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Original Article


## Assessing vegetation community distribution characteristics and succession stages in mountainous areas hosting coming Winter Olympics Games

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**Abstract:** Alpine mountain ecosystem shows strong interactions between abiotic and biotic parameters. They also receive high attention from human activities (natural tourism, trekking, skiing, etc.). However, as the potential disturbance risk areas in alpine mountains are increasing, it is necessary to understand the relationship between environmental factors and plant communities. This is also the key consideration for the coming international events such as the Winter Olympic Games, which could generate uncontrolled ecosystem issues not previously studied. The Yin Mountains in Chongli district, Zhangjiakou City, Hebei Province, China will be the core area of the 2022 Winter Olympic Games. We hypothesize that disturbances will be caused, therefore, the previous relationships between the habitat factors and plant community and the main

environmental limiting factors before hosting them must be assessed to design future restoration plans. Therefore, we used the two-way indicator species analysis (TWINSPAN) and market basket analysis (MBA) for vegetation classification in 91 sampling plots. Plant community and relationships among environmental variables (altitude, slope position, aspect, direction, inclination, soil porosity, soil bulk density, organic matter content and soil pH) were investigated through the trend correspondence (DCA) and canonical correspondence analyses (CCA). Also, the TWINSPAN was used to classify the vegetation into 6 different groups. CCA analysis showed that i) the spatial variation of soil moisture and the content of soil organic matter are the main factors limiting the development of shrub and herb communities; ii) the distribution of different forest communities was mainly affected by terrain factors (altitude, aspect and slope position); iii) the dynamic changes of vegetation communities in different altitudes were affected by

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the fluctuation of environmental factors and human disturbance, and the shrubs and herbaceous plants in mid-to-high altitude areas (above 1400 m) generally show the process of transformation from the pioneer community to transitional community in the competition. We concluded that under the strong interference of human activities in the core construction area of the Olympic venues, higher damage intensity and lower resilience in the low altitude area is observed compared with the pioneer community. Whereas in the low altitude area (below 1400m) with a fragile ecological environment, although the plant diversity and coverage are poor, the potential impact and damage degree of the Olympic Games are greatly reduced due to the distance from the construction area of the core venues and good resilience. This information can help land managers and policymakers to anticipate human disturbances on plant communities and support guiding the most efficient ecological restoration after the Winter Olympic Games in 2022.

**Keywords:** Vegetation classification; Topographic factors; Community distribution; Winter Olympic Games.

## 1 Introduction

Climate and human activities play a key role in the growth of vegetation, especially in mountainous areas (Parmesan and Yohe 2003; Li et al. 2017). However, Winter Olympic Games are one of the largest human events that can interfere with environmental sustainability. May (1995) showed some pioneer results related to the 1992 Winter Olympics and the difficulties to assess its potential direct adverse effects on the environment. This author emphasized the assessment of secondary and longer-term impacts, which are difficult to be foreseen. Moreover, other common issues of these big events are related to floods and erosion, and the damage to young trees, natural flora and fauna due to skiing, which is not restricted to runs (Vanwynsberghe 2015). Therefore, an appropriate interpretation of the relationship between alpine vegetation types and the environment with human activities cannot be fully understood without considering other factors such as soils (Rodrigo-Comino et al. 2018), hillslope morphologies (Saco et al. 2007) and water availability (Brown et al. 2005). Then, holistic studies considering all the above-mentioned factors must be one of the

main tasks of vegetation ecology scholars. According to, environmental heterogeneity is not only considered as one of the most important factors to control the species richness gradient (Stein et al. 2014; Khanalizadeh et al. 2020) but also closely related to the micro-climatic conditions induced by topography and the distribution of plant species (Scherrer and Körner 2011). Therefore, revealing the relationship between vegetation distribution and environmental factors could quantitatively explain the interaction between driving factors and environmental processes (Sohoulande Djebou et al. 2015). Furthermore, this would allow finding the main factors restricting the development of different communities and leading to environmental changes.

The difference among parent materials, the vegetation community changes sensitively with the modification of each limiting factor. Therefore, it is of great significance to decompose the complex coupling system into a single quantitative environmental factor to design efficient vegetation restoration and reconstruction in mountainous areas. However, the Chongli district with apparent ecosystem vulnerability and sensitivity, is located in a typical transition belt between semiarid and subhumid climate regions. This area represents an ecological barrier of the 2022 Winter Olympic Games, which is not only related to the ecological service function of large-scale events and the vegetation restoration after the games but also the most important water supply and ecological service area in Hebei, Beijing and Tianjin. Therefore, the largest land retirement programme in the developing world (also called the Sloping Land Conversion Program and the Farm to Forest Program) was launched in 1999 and covered the middle and western developing regions of China (Zhou et al. 2021). Under the Grain to Green Program (GTGP) on a large scale in North China, the impacts of plantation and restoration have received more attention. On the one hand, plantations can enhance the soil and water conservation function of the soil surface and significantly improve soil quality (Martín-Peinado et al. 2016; Yu et al. 2020). However, on the other hand, due to specific tree species, soil texture, water and climate conditions, the effect of vegetation construction model in different regions is not the same and even shows a negative impact on the ecological environment (Abbate et al. 2006). Some determinant problems are the soil water shortage and drying, the scarcity of surface herbs, and the

formation of "green desert" landscapes (Li 2019). Because the early contribution of the plantation to an ecosystem is not obvious, and even reduces the function of the ecosystem (Dislich et al. 2017), it is difficult to be listed as a suitable research object. But over time, plantation plays an increasingly important role in ecosystem services, especially the substantial global contribution of SOC sequestration to ecosystem carbon sink provided by planted forests (Wang and Huang 2020).

In North China, after decades of closing mountains for forest cultivation and nature conservation, human disturbance is greatly reduced, and the artificial forest, the natural forest and the undergrowth vegetation are interacting, and the regeneration and succession are gradually completed in the process of mutual competition and integration. Therefore, plantations such as *Larix gmelinii* (*Ruprecht*) *Kuzeneva* located in this study area were included in the research scope, not only because of its wide distribution range and its influence on the ecosystem that cannot be ignored but also because of its function of landscape construction in a mountainous area (Fang et al. 2020). However, this is poorly understood in the scientific literature. Now, paying attention to the organization of the Winter Olympic Games in 2022, recently, some authors highlight the relevance to demonstrate, for example, the construction of a zero-carbon landscape in the ecological conservation area, which could achieve the regeneration of visual elements of plant zero-carbon landscapes, spatial emotions and ecological environments (Li et al. 2018).

The main aim of this paper is to assess the difference between the impact of plantation and natural secondary forest on the ecosystem before the realization of the Winter Olympic Games. This would provide theoretical support for vegetation restoration and reconstruction in this large area considering the distribution range and characteristics of the plantations before any human disturbance. In this research, the plant communities of the Yin Mountains in North China were studied considering; i) the spatial distribution of Yin Mountains and vegetation communities in the region as a function of a set of measurable environmental variables; ii) the two-way indicator species analysis to assess the distribution characteristics and succession stages of communities in the whole ecosystem including the plantations were used; iii) the direct ordination method to observe the

relationships between vegetation communities and measurable environmental variables (e.g. topography). Furthermore, as the host of the 2022 Winter Olympic Games, Chongli needs to have a further understanding of the floristic composition and ecological distribution of the plant community to avoid any uncontrolled impact (May 1995).

