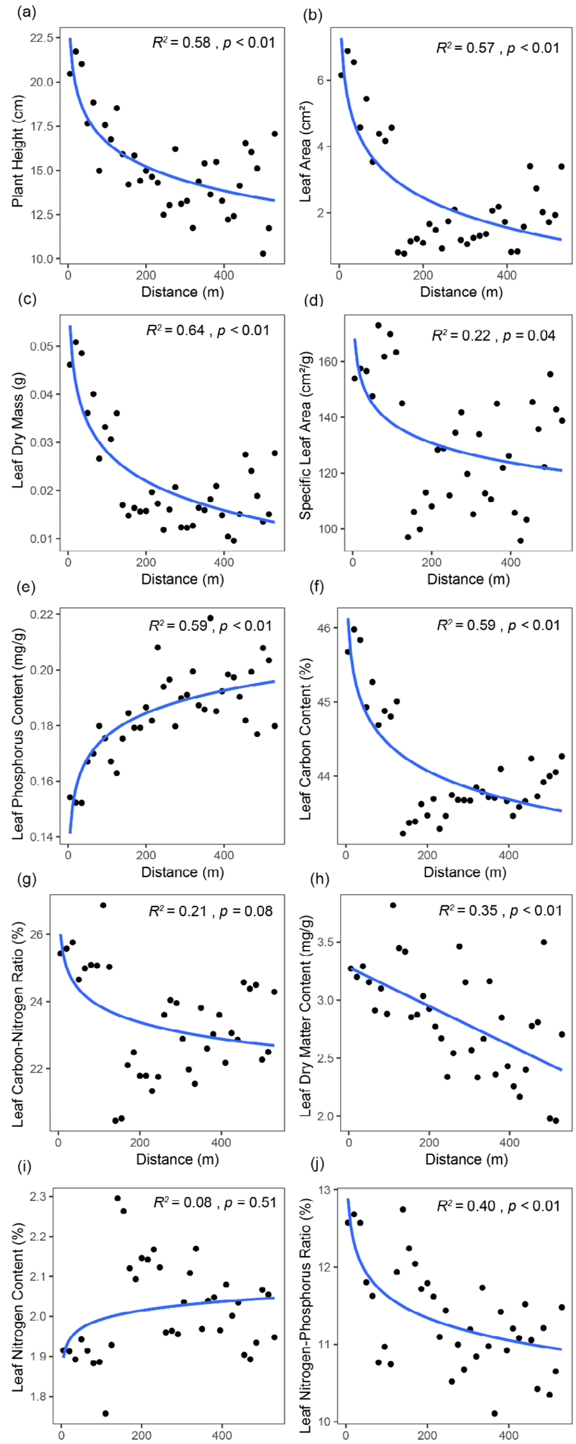

Fig. 5 Wind farms' impact on functional structure of plant. (**a**) The correlation between plant height and distance from turbines. (**b**) The correlation between leaf area and distance from turbines. (**c**) The correlation between dry mass and distance from turbines. (**d**) The correlation between specific area and distance from turbines. (**e**) The correlation between phosphorus content and distance from turbines. (**f**) The correlation between carbon content and distance from turbines. (**g**) The correlation between carbon-nitrogen ratio and distance from turbines. (**h**) The correlation between dry matter content and distance from turbines. (**i**) The correlation between nitrogen content and distance from turbines. (**j**) The correlation between nitrogen-phosphorus ratio and distance from turbines

