SPATIAL VARIABILITY OF PLANT FUNCTIONAL TYPES OF TREES ALONG NORTHEAST CHINA TRANSECT

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Abstract. Studying the spatial variability of plant functional types at large scale is important to understand the effects of environmental change on ecosystems. Here we classified the tree species in the forest area of Northeast China Transect (a middle-latitude transect and its environmental gradient was mainly driven by moisture) into three plant functional types (PFTs): drought tolerant, drought intolerant and middle type PFTs. We found that the average percentage of the drought intolerant and middle type of PFTs both increased significantly from 1986 to 1994. The drought tolerant and middle type of PFTs increased their covered areas at the western part of transect, but the covered area of the drought intolerant PFTs decreased about 48% at the western part. The dominance of the drought intolerant PFTs decreased while the dominance of the other PFTs increased. The net increments of these three PFTs were higher at 0–220 km than at 220–400 km. The negative net increments concentrated mainly at 150–350 km. The spatial autocorrelation of the drought intolerant and middle type of PFTs changed slightly from 1986 to 1994. The information entropy of the drought intolerant PFT increased across all scales and it indicated that impact from local disturbances was limited. All these indicate that the drought intolerant PFTs is vulnerable to the current environmental change. The spatial variations of different PFTs at large scales were mainly caused by the fluctuations of gradient of annual precipitation along this transect.
Keywords. *Northeast China Transect, plant functional type, precipitation gradient, spatial variation, tree species*

Introduction

Plant functional types (PFTs) can be defined as a group of species sharing the same response to a perturbation [14]. Recent research indicated that the climate change will affect the spatial distribution of PFTs and their relative abundances [13, 25]. Comparison of the spatial distribution and its change for PFTs at a large area may help us to determine the general patterns of vegetation change as a consequence of environmental change.

Northeast China Transect (NECT) is identified as a middle-latitude transect for terrestrial ecosystem studies by the Global Change and Terrestrial Ecosystem (GCTE) (*Fig. 1*) [17]. Because this transect is parallel with latitude, its environmental gradient is mainly driven by moisture. In fact, the annual precipitation decreases from as high as 800 mm in the east to 100 mm in the west. Detecting the change of spatial characteristics of tree species under precipitation gradients would be helpful to study species dynamics in a large region under environmental change. Although some spatial characteristics and change of tree species, such as geographical distribution and frequency, have been studied [5, 7], the response of each individual species may severely restrict our ability to assess the possible vegetation change at large area. Aggregating species by shared traits into PFTs is a common methodology for linking properties of species level to environmental factors at large spatial scale [3, 11].

Figure 1. *The location of Northeast China Transect (NECT).*

The change of PFTs in ecosystem would alter ecosystem functions (such as biogeochemical cycles, invasion resistance and stability in the face of disturbance) [20]. Prediction of the sensitivity of plant biogeography to climate dynamics and concurrent effects on ecosystem function is a pressing issue in global change science [26]. The aims of this research are (1) to compare the spatial distribution pattern and its change for each PFTs from 1986 to 1994 by using spatial analysis methods; (2) to study the relationships of different PFTs; (3) to find the possible causes for the change of vegetation along NECT; and (4) to assess the possible vegetation change along NECT under the environmental change.

Materials and methods

Study area

In this research, we chose the study area at approximately 125–130ºE and 43.55ºN. The data set was selected from the plot records conducted every 4 km in 1986 and 1994. The area of each plot was 30×30 m^2. These plots are permanent and are protected by local agencies. The information of each plot was used to represent the forest structure in this corresponding area. The total length is about 400 km. The main tree species in the forest area along NECT are *Betula platyphylla*, *Abies nephrolepis*, *Tilia* spp., *Betula costata*, *Betula dahurica*, *Juglans mandshurica*, *Phellodendron amurense*, *Fraxinus rhynchophylla*, *Populus davidiana*, *Ulmus pumila*, *Quercus mongolica*, *Pinus koraiensis*, *Acer mono*, *Fraxinus mandshurica*, *Picea* spp., and *Larix olgensis*. Other information about this research area can be found in [4, 5, 7].

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Methods

An integrated classification of PFTs was used in this study based on species' ecophysiological and morphological characters. This classification method proved successful to study the possible response of this ecosystem after the change of species composition [8, 9]. Three types of PFTs were classified in this research (*Table 1*), and they can be simply described as drought tolerant, drought intolerant and middle type PFTs. The relative percentage of each PFTs and the net increment ratio (λ) were calculated by their abundances and change, respectively. If one PFTs appeared in one plot, then this PFTs covered this corresponding area.