## 2 Materials and Methods

### 2.1 Study area

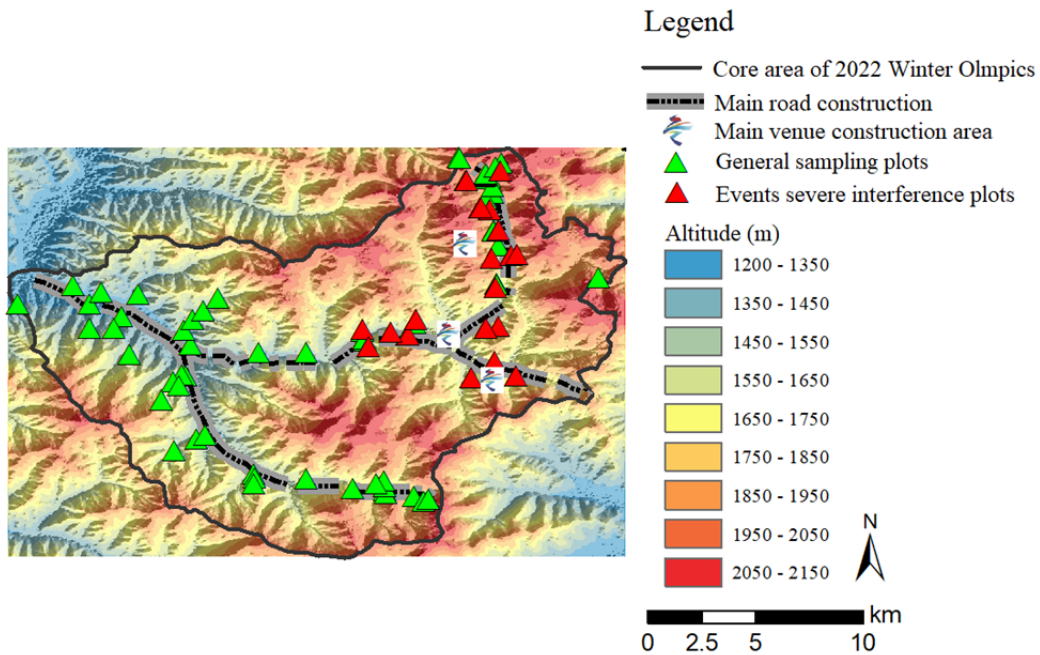
The study area (864.79 km<sup>2</sup>) is located in the branch of Yin Mountain in North China, and its administrative division is subordinate to Chongli district, Zhangjiakou City, Hebei Province, China (40°47'54"–41°02'38"N, 115°13'42"–115°30'52"E). The landform of this area belongs to middle and high mountain landforms. The general altitude trend is high in the northeast and lowers in the southwest. Its altitude ranges from 820 to 2129 m a.s.l. (Du et al. 2019; Zhang et al. 2021). The minimum altitude of the 91 samples was collected at 1220 m and the maximum one up to 2040 m (Fig. 1).

The Chongli mountain area is widely distributed occupying 80% of the county territory, and the forest coverage rate reaches 52.4%. The climate belongs to the East Asian continental monsoon climate and moderate temperate sub-arid zone. The annual average temperature is 3.7°C. The average temperature is in summer is 19°C and in winter is -12°C (Song et al. 2018). The snowfall is early and the snow is thick, with a long snow-storing period. The annual precipitation averages 483.3 mm (Song et al. 2018). Therefore, due to its climatic and topographical conditions, the ecosystem of the study area includes mottled meadow ecosystems, deciduous broad-leaved and coniferous forests, alpine shrub and meadow ecosystems (Zhang et al. 2021). In the mountainous area, forest soil types are mainly cinnamon soil and brown soil, and birch and larch trees, *Spiraea* and *Rosaceae* shrubs and herbaceous are the main vegetation species (Song et al. 2018).

### 2.2 Field sampling

A total of 91 sample plots considering different aspects following the strategy described by Lindsey (1956) were collected on the sunny, shady, semi-





**Fig. 1** Main venue, road construction area and location of the sampling plots in the study area located in the branch of Yin Mountain in North China.

**Table 1** Habitat and characteristics of 91 sampling plots.

Aspect	Direction	Quantity	Altitude (m)	Description
Sunny	45°~ 135°	34	1220~1950	It is mainly composed of shrubs and herbs, with a larger soil bulk density and more gravel content.
Shady	225°~ 315°	38	1290~2040	Shoulder and backslope are mainly composed of trees and shrubs, and the footslope by shrubs and herbs. Soil bulk density is lower and is the surface layers wetter.
Semi-sunny and semi-shady	315°~ 45° and 135°~ 225°	19	1640~1920	Mainly distributed in the middle and high altitude areas, the footslope position is mainly composed of shrubs and herbs, and the backslopes and shoulders by trees and herbs.

sunny and semi-shady hillslopes in the altitude 1220 to 2040 m a.s.l. (Table 1).

The number of sampling plots was determined according to the altitude range of the hillslope aspect, and distribution along the altitude contour line with a gradient of 50 m. The first field survey season was between August and September 2018, the second one from July to September 2019. It is important to highlight that the surveyed sampling plots in 2018 were revisited during the second survey.

The optimum size selected to survey each particular vegetation type was estimated using the concepts of minimal area and species-area curves (Kent 2011). We selected 20m×20m sampling plots dominated by trees and 10m×10m by shrubs and herbs (Fig. 2). The species coverage (%) is assessed as the vertical projection of all above-ground parts of a single species onto the ground, expressed as a percentage of the unit area of the species (Greig-



**Fig. 2** Field sampling plots. 1: sampling point of *Betula platyphylla* Suk. forest; 2: sampling point of *Larix gmelinii* (Ruprecht) Kuzeneva plantation; 3 and 4: sampling plots of shrubs and herbs.

Smith 1983). Additional recorded environmental factors include the location (longitude, latitude),

altitude, aspect, inclination, and forest canopy. Moreover, five soil surface samples were randomly taken from each plot and transported to the laboratory. The soil organic matter content was measured by the potassium dichromate method (Walkley and Black 1934). The soil bulk density and porosity were measured by the core method (Margesin and Schinner 2005). Soil pH was measured in a suspension using an electronic pH-meter. The nomenclature and classifications of all plant species in this article are based on the handbook Flora of China edited by Lin (1991).

### 2.3 Data analysis

Two-way indicator species analysis (TWINSPAN), a binary indicator species analysis similar to the multi-level dichotomy method was used to study ecological factors and species (Kooch et al. 2008; Rawat et al. 2020). The advantage of this method is that the species classification can be completed at the same time as the sample plot classification. The TWINSPAN 2.3, for Windows (Hill and Hill 1979; Peeters and Gylstra 1997) was used to classify the vegetation data. The analysis using this method took into account the following considerations: the maximum number of division levels was 3, the minimum group size for the division was 5 and the maximum number of indicators per division was 5.

The indicator species analysis (ISA) (Dufrêne and Legendre 1997) and the Monte Carlo methods were used to test the significance of the indicator value (*IV*) for each species (Dai et al. 2006). The *IV* used by ISA allowed the combination of the relative abundance (*RA*) and relative frequency (*RF*) information of the species in each group. The values of *IV* ranged from 0 (no indicator) to 100 (perfect indicator) (McCune and Mefford 1999).

After calculating the ISA, the market basket analysis (MBA) was carried out for all species about each community. The working principle of an MBA is to mine a data set, which is composed of a group of projects. In this case, it is the species and their respective communities. These populations correspond to the species found at each sampling point, and all populations can be analyzed to find a set of species frequently placed together in each community. The Apriori algorithm (Agrawal and Srikant 1994) of market basket analysis uses to be applied to analyze the existence of species

combination in each habitat, and the results of the association rules of species *A* and *B* in community *X* were generated. When  $\alpha = 0.05$ , Fisher's exact test and Holm Bonferroni's correction are used to test the significance. In addition to indicating which species appear in which community, these rules also have three main parameters. First, the support (*S*) is the proportion of the whole data set, showing the probability of the species combination occurring in the community. Second, the confidence (*C*) is the value that allows indicating the probability of finding a habitat if a given species combination is found. Finally, the third one is the lift (*L*), which is a method to measure the correlation between the species group and the community (Leote et al. 2020). Because ISA is only used for the species and their characteristics among the screening community, it does not have the relevant information between the characteristic species and the species and the community. As a result, the MBA is used to supplement ISA. Therefore, two species meeting the MBA threshold ( $S=0.25$ ,  $C=0.8$ ) and *IV* maximum were selected in each community to name the whole community.

ISA analysis was performed using PC-ORD 5.0 (McCune and Mefford 1999). For the market basket analysis (MBA), the data were analysed using the R software v.3.6. 2 (R.C.Team 2018), and the package arules (Hahsler and Hornik 2007) also demonstrated how to use data sets to combine clustering and association rule mining.

Vegan package (Oksanen 2013) in R software v.3.6. 2 (R.C.Team 2018) was used to perform detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) of species and environmental data (Ter Braak 1986). Then, sorting is used to analyze the relationship between species composition and environmental factors. The prior DCA shows that the longest gradient length is greater than 4, indicating the greater heterogeneity in species composition data. Therefore, the CCA could be considered as a suitable method to determine the relationship between environmental variables and community distribution by correlating community differences with environmental variables (Lepš and Šmilauer 2003). Rarity is eliminated by using coverage of less than 5% or a frequency of less than 5% species. The remaining 48 common species were used in both classification and ordination analyses, and to identify potential differences in the contribution of environmental variables among sampling plots. The

CCA axis was statistically evaluated by the Monte Carlo displacement test ( $P = 0.001$ ).