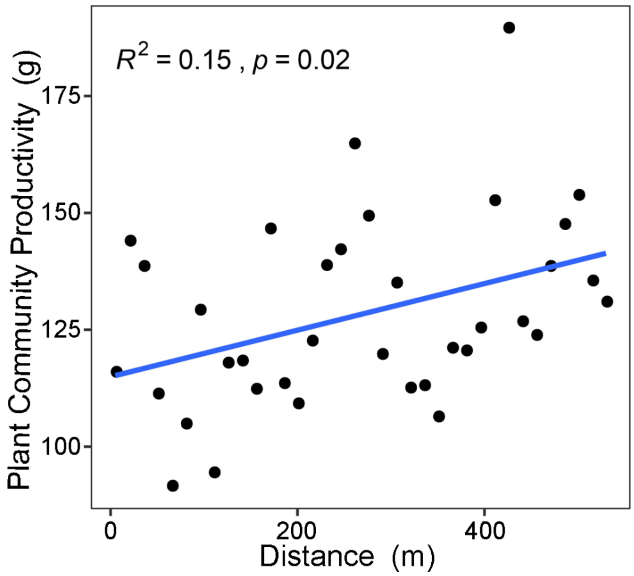

Fig. 6 Wind farms' impact on plant community productivity

Wind farms lead to more complex functional structures

There is a lack of clear understanding of how wind farms affect the plant functional structure. The study pioneered the examination of wind farms' impacts on the plant functional structure, analyzing ten functional traits in a grassland region of Inner Mongolia. It was found that wind farms significantly affected the community weight means of eight functional traits, among which the community weight means of height, leaf area, dry mass, specific area, dry matter content, carbon content, and carbon-nitrogen ratio showed a trend of significant increase with the enhancement of the effect of wind farms, and the community weight means of leaf phosphorus content showed a trend of significant decrease (Fig. 7). The results align with Yan et al. [32] findings on plant drought adaptation strategies in the typical grassland regions of Inner Mongolia, and is consistent with the global plant size spectrum and leaf economic spectrum [38, 39]. The data imply that wind farms prompt plants to enlarge for competitive advantage and adopt conservative resource use, enhancing disturbance resistance [39]. The main reason for this transformation may be that the establishment of wind farms will bring more noise and road interference, leading to a reduction in plant community resources and a decrease in plant richness, which in turn exacerbated the competition among species in the community, annual and biennial plants such as *Artemisia scoparia* and *Salsola collina* can better adapt to the disturbance environment, grow rapidly in resource limited environments, occupy the ecological niche of perennial plants such as *Leymus chinensis*, and significantly increase height, leaf area, and specific area showing a significant increase [40]; simultaneously, resource constraints make plants adopt a conservative ecological strategy that carbon content, leaf dry mass, dry matter content, and carbon-nitrogen ratio showed significant increases [38, 39]. Therefore, the study emphasized that the impacts of wind farms on plant communities were mainly in the form of limitation