Table 1. *Classification of plant functional types (PFTs)* [8, 9, 12]

PFT	included species	growth character	drought tolerance	shade tolerance	morphological character	occurring stage of succession
drought tolerant	*B. platyphylla*, *B. dahurica*, *P. davidiana*, *U. pumila*, *Q. mongolica*, *L. olgensis*	fast	higher	shade intolerant	mostly deciduous, broadleaved, only *L. olgensis* coniferous	early stage
drought intolerant	*A. nephrolepis*, *P. koraiensis*, *Picea* spp.	very slow	low	very shade tolerant	coniferous	late stage
middle type	*Tilia* spp., *B. costata*, *J. mandshurica*, *P. amurense*, *F. rhynchophylla*, *Acer mono*, *F. mandshurica*	middle	middle	middle shade tolerant	broadleaved	middle stage

The spatial scale of autocorrelation was computed by GS^{+TM}5 (Gamma Design Software, USA) for each PFTs in 1986 and 1994 by Moran's I. The Moran's I statistic is a conventional measure of autocorrelation. With Moran's I, higher values indicate strong spatial correlation. The Moran's I in this study is defined as [24]:

$$I = \frac{\sum_{i}^{n}\sum_{j\neq 1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i}^{n}\sum_{j\neq 1}^{n} w_{ij}}, \quad \text{(Eq. 1)}$$

where I is the measure of autocorrelation; n is the total number of samples; x_i and x_j are the observed values of the sample at site *i* and *j*, respectively; $\bar{x}$ is the average of *x*; S^2 is variance. w_{ij} is a symmetric weight matrix; in this study, w_{ij} is 1 if location *j* is within distance *d* from *i* or 0 otherwise.

The dominance of each PFTs, D_i, which was calculated at every location according to the following:

$$D_i = \sum n_i \frac{(n_i - 1)}{N(N - 1)}, \quad \text{(Eq. 2)}$$

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where n_i is the abundance of *i*th PFTs, and N is the total abundance of all PFTs at each location [23].

The data from each plot was combined into data set of scales in 4, 8, 16, 20, 40 and 80 km by pooling of contiguous quadrates along the transect. The Shannon entropy $H_\varepsilon(x)$ of each PFTs at different scales of ε was calculated as the following [21]:

$$H_\varepsilon(x) = \sum p_\varepsilon(x)\log_{10} p_\varepsilon(x), \qquad \text{(Eq. 3.)}$$

where $p_\varepsilon(x)$ is the probability of observing PFTs x at the *i*th patch element measured using samples of ε units in size.