Before performing the CCA analysis, a logarithmic conversion was performed based on the above-mentioned environmental variables that do not obey normal distribution such as altitude and inclination. According to the current inclination degree, the hillslope position of the experimental plot was divided into three different types by the method of value assignment, 1 for the shoulder, 2 for the backslope, and 3 for the footslope position (Shao et al. 2012). For this aspect, we introduced two variables: northness and eastness. Northness will take values close to 1 if the aspect is generally northward and close to -1 if the aspect is southward, or close to 0 if the aspect is either east or west (Vogiatzakis et al. 2003).

### 3 Result

#### 3.1 Community classification

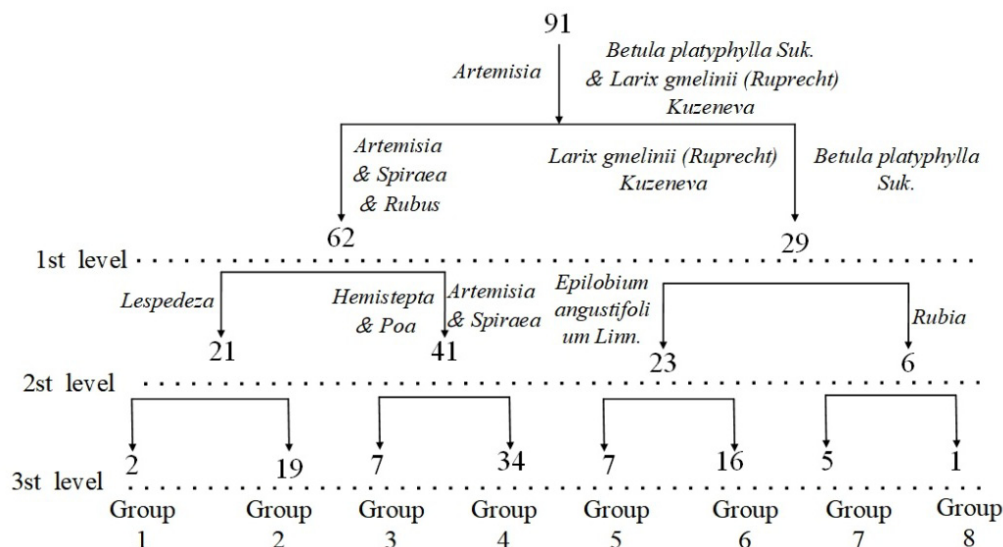
Based on the flora composition of the study area, the TWINSpan method divided 91 sampling plots into eight groups, and the classification stopped at the third level (Fig. 3). Each group contained a sufficient number and variety of samples to make different vegetation communities considering their characteristics.

According to the analysis results of ISA (Table 2) and MBA (Table 3), the original eight TWINSpan

groups were reduced to six community types. In ISA, the characteristic species (*Pteridium aquilinum* (Linn.) Kuhn var. *latiusculum* (Desv.) Underw. ex Heller and *Juncus effusus* Linn.) of groups 1 and 2 occupy the most important position in the IV ranking within the group, except for similar geographical coordinates and topographic factors. In the MBA, the support and confidence of *Pteridium aquilinum* (Linn.) Kuhn var. *latiusculum* (Desv.) Underw. ex Heller and *Juncus effusus* Linn. are greater than 0.5 and 0.9 respectively, so groups 1 and 2 were amalgamated. Similarly, groups 7 and 8 were assigned to the same group (i. e. *Larix-Carex* Community type). Information about indicator species and environmental variables for the six community types are included in Table 2 and Table 4, respectively.

#### 3.2 Vegetation grouping

Group 1-Group 2 (*Pteridium-Juncus* community type) includes a community with 27 species, mainly herbs, with a small number of shrubs. The characteristic species belonging to this community are *Pteridium aquilinum* (Linn.) Kuhn var. *latiusculum* (Desv.) Underw. ex Heller, *Juncus effusus* Linn., *ium linearifolium* Turcz., etc. It is mainly distributed on the sunny hillslopes at high and middle altitudes, with steep slopes between 20° and 40°. The content of organic matter in soil was (9.06±1.47)%, which is second to the *Betula-Rosa* community type. The vegetation community is mainly distributed around



**Fig. 3** Dendrogram derived from the TWINSpan (two-way indicator species analysis) of the vegetation data collected at the study sites.

**Table 2** Monte Carlo permutation test of significance of observed maximum indicator value (IV) for each species, based on 1000 randomizations.

Community type	Characteristic species	Indicator Species Analysis			
		IV	IV from randomized groups		
			Mean	Standard deviation	P
<i>Pteridium-Juncus</i>	<i>Pteridium aquilinum</i> (Linn.) Kuhn var. <i>latiusculum</i> (Desv.) Underw. ex Heller	41.02	25.20	5.2	0.001
	<i>Juncus effusus</i> Linn.	45.95	26.10	5.53	0.001
	<i>Galium linearifolium</i> Turcz.	57.14	12.50	5.36	0.001
	<i>Sanguisorba officinalis</i> Linn.	49.27	21.60	5.17	0.001
<i>Armenia-Poa</i>	<i>Poa annua</i> Linn.	63.68	29.80	6.92	0.001
	<i>Armenica sibirica</i> (Linn.) Lam.	23.10	24.10	6.22	0.001
	<i>Caragana acanthophylla</i> Kom.	27.67	21.70	7.57	0.001
<i>Spiraea-Artemisia</i>	<i>Spiraea fritschiana</i> Schneid.	35.28	20.60	2.87	0.001
	<i>Artemisia carvifolia</i> Buch.-Ham. ex Roxb.	37.05	22.00	2.28	0.001
	<i>Polygonum divaricatum</i> Linn.	23.53	14.90	4.86	0.001
<i>Betula-Potentilla</i>	<i>Betula platyphylla</i> Suk.	35.38	*	*	*
	<i>Potentilla fruticosa</i> Linn.	55.71	24.20	6.02	0.001
	<i>Epilobium angustifolium</i> Linn.	95.93	23.30	8.24	0.001
	<i>Phaenosperma globosa</i> Munro ex Benth.	35.37	14.30	6.56	0.001
	<i>Elymus dahuricus</i> Turcz.	32.38	16.10	4.77	0.001
<i>Betula-Rosa</i>	<i>Betula platyphylla</i> Suk.	57.69	21.60	5.87	0.001
	<i>Rosa xanthina</i> Lindl.	46.77	28.90	6.64	0.001
	<i>Corylus mandshurica</i> Maxim.	41.67	13.30	5.54	0.001
<i>Larix-Caex</i>	<i>Larix gmelinii</i> (Ruprecht) Kuzeneva	88.68	26.70	8.73	0.001
	<i>Carex doniana</i> Spreng.	44.78	21.40	4.79	0.001
	<i>Brachypodium sylvaticum</i> (Huds.) Beauv.	25.65	23.30	6.44	0.001
	<i>Saussurea japonica</i> (Thunb.) DC.	24.77	24.40	4.11	0.001

\* The IV of *Betula platyphylla* Suk. is the highest in the *Betula-Rosa* community, so mean, standard deviation and p values are not shown here.

the main venues construction area of the coming winter Olympic Games. Venues, racetracks and residential areas are mainly distributed in this area. Among the 21 sampling plots, 12 are seriously or extremely seriously disturbed due to the first activities, and the remaining 9 plots were indirectly disturbed (e.g. close to transport roads or tracks).

*Group 3* (*Armenia-Poa* community type) consists of only 7 sampling plots and 9 common species. These sampling plots are mainly found in low-altitude (1318.57±57.03) m and sunny hillslope areas, with a wide range of different inclinations (5°~45°). The characteristic species are *Poa annua* Linn., *Caragana acanthophylla* Kom., and *Armenica sibirica* (Linn.) Lam. These species are mainly shrubs, which are resistant to drought, cold and barren. The soil organic matter content of this community is the lowest among all community types, only (3.82±4.15)%. All 7 plots were affected by human habitation (including abandoned farmland and grazing).