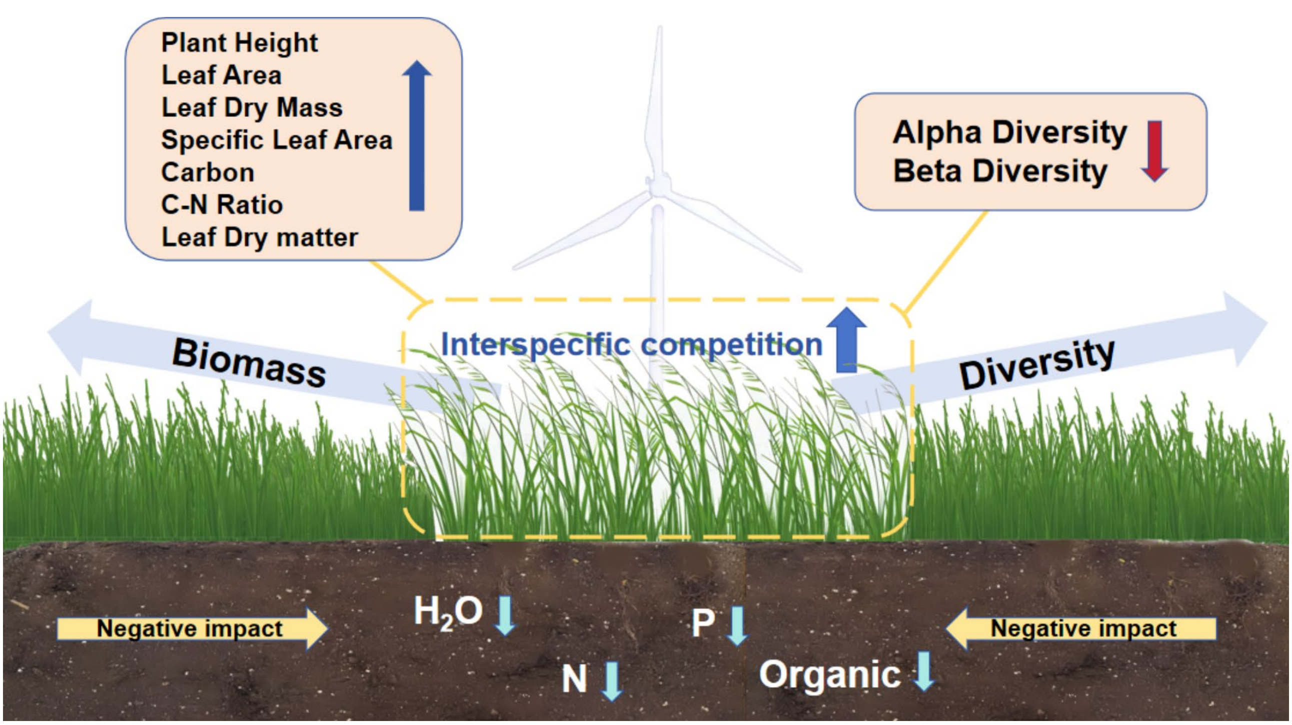

Fig. 7 Research mechanism chart

of nutrients for plant growth and development. The restoration and protection of vegetation in wind farm areas should be focused on in the future.

Wind farms can reduce the productivity of grassland plants

Productivity, reflecting ecosystem function, is widely used across ecosystems and is considered one of the most important functions of ecosystems [41, 42]. Vaz et al. [43] found that wind farms significantly reduced the productivity of neighboring communities. Our research indicates that wind farms have a notable adverse effect on grassland ecosystems, significantly reducing both the diversity and productivity of plant communities at the community level. This reduction encompasses both species diversity and functional trait composition, ultimately impacting the overall productivity and ecological function of these communities (Fig. 7).

Wind farms negatively impact plant functional diversity and productivity, primarily due to two reasons: Firstly, they limit the ecological niche differentiation within plant communities, curtailing their resource utilization efficiency. This, in turn, diminishes the overall productivity of these communities. The size of the ecological niche of the plant community and the degree of differentiation also determines the ecosystem function. Extensive research into the biodiversity-ecosystem function relationship reveals that plants' ecological niche differentiation amplifies niche complementarity. This enhancement boosts plant communities' resource utilization efficiency, and thus improving ecosystem function [44]. On the other hand, wind farms may reduce the nutrients required for plant growth and development, thereby limiting plant growth and reducing plant productivity. Therefore, this study emphasized that wind farms in grassland areas not only reduce the productivity of plant communities but also plant diversity, which may threaten the maintenance of ecosystem functions and require further research in the future.

Our research still has some shortcomings. Insufficient exploration in the fields of interactions between wind farms and the environment, chemistry, mechanical and social concerns, etc. In the future, our research will delve into the broader environmental and chemical interactions, aiming to uncover how wind farms influence soil conditions, microorganisms, animal populations, and other ecological facets. Future research will extend to analyzing wind farm variables and their effects on mechanical materials, enabling the refinement of construction techniques and spatial arrangements to enhance efficiency and minimize ecological disruption. Besides, surveys and other methods can be used to investigate whether there is any impact on pastoral households.

Conclusion

This research aims to fill the gap in knowledge regarding wind farms' impact on plant community diversity, particularly in Inner Mongolia. Through extensive field surveys, the study investigated how these energy installations affect the variety of plant life in the region. Our findings indicated that wind farms notably diminish species diversity, functional diversity, and overall productivity within grassland plant communities and led to plant community convergence. In future studies, a long-term monitoring system can be established to track the dynamic changes of plant communities and reveal the long-term effects of wind farms on species diversity and abundance, while ecological models can serve to anticipate the effects of future expansions of wind farms on grassland plant communities. These predictions can aid in crafting sustainable development approaches and provide a scientific foundation for the planning of new wind farms and the protection of ecological systems.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12862-025-02350-6.

Supplementary Material 1

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Author contributions

Xuancheng Zhao: Methodology, Validation, Formal analysis, Writing - Original Draft Fengshi Li: Data Curation, Visualization Yuan Yuan: Writing - Review & Editing, SupervisionGuna Ari: SupervisionYongzhi Yan: SoftwareQing Zhang：Supervision, MethodologyAruhan Olhnuud: Software, MethodologyPengtao Liu: Conceptualization, Writing - Review & Editing, Supervision.

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Data availability

This manuscript does not report data generation or analysis.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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