*Group 4* (*Spiraea-Artemisia* community type) contains 34 sampling plots, which are widely distributed on shady and sunny hillslopes between 1290 and 1901 m a.s.l., and when they are distributed

**Table 3** MBA (market basket analysis) was used to select the species combined with the highest support degree to classify each vegetation community.

Community type	Support	Confidence	Lift
<i>Pteridium-Juncus</i>	0.52	0.97	1.28
<i>Armenia-Poa</i>	0.29	1	1.17
<i>Spiraea-Artemisia</i>	0.53	1	1.06
<i>Betula-Potentilla</i>	0.86	1	1
<i>Betula-Rosa</i>	0.50	1	1
<i>Larix-Caex</i>	0.83	1	1

on shady hillslopes, they use to occupy the footslopes. Their characteristic species are *Artemisia carvifolia* Buch.-Ham. ex Roxb., *Spiraea fritschiana* Schneid., *Polygonum divaricatum* Linn. and *Scutellaria baicalensis* Georgi, which are conditioned by warm and humid environments and well-developed soil. The inclination ranges from 7° to 46°. The soil color is slightly darker than that of the *Pteridium-Juncus* and *Armenia-Poa* communities. Soils are loamy, and the content of organic matter is in the middle of all community types (6.77±2.45)%. The soil and vegetation of this community could be classified as an intermediary type between the shrub grass and the arbor communities (transitional). 23 sampling plots



**Table 4** Mean and standard deviation ( $\pm$ ) of environmental variables in the studied sampling plots associated with six community types

Environmental variables	Community type					
	<i>Pteridium-Juncus</i>	<i>Armenia-Poa</i>	<i>Spiraea-Artemisia</i>	<i>Betula-Potentilla</i>	<i>Betula-Rosa</i>	<i>Larix-Carex</i>
Number of sampling plots	21	7	34	7	16	6
Altitude(m)	1520~2040	1210~1400	1260~1900	1800~2000	1420~1950	1300~1900
Organic matter (%)	9.06 $\pm$ 1.47	3.82 $\pm$ 4.15	6.77 $\pm$ 2.45	8.02 $\pm$ 1.90	9.74 $\pm$ 2.08	6.04 $\pm$ 3.80
Slope( $^{\circ}$ )	27.19 $\pm$ 6.83	24.14 $\pm$ 15.60	25.97 $\pm$ 11.03	19.86 $\pm$ 5.52	24.50 $\pm$ 3.54	20.00 $\pm$ 6.36
Soil porosity (g/cm <sup>3</sup> )	1.18 $\pm$ 0.13	1.15 $\pm$ 0.14	1.0 $\pm$ 0.2	0.82 $\pm$ 0.18	0.89 $\pm$ 0.12	0.99 $\pm$ 0.18
Soil bulk density (%)	40.75 $\pm$ 5.54	56.35 $\pm$ 5.75	58.56 $\pm$ 10.69	73.91 $\pm$ 6.37	64.18 $\pm$ 11.26	70.09 $\pm$ 11.85
Aspect	S ES	S	N S	E	N	N WN
pH	7.72 $\pm$ 0.66	7.7 $\pm$ 0.38	7.18 $\pm$ 0.3	7 $\pm$ 0.13	6.98 $\pm$ 0.29	7.14 $\pm$ 0.57

(concentrated below 1700m) were disturbed by human activities. Among them, 10 plots were seriously disturbed by the construction of supporting facilities for the event, and 13 plots were disturbed by human settlements (mainly farmland).

**Group 5** (*Betula-Potentilla* community type). This community contains only 7 sampling plots, but they are all distributed on the semi-sunny or semi-shady hillslopes with altitudes up to 1980 m. Its characteristic species are *Betula platyphylla* Suk., *Epilobium angustifolium* Linn., *Potentilla fruticosa* Linn. and *Phaeosperma* and *Elymus dahuricus* Turcz. . It is relevant to highlight that *Betula platyphylla* Suk. is a pioneer tree species, and gradually was replaced by other tree species after planting. The soil is loamy, and the pH is neutral. The community is located at a high altitude in this area, which is not affected by human activities and other factors.

**Group 6** (*Betula-Rosa* community type) has 16 sampling plots. As in the *Betula-Potentilla* community, the pioneer and main tree species are the *Betula platyphylla* Suk., but the difference is that most of the sampling plots are distributed on shady hillslopes, the inclinations are about 25 $^{\circ}$ , and the altitude range from 1423 to 1950 m a.s.l. In addition to *Betula platyphylla* Suk., its characteristic species include *Rosa xanthina* Lindl. and *Corylus mandshurica* Maxim. The soils are similar to the *Betula-Potentilla* community, they are loamy. However, the soil organic matter content is the highest among all community types (9.74 $\pm$ 2.1)%, and the soil texture is loose and neutral. Due to the influence of enclosure measures, the influence of human activities is not obvious. Only some afforestation activities were found around the area below 1600m altitude (5 sampling plots), such as road traces left by human transportation and trampling.

**Group 7-Group 8** (*Larix-Carex* community type)

is characterized by species such as *Larix gmelinii* (Ruprecht) Kuzeneva. Except for the footslope position of sample plot 65 on the semi-shady hillslope, other sampling plots are distributed along the balckslopes of the shady faces. The altitude ranges from 1298 to 1900 m a.s.l. The inclination is not greater than 25 $^{\circ}$ . Other characteristic species include some herbaceous plants such as *Carex doniana* Spreng. , *Brachypodium sylvaticum* (Huds.) Beauv., *Saussurea japonica* (Thunb.) DC., and *Vicia sepium* Linn. *unijuga* A. Br., and a few sampling plots have a small number of shrubs. The soil is loose as the *Betula-Potentilla* and *Betula-Rosa* communities. The organic matter content changes significantly with altitude, in the low altitude range (1595.5 $\pm$ 263.61) m, the organic matter content fluctuated around 6.04. The pH value is neutral to weakly alkaline. 2 sampling plots in lower altitude area (Below 1600m) were seriously disturbed by the race track and road construction. While 3 sampling plots in higher altitude area (1600~1900m) had artificial footprints and planting pits, but the influence was not obvious.

### 3.3 Limitation of environmental factors on plant species

In this study, the characteristic values of the first two coordination axes of DCA are 0.63 and 0.45, which are larger than the characteristic values of the first two coordination axes of CCA (0.39 and 0.26, respectively; Table 5). Therefore, TWINSpan was used to organize and classify vegetation and sampling plots, because the first step of the TWINSpan method is to perform DCA ordination. Unlike DCA, which belongs to indirect gradient analysis, CCA is a direct gradient analysis and more beneficial to the ecological sense, and CCA can reflect the similarity

of species composition and environmental factors at the same time, and even reflect the correlation between environmental factors and sampling plots from the side. Therefore, we used CCA to explain the relationship between environmental factors and various species.

**Table 5** Summary statistics for the two CCA (canonical correspondence analysis) ordinations and comparison of the results using DCA (detrended correspondence analysis).

Summary of ordination		Axis 1	Axis 2
CCA	Eigenvalues	0.39	0.26
	Cumulative percentage variance of species data (%)	5.81	9.64
	Species- environment correlation	0.79	0.73
	Test of significance of all canonical axes	$F=2.65, P=0.001$	
DCA	Eigenvalues	0.63	0.45
	Cumulative percentage variance of species data (%)	9.31	15.86
	Gradient length	4.41	3.60

**Table 6** Correlation between the environmental factors of plant communities in the investigated area and the first two ordination axes of CCA (canonical correspondence analysis).

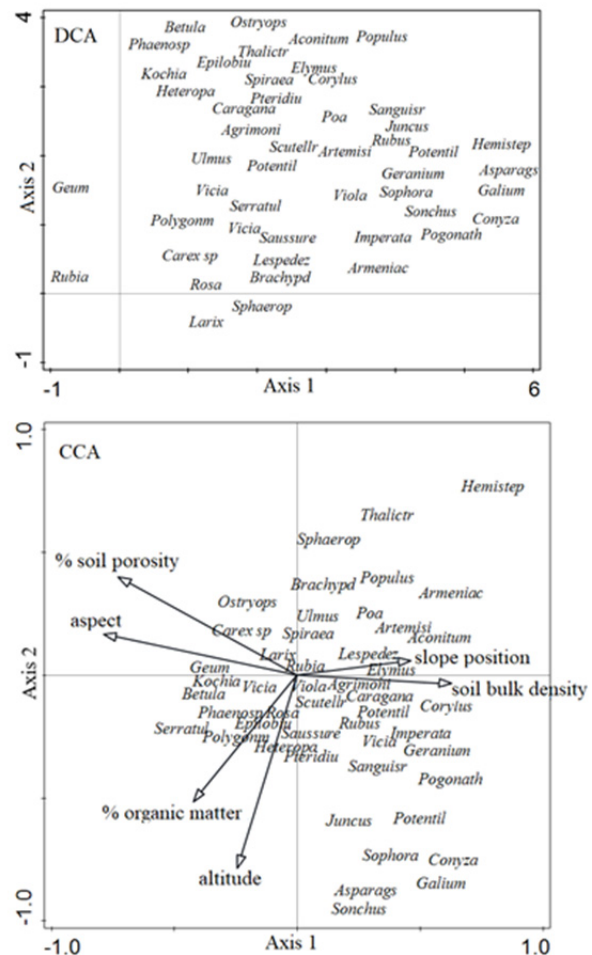
Environmental variables	Axis 1	Axis 2
Altitude	-0.24*	-0.79***
Organic matter	-0.42	-0.52*
Aspect	-0.79**	0.17
Soil porosity	-0.73*	0.40**
Soil bulk density	0.63*	-0.04
Slope position	0.46*	0.06

\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$

Fig. 4 shows the distribution pattern of species in this area by unconstrained ordination of IV indicators of species. Also, environmental factors are added to constrain the ordination of species (Fig. 4). By comparing the scoring order of species on DCA Axis 1 and CCA Axis 1, the species with the highest score (to the right) or the lowest (to the left) in the 2 figures register some differences. For example, the species ranked later are *Geum aleppicum* Jacq., *Betula platyphylla* Suk. and *Phaenosperma globosa* Munro ex Benth., etc. While the top-ranked species are *Hemistepta lyrata* (Bunge) Bunge, *Conyza canadensis* (Linn.) Cronq., *Pogonatherum crinitum* (Thunb.) Kunth, etc. In summary, the potential influencing factors that affect the ranking and classification of axis 1 from DCA have a great correlation with the environmental factors that affect the ranking of axis 1 from CCA. While the

performance on Axis 2 is not as obvious as Axis 1.

From Fig. 4 (②), we can see the correlation between species and environmental factors. The environmental factors that have a significantly positive correlation with axis 1 are soil bulk density ( $r=0.63, P<0.05$ ) (Table 6) and hillslope position ( $r=0.46, P<0.05$ ). The environmental factors that obtained a significant negative correlation with axis 1 are aspect ( $r=-0.79, P < 0.01$ ) and soil porosity ( $r=-0.73, P<0.05$ ). Species with high positive scores on the first axis are *Hemistepta lyrata* (Bunge) Bunge, *Pogonatherum crinitum* (Thunb.) Kunth, *Conyza canadensis* (Linn.) Cronq., *Sophora flavescens* Alt., *Corylus mandshurica* Maxim., *Armeniaca sibirica* (Linn.) Lam., and *Galium linearifolium* Turcz. Some of these species, such as



**Fig. 4** DCA (detrended correspondence analysis) and CCA (canonical correspondence analysis) species ordination. The length of the vector is proportional to its importance and the angle between the two vectors reflects the degree of correlation between variables. The angle between a vector and each axis is related to its correlation with the axis. For species abbreviations, see Appendix 1.

*Galium linearifolium* Turcz., *Hemistepta lyrata* (Bunge) Bunge, and *Pogonatherum crinitum* (Thunb.) Kunth is the main species in the footslopes, widely distributed on the sunny hillslopes, while others such as *Conyza canadensis* (Linn.) Cronq. and *Armeniac a sibirica* (Linn.) Lam., are usually associated with back-and footslope positions' shrubland. Species with low scores on the first axis include *Serratula centauroides* Linn., *Betula platyphylla* Suk., *Geum aleppicum* Jacq., *Polygonum divaricatum* Linn., *Vicia sepium* Linn. *unijuga* A. Br., *Kochia scoparia* (Linn.) Schrad. and *Larix gmelinii* (Ruprecht) Kuzeneva. Among them, *Betula platyphylla* Suk. and *Larix gmelinii* (Ruprecht) Kuzeneva are the main tree species on the shady and semi-shady hillslopes in the area, and most of them are pure forests, if on the same hillside, *Betula platyphylla* Suk. is generally distributed at the higher altitudes than *Larix gmelinii* (Ruprecht) Kuzeneva. While other species such as *Geum aleppicum* Jacq., *Vicia sepium* Linn. *unijuga* A. Br. and *Kochia scoparia* (Linn.) Schrad. are undergrowth vegetation. These species ranked low on the first axis are widely distributed on the shady or semi-shady hillslope, with thick humus layers, shoulder position and loose soil, the soil porosity is above 66.7%, and the soil organic matter content is above 7.6%, which are significantly higher than the average values of 60.6% (soil porosity) and 7.2% (soil organic matter content) in all sampling plots.

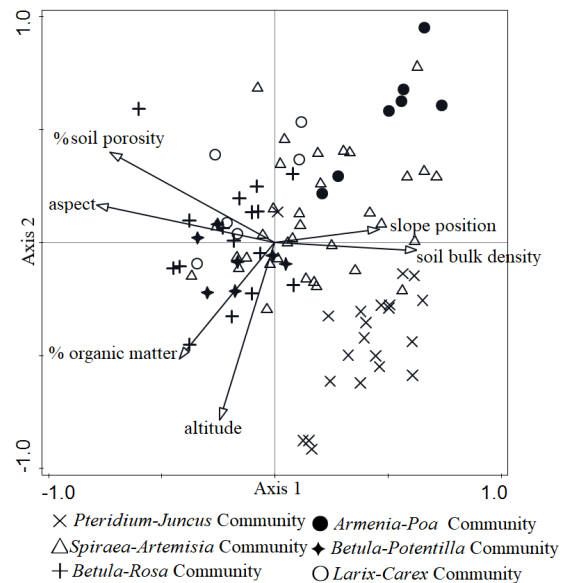
In the middle of the first axis, most species are related to shrubland or usually distributed in standing forest. For example, *Saussurea japonica* (Thunb.) DC., *Lespedeza bicolor* Turcz., *Potentilla fruticosa* Linn., etc. It is difficult to observe any pattern of land directivity. In summary, the environmental factors that are most sensible with the distribution of plants on axis 1 are "aspect" and "hillslope position". The two ends of the axis represent the footslope position of the sunny hillslope and the footslope position of the shady hillslope, respectively.

The environmental factors with strong correlation with the axis 2 are altitude ( $r = -0.79$ ,  $P < 0.001$ ) and organic matter ( $r = -0.52$ ,  $P < 0.05$ ), and both are negatively correlated. Species with higher scores on axis 2 include *Hemistepta lyrata* (Bunge) Bunge, *Thalictrum aquilegifolium* Linn. var. *sibiricum* Regel et Tiling, *Sphaerophysa salsula* (Pall.) DC. and *Brachypodium sylvaticum* (Huds.) Beauv. are widely distributed in low and middle altitude areas. They are present in shrub sampling plots and standing forest sampling plots, and have a

negative correlation with the percentage of soil organic matter. The species with low scores on axis 2 are *Sonchus arvensis* Linn., *Asparagus cochinchinensis* (Lour.) Merr., *Galium linearifolium* Turcz., *Conyza canadensis* (Linn.) Cronq., *Sophora flavescens* Alt. and *Potentilla chinensis* Ser. *fruticosa* Linn., especially *Potentilla fruticosa* Linn. and *Sonchus arvensis* Linn., are the main species in shrublands above 1700 m a.s.l., and a few under the standing forest in the high altitude area.

### 3.4 Regional distribution characteristics of species community

In order to differentiate the community types obtained by the TWINSpan method and compare the classification and ordination results among them, the final six community types were superimposed on the CCA sample ordination, and the final results are shown in Fig. 5.



**Fig. 5** CCA (canonical correspondence analysis) sampling plots ordination of the study area with the community types derived from TWINSpan (two-way indicator species analysis) superimposed. The vectors represent environmental variables. The length of the vector is proportional to its importance and the angle between the two vectors reflects the degree of correlation between variables. The angle between a vector and each axis is related to its correlation with the axis. For species abbreviations, see Appendix 1.

As mentioned in Table 6, there are four main factors related to axis 1. The positive correlation includes soil bulk density ( $r = 0.63$ ,  $P < 0.05$ ) and

hillslope position ( $r=0.46$ ,  $P<0.05$ ). Negative correlations include aspect ( $r=-0.7875$ ,  $P<0.01$ ) and soil porosity ( $r=-0.73$ ,  $P<0.05$ ). From Fig. 5, the distribution characteristics of the six communities can be distinguished. *Pteridium-Juncus* community with *Galium linearifolium* Turcz., *Sanguisorba officinalis* Linn., *Juncus effusus* Linn., and *Pteridium aquilinum* (Linn.) Kuhn var. *latiusculum* (Desv.) Underw. ex Heller as the main characteristic species are concentrated in the lower right of the plot. However, *Armenia-Poa* community with *Poa annua* Linn., *Caragana acanthophylla* Kom. and *Armeniaca sibirica* (Linn.) Lam. as the main characteristic species is concentrated in the shoulder of the plot. The main vegetation components of the *Pteridium-Juncus* community and *Armenia-Poa* communities are shrubs and herbs, which are positively correlated with hillslope position and soil bulk density, and negatively correlated with aspect. Most of them are distributed in the footslope position of the sunny hillslope, and the soil is compacted. The difference among them is that the altitude and the percentage of soil organic matter in the *Pteridium-Juncus* community are higher than that in the *Armenia-Poa* community. *Spiraea-Artemisia* community, with *Artemisia carvifolia* Buch.-Ham. ex Roxb., *Spiraea fritschiana* Schneid., *Polygonum divaricatum* Linn. and *Scutellaria baicalensis* Georgi as the main species, is the same as the *Pteridium-Juncus* community and *Armenia-Poa* community, both of which are shrub sampling plots, but the community is widely distributed on two axes. *Betula platyphylla* Suk. is the main species in the *Betula-Potentilla* community, and the undergrowth vegetation is mainly *Epilobium angustifolium* Linn., *Potentilla fruticosa* Linn., *Phaenosperma globosa* Munro ex Benth. and *Elymus dahuricus* Turcz. It is distributed in the area with an altitude of more than 1800 m a.s.l., and mainly concentrated in the semi-shady hillslope, the average content percentage of soil organic matter in the community is the highest among all the six communities. As in the *Betula-Potentilla* community, the main tree species of the *Betula-Rosa* community are *Betula platyphylla* Suk., but the undergrowth vegetation with *Rosa xanthina* Lindl. and *Corylus mandshurica* Maxim. as the main species are different. Furthermore, the obvious difference is that most of them gather on the shady hillslope below 1800 m a.s.l. The percentage of soil organic matter in this community is slightly lower than that in the

*Betula-Potentilla* community. The main tree species of the *Larix-Carex* community is *Larix gmelinii* (Ruprecht) Kuzeneva, and the undergrowth is mainly *Carex doniana* Spreng., *Brachypodium sylvaticum* (Huds.) Beauv., and some other herbs. On-axis 1, it is mainly distributed on the left half or near the middle, while on axis 2, it is relatively scattered. The community is widely distributed considering the altitude, mainly in the backslope of the shady hillslope, and only a few in the semi-shady hillslope.

## 4 Discussions

In most of the vegetation studies in the mountainous area of the semi-arid region of northern China (especially in the Chongli area), the relationship between environmental variables and vegetation communities is described by the ecological characteristics of single or several types of vegetation, and few analysis of different topography variables in the unified magnitude and dimension are conducted. The novelty of the methods used in this study is to quantify the different environmental variables (mainly topography) according to the basis, to determine the distribution patterns of the community by using the multivariate analysis techniques and to directly associate these distribution patterns with the quantitative environmental variables, to map the distribution of vegetation and population.

### 4.1 Zonal characteristics of six vegetation communities

The area in this study belongs to a typical warm temperate deciduous broad-leaved forest. The geographical composition of the flora shows an obvious transition pattern. In addition to the European Siberian species composition, it can also the flora of the Black Sea and Central Asian steppe flora. Forest vegetation types are mainly natural secondary forest vegetation, followed by artificial forest one. According to TWINSpan analysis and characteristic species screening, the six community types determined are abstract, and no fully determined species collocation and combination, just using these dominant indicator species and environmental factors to describe a community, and verify it with DCA and CCA methods respectively.

*Betula platyphylla* Suk. has obvious distribution



characteristics in this area, as the most common warm temperate pioneer tree species in the middle and high altitude regions of the north. *Betula platyphylla* Suk. is only distributed at an altitude higher than 1500 m a.s.l. in this area. This could be because of its heliophilous and hydrophilous characteristics. Most of them are on the shoulder of the shady hillslope, and a small amount of them is distributed on the backslope. The soil moisture is significantly higher than that of the grassland on the sunny hillslope, but it is significantly lower than that of the *Larix gmelinii* (Ruprecht) Kuzeneva plantation or the grassland under the secondary forest of *Betula platyphylla* Suk. Due to the aspect factors and almost no human disturbance, the percentage of soil organic matter content is significantly higher than other forests or grasslands, and it increases with the elevation. Therefore, the main limiting factor of *Betula platyphylla* Suk. distribution in this area is the mountain environment, including altitude, illumination, moisture content and soil organic matter content (Peterson 1998; Cumming 2002). One representative example is the research conducted by (Xu et al. 2015) in China, under humid alpine areas. These authors confirmed changes in leaf morphology, water viscosity and carboxylation efficiency with temperature, which, are subsequently affected by the altitude and aspect.

Among the six communities in TWINSPAN classification results, the dominant species in *Betula-Potentilla* community and *Betula-Rosa* community include *Betula platyphylla* Suk.. The difference between the two communities was mainly manifested as undergrowth. The undergrowth of the *Betula-Potentilla* community was subalpine shrubs and herbs dominated by pioneer species. These pioneer species need not only a certain amount of light, but also suitable soil moisture, and also have obvious strong diffusion ability in a certain altitude range (Turrill 1953). Therefore, the *Betula-Potentilla* community is located in a semi-shady slope with an altitude of more than 1800m (It should be emphasized here that a few sampling plots of *Betula-Potentilla* community are mixed forests of *Betula platyphylla* Suk. and *Larix gmelinii* (Ruprecht) Kuzeneva, which follow a rule that the proportion of *Betula platyphylla* Suk. is higher and higher with the increase of altitude, while that of *Larix gmelinii* (Ruprecht) Kuzeneva is the opposite). The undergrowth vegetation in the *Betula-Rosa* community is composed of shade-resistant transitional vegetation

in the backslope and footslope positions. Furthermore, in addition to the pioneer or transitional species that are unique to the *Betula-Potentilla* community or *Betula-Rosa* community, there are also a significant number of overlapping species in the two communities, they have a wide niche and can survive in complex and diverse environments (Dragon and Barrington 2009). Geographically, the community is widely distributed on altitude gradients (1400-2000 m), most of them appear on shady hillslopes, and there are also very few sampling plots on semi-shady hillslopes, which are only distributed on the shoulder or in the backslopes. In summary, it can be seen that the undergrowth vegetation of the *Betula-Rosa* community has partially or completely completed the conversion from pioneer species to transitional species. However, the *Betula-Potentilla* community located in the high altitude area is still occupied by pioneer species.

*Larix gmelinii* (Ruprecht) Kuzeneva forest is the largest and most widely distributed plantation tree species in the region. Since 1979, the stand management and vegetation succession for 40 years up to the investigation date, as well as the closure management and protection from human interference have also lasted for more than 20 years. The *Larix gmelinii* (Ruprecht) Kuzeneva community has developed into a near-natural state. Due to the high requirements of *Larix gmelinii* (Ruprecht) Kuzeneva on soil conditions, it not only needs a certain amount of soil water, but also needs good drainage, and is born in the deep and fertile soil layer (Leng et al. 2008). Therefore, after 20 years of natural succession, the *Larix gmelinii* (Ruprecht) Kuzeneva forest in the *Larix-Carex* community has developed to appear only in the backslope of the shady hillslope, it is close to and under the *Betula platyphylla* Suk. forest. The reason is that the natural secondary forest (*Betula platyphylla* Suk.) in this area has been developing for a long time, the biodiversity is increasing, and the organic matter content and other nutrients in the soil are accumulating, which provide sufficient nutrients for the natural growth of *Larix gmelinii* (Ruprecht) Kuzeneva forest (Table 3). As we mentioned above, the growth of *Larix gmelinii* (Ruprecht) Kuzeneva needs wet soil with good drainage performance. However, in the mountainous area where the rainfall is concentrated in time and space, the position of footslope is easy to have poor drainage, high soil humidity, even waterlogging disaster, which affects the growth and development of deep root vegetation



(Kastanek 1988; Berry et al. 2016). Therefore, the natural development of *Larix gmelinii* (Ruprecht) *Kuzeneva* forest in the backslope is promoted by the smooth drainage, appropriate humidity and nutrients, while the footslope position is occupied more by grassland. Furthermore, due to its distribution characteristics on the hillslope, the sunlight is not as ample as that of shoulder positions. The undergrowth vegetation of *Larix gmelinii* (Ruprecht) *Kuzeneva* is dominated by herbaceous vegetation. Moreover, the shrub and herb coverage was significantly lower than *Betula platyphylla* Suk. community.

*Pinus tabuliformis* Carr. plantations are distributed in a few areas on the sunny slope of the study area (due to serious human interference), most areas are natural grasslands (Wu et al. 2018), but the regional and soil texture make the vegetation composition significantly different. In the footslope position of the shady hillslope in this area also some of the grassland (see Table 1 and Table 4). We found the *Armenia-Poa* community in the low altitude area (1220 - 1380 m), with obvious inclination difference (5-45°), poor soil with more gravel, rare species composition and more bare land. Because the distribution of this community is low in elevation and mostly in the footslope position, compared to other communities, the fragile ecological environment is more sensitive to the interference of human activities. (Gabarrón-Galeote et al. 2013). In addition, the *Pteridium-Juncus* community is an alpine meadow community that was found in the middle and high altitude areas (1520 - 2040 m), and some of the cold-resistant alpine shrubs in the sampling plots, and the content of soil organic matter and biodiversity increased with altitude. The community of *Spiraea-Artemisia* community is the most widely distributed and numerous shrub herbage sample plot in this area, and no special distribution rule from the data, but from the analysis results of TWINSPAN, *Artemisia carvifolia* Buch.-Ham. ex Roxb. and *Spiraea fritschiana* Schneid. are the characteristic species of this community. From the results of indicator specifications analysis, in addition to these two species, *Polygonum divaricatum* Linn. and *Scutellaria baicalensis* Georgi are also regarded as characteristic species of the community, but these species are all without major characteristics, that is, they can thrive in fertile soil and survive in poor soil (Lin 1991). In particular, it also displayed in the DCA analysis (Fig. 4) that lots of species are closest to the

center of the figure (such as *Artemisia carvifolia* Buch.-Ham. ex Roxb.), which shows that species exists in most of the investigated sampling plots, including some woodlands, and only in quantity difference. Therefore, logically speaking, the *Spiraea-Artemisia* community is more like the remaining community of these grouping and classification methods, which has loose requirements for altitude, light, water and nutrients.

#### 4.2 Limiting factors of six communities

Although a certain degree of overlap in the ordination space among different groups, CCA confirmed the community types from TWINSPAN classification. CCA analysis of this area shows that the most significant correlation with the first axis of CCA is the slope direction ( $r=-0.79, P<0.01$ ), soil porosity ( $r=-0.73, P<0.05$ ) and soil bulk density ( $r=0.63, P<0.05$ ) (Table 6). The correlation between environmental variables (Table 7) shows that soil porosity is positively correlated with aspect ( $r=0.43, P<0.01$ ), and negatively correlated with soil bulk density ( $r=-0.62, P<0.01$ ). Therefore, the first axis of CCA is closely related to the aspect and soil porosity, and aspect directly affects the evaporation and conservation of moisture on the slope (Miller and Poole 1983), and the soil moisture can be controlled by the vegetation type on the soil surface (Moustafa and Zaghoul 1996). Therefore, the first axis of CCA represents the moisture gradient.

**Table 7** Correlation among six environmental variables in the study area.

	Alt	OM	Asp	SP	SBD	Posi
Alt	1					
OM	0.51**	1				
Asp	-0.11	0.20	1			
SP	-0.04	-0.01	0.43**	1		
SBD	-0.26*	-0.29**	-0.35**	-0.62**	1	
Posi	-0.11	-0.27**	-0.15	-0.12	0.16	1

**Notes:** Alt= Altitude; OM= Organic matter; Asp= Aspect; SP=Soil porosity; SBD= Soil bulk density; Posi=Slope position; \* $P<0.05$ , \*\* $P<0.01$ .

The second axis of CCA is closely related to the altitude and the percentage of organic matter content, and the positive correlation between the altitude and the percentage of organic matter content is significant ( $r=0.507, P<0.01$ ). This is because the altitude affects the regional average temperature and precipitation in the mountain area (Dai and Huang 2006), promotes

the accumulation of organic matter. In addition, the high altitude area is rarely visited, which greatly reduced the impact of human interference. Under various factors, the soil organic matter increases with elevation. Although a certain correlation between soil porosity and the second axis, it fails to pass the significant correlation test with altitude or organic matter content, so the second axis represents the altitude gradient.

To sum up, due to the topography limitations of different communities, various limiting factors restrict their development and diffusion. The first three communities (i.e. grassland) are widely distributed in sunny and semi-sunny hillslopes under the influence of light factors and soil compactness, compared to forest stand, the requirement of soil water and nutrient is lower. For the *Armenia-Poa* community, the spatial variation of soil moisture in different hillslope positions is the main factor limiting the development of the community. For the *Pteridium-Juncus* community, the content of soil organic matter is the main factor restricting its distribution. The *Spiraea-Artemisia* community is the most widely distributed, and no obvious topographic factors are restricting the development of the *Spiraea-Artemisia* community. For arbor communities (including natural forest and artificial plantations), the limiting factors of the arbor community are more strict than grassland. First, all the three arbor communities are distributed on the shady or semi-shady hillslopes, which have higher requirements for soil moisture and soil nutrients. Moreover, there are different requirements for altitude, aspect and soil porosity. *Betula-Potentilla* community is a typical pioneer community, which only appears on the upslope position above 1800 m altitude, so its main topographic limiting factors are aspect, altitude and slope position. *Betula-Rosa* community is a typical transitional community, with a wide range of altitude distribution, and it appears on the shoulder and backslope position. Its limiting factor is the aspect. The *Larix-Carex* community belongs to the artificial plantation, and the main limiting factor is the slope position, which has higher requirements on the original organic matter content of the soil. And that some communities dominated by *Larix gmelinii* (Ruprecht) Kuzeneva or *Betula platyphylla* Suk. on the hillslope gradually from competition to integration, gradually form mixed forest. And in

the mixed forest, *Betula platyphylla* Suk. is the dominant species in high altitude area, while *Larix gmelinii* (Ruprecht) Kuzeneva species are dominant in low and medium altitude areas.

Different vegetation and communities have their fixed distribution areas, which can be directly seen from CCA species ordination of the study area (Fig. 4) and TWINSpan classification results superimposed on CCA (Fig. 5). The variance of the two CCA axes was 15.9%. These low values can be attributed to high noise levels typical of species-abundance data (Ter Braak 1986). Furthermore, in order to test the significance of the environment variables, the eigenvalues of CCA and DCA are compared. The results show that the eigenvalues of the CCA axis are lower than those of DCA, indicating that important explanatory site variables were not fully included in the analysis. On this point, most scholars agree on the interpretation of Palmer (1993) and (Vogiatzakis et al. 2003). CCA is an interpretative technology, which aims to separate subsets of environmental factors, to explain relevant gradients in several dimensions. Therefore, because it is a constrained ordination technology when additional environmental variables are used, the interpretable variables will increase.

#### 4.3 Vegetation dynamics

It is generally believed that the mixed forest is superior to the single stand in terms of productivity, ecological function and stability (Xu et al. 2020; Zhou et al. 2020). In boreal forests, Shanin et al. (2014) showed that the tree species composition in the succession process of different stands depends on the site fertility and the initial proportion of tree species, and in the *Betula-Pinus* mixed forests, the proportion of *Pinus* trees increased in the poorer soils and decreased in the fertile ones. Taking into account the forest history in northern China, some scholars infer that the extension of *Betula* forests will increase but not the *Pinus* ones in future scenarios (Wang et al. 2017). However, in the Chongli area, the composition of the two main tree species varies with the altitude. This could be mainly affected by the initial proportion of tree species and soil fertility at the initial stage of afforestation. As shown in Table 4, the content of organic matter closely related to soil nutrients reaches the highest value (9.7±2.1)% below 1700 m, which greatly increases the survival rate of artificial afforestation. In addition, the current afforestation

from low areas to the plateau and the principle of operability, the altitude of 1700 m became the dividing line of afforestation. Above this critical line, the initial density and survival rate of this plantation decreased with the increase of altitude. Therefore, in areas below 1700 m altitude, the *Larix gmelinii* (Ruprecht) Kuzeneva plantations would tend to migrate to the shoulders and squeeze the living space of *Betula platyphylla* Suk. natural forests, dominating in the mixed zone gradually. However, in areas above 1700 m altitude, the opposite can occur. While facing the competition of other community species, *Betula-Rosa* community also experienced the competitive succession of understory vegetation within the community. Teixeira et al. (2020) in the Atlantic forest demonstrated that forest age is the key factor of community succession, and the recovery rate of soil function is often faster than that of aboveground vegetation, because of the rapid recovery of soil function at the beginning of succession. This improves soil moisture and nutrient status and promotes the germination and growth of new species (Chua and Potts 2018; Qiu et al. 2018). This is consistent with the growth status of aboveground vegetation of *Betula-Rosa* community (the prediction of forest age by DBH and tree height) and soil nutrient status (mainly refers to the content of soil organic matter). An obvious example of species transformation, such as the transformation of *Rosa xanthina* Lindl. into *Corylus mandshurica* Maxim. and other shade-resistant transitional vegetation. Therefore, *Betula-Rosa* community prepared for the next succession stage under the coexistence of external pressure and internal driving force.

The growth potential of specific community vegetation is mainly limited by climate and other related environmental factors (Kucsicsa and Bălțeanu 2020). However, in recent years, with the enhancement of human activities and land-use intensity, natural regeneration and soil properties are prevented (Stöhr 2007; Yu et al. 2017). The present upper forest limit is less than the potential limit (Holtmeier and Broll 2007). In the Chongli mountain area, the growth potential of the *Armenia-Poa* community, which is dominated by low shrubs and herbs, is far from fulfilling its growth potential below 1500 m altitude. It is affected not only by land use and site conditions, but also by serious human disturbance. Therefore, barren tolerant herbaceous

plants are dominant in the *Armenia-Poa* community, and a small amount of *Armeniaca sibirica* (Linn.) Lam. grows in some areas. Here, we mainly discuss the alpine meadow community with *Pteridium-Juncus* community type. We find that the transition species such as *Pteridium aquilinum* (Linn.) Kuhn var. *latiusculum* (Desv.) Underw. ex Heller, *Juncus effusus* Linn. and *Galium linearifolium* Turcz. are dominant in the community (van der Knaap and van Leeuwen 1995; Oh et al. 2010) with the increase of altitude, the dominant position of these transitional species is more obvious. This is very similar to the transitional type of arbor community (*Betula-Rosa* community) in this area, only existing in high altitude areas. From soil nutrients and physical properties, soil organic carbon increases with the increase of altitude, and the bulk density of surface soil decreases with the increase of altitude. Both of these soil properties play an important role in driving the succession of vegetation communities. Therefore, we suppose that the community succession in this area occurs from the top to bottom in terms of soil and vegetation, which is not only determined by the perennial accumulation of soil organic carbon and the internal driving force of soil microbial community transformation on vegetation succession (Shao et al. 2019), but also the artificial disturbance of afforestation activities and land use patterns. This also plays an important role in the speed and direction of community succession.

To sum up, the succession law of the *Betula-Rosa* community and *Pteridium-Juncus* community in high altitude area is earlier than that in low altitude area. We do not rule out that the influence of human factors is greater than that of climatic factors and biological factors in low altitude areas. The initial stage of artificial afforestation has made a great contribution to vegetation restoration and biodiversity restoration in this area. However, the influence of artificial afforestation may hinder the succession speed and direction of original secondary communities in a certain altitude range, which is especially obvious in the mixed forest belt with a medium altitude gradient. It would be necessary to repeat this assessment after the Winter Olympic Games to see if big events can modify this trend or not.

#### 4-4 Uncertainty of the relationship between environment and vegetation

In this paper, in addition to the influence of

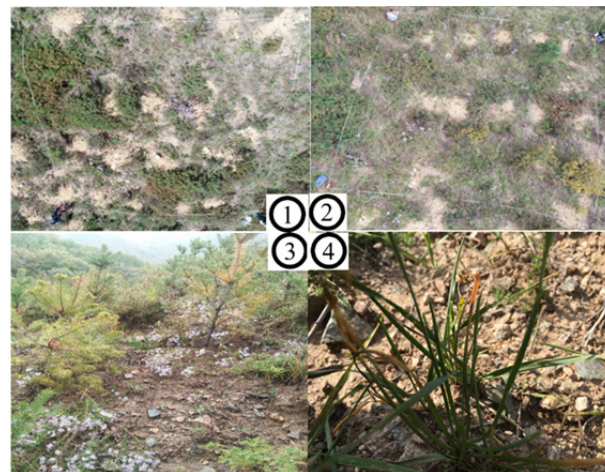
topography and geomorphology on the distribution of ecosystem vegetation community, environmental variables (including rainfall, surface temperature, soil moisture) under the influence of climate should not be underestimated (Giaccone et al. 2019). The aspect is related to microclimate (aspect is indirectly related to solar radiation, solar radiation affects temperature and humidity), but no reliable precipitation and surface temperature data in the Chongli mountain area, so it is excluded that other climate data can be included in the ordination. However, further research on the influence of climate factors in the region will be carried out in the future.

In addition, although the inclination is measured and analyzed as a topographic factor, it has a low correlation with ordination axes. On the other hand, due to the time difference of weather, the soil moisture content of each plot cannot be quantified at the same time. Therefore, the two environmental factors are not considered in the model generation. Grazing also has a certain impact on the plant diversity and richness in mountain areas, but this area benefits from the policy of returning farmland to forest and grazing to grass (Pulido et al. 2018). The forest and grassland in the mountain area are in a natural growth state in the past 20 years, so the threat of grazing on vegetation species can be ignored.

## 5 Conclusions and Final Remarks

This research considers the floristic composition of vegetation in Chongli district, the core area of the 2022 Winter Olympics, which is affected by the change of topography and land uses for thousands of years. During the Winter Olympic Games, human disturbances (including venues, tracks and roads construction) will be further intensified. The early construction of the venue areas has caused serious damage to the surrounding vegetation communities. This strong interference will further expand the scope and extent of its influence with the construction of the rest of the infrastructures during the events. In terms of the community types disturbed, at present, the negative effects mainly occurred in the grassland communities (i.e. *Pteridium-Juncus* and *Spiraea-Artemisia* community) which were more sensitive to human disturbance (Fig. 6). Furthermore, because the community with more pioneer species (i.e. *Armenia-Poa* community) has good resilience, it can return to its

original state in one or two years after serious human disturbance. Therefore, the resistance of vegetation restoration will not be limited to the grassland communities below 1400 meters, but also the grassland and even arbor communities above 1400m in the middle and high altitude areas. Moreover, how to strengthen the stress resistance of the vegetation community, and how to build and restore the vegetation community quickly after the major event is the problems that we need to solve urgently. The managers of this area (especially Chongli district, the core area of the Winter Olympic Games) need to have a detailed understanding of the floristic composition and ecological distribution of the vegetation communities, which not only provides the basis for vegetation monitoring and mapping, but also helps to assess the impact of human disturbance (construction of venues, tracks and roads, etc.) on the vegetation communities, and provides instructive opinions for promoting the ecological restoration and construction after the Winter Olympic Games at 2022.



**Fig. 6** Large number of bare ground and soil surface gravels on the slopes of shrub and herb sampling plots below 1400 m (1 and 2 are aerial photos, and 3 and 4 are close shots).

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