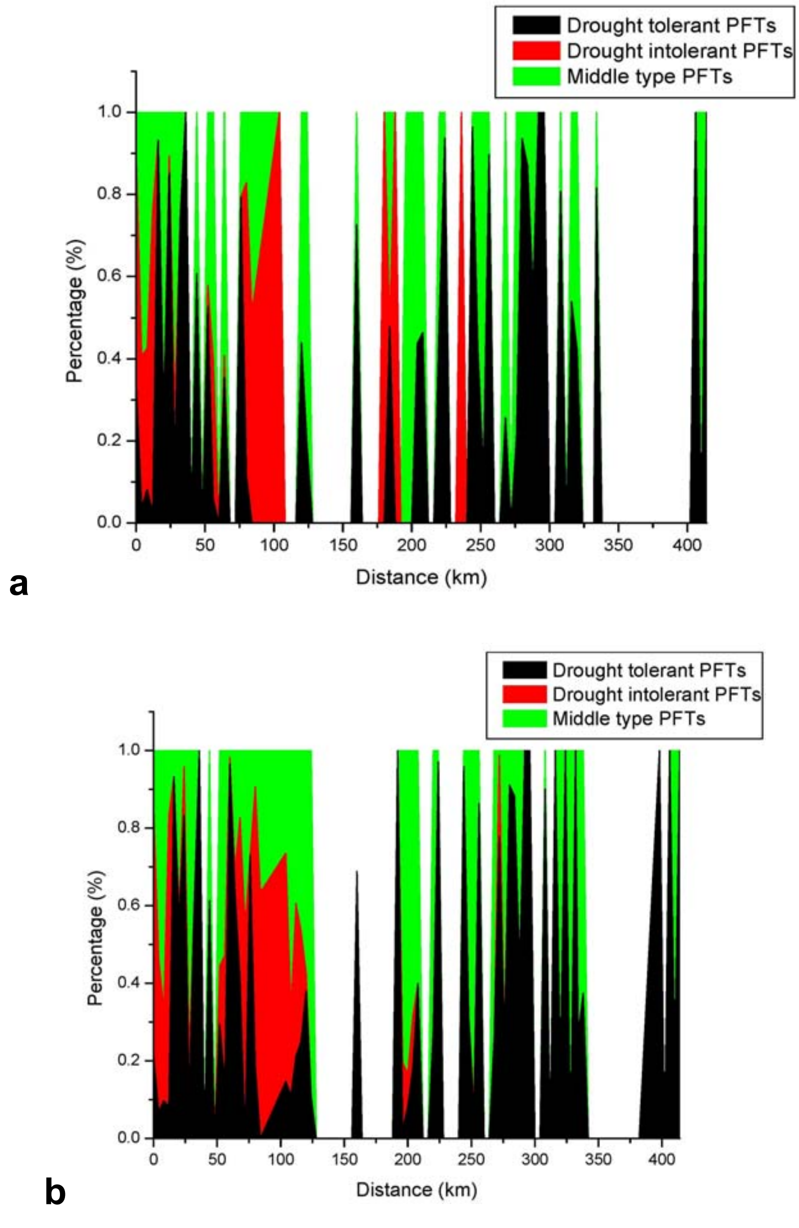

Figure 2. *The percentage of covered area of three plant functional types (PFTs) along NECT in* a: *1986 and* b: *1994*

The interactions among PFTs were estimated by Taylor's power, which describes the PFTs-specific relationship between the temporal or spatial variance of PFTs and their mean abundances. The negative interactions among species in a community can decrease slopes of Taylor's power law [18]. In this research, the slope of log (mean abundance) and log (variance) of each PFTs in 1986 and 1994 was estimated along NECT. The results of each PFTs were compared between 1986 and 1994.

Climate information was collected from about 14 meteorological stations at or near this study area and was interpolated by Kriging of GS^+. The gradient (G) of annual precipitation at distance i was estimated by $G_i = P_{i+n} - P_n$, where P_n and P_{i+n} are the annual precipitations at location n and next location $i+n$.

Results

Spatial distribution patterns of PFTs in 1986 and 1994

On the whole research area the average percentages of the drought intolerant and middle type PFTs increased significantly ($p<0.05$) from 1986 to 1994, respectively, but the percentage of the drought tolerant PFTs changed not significantly ($p>0.05$) (*Fig. 2a* and *b*). For both the drought tolerant and middle type PFTs there was a higher covered area at the western part of transect (150–400 km) than the eastern part (0–150 km). For the drought intolerant PFT there was a higher covered area in the eastern part than that at the western part. This overall distribution pattern for each PFTs was not changed significantly during the time period from 1986 to 1994, but the covered area changed at different parts of NECT. For the drought tolerant PFTs the covered area increased about 25% and 27% at the eastern part and the western part, respectively. For the drought intolerant PFTs the covered area increased about 17% at the eastern part, but it decreased about 48% at the western part. For the middle type PFT the percentage increased about 6% and 23% at the eastern and western parts, respectively.

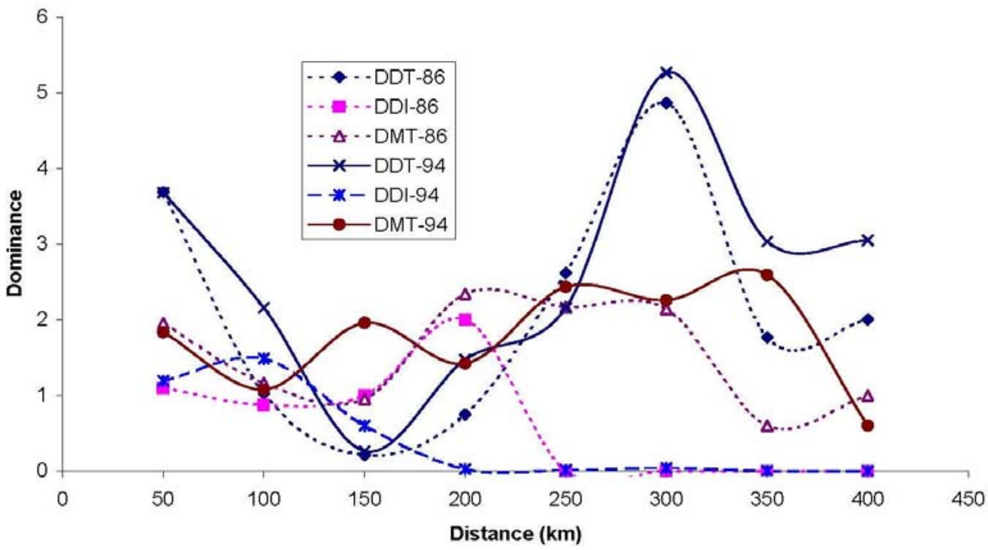

Figure 3. *The dominance of three PFTs along NECT (DDT-86: dominance of the drought tolerant PFTs in 1986; DDI-86: dominance of the drought intolerant PFTs in 1986; DMT-86: dominance of the middle type PFTs in 1986; DDT-94: dominance of the drought tolerant PFTs in 1994; DDI-94: dominance of the drought intolerant PFTs in 1994; DMT-94: dominance of the middle type PFTs in 1994).*

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The total dominance along transect of the drought tolerant and middle type PFTs increased from 16.92 and 11.31 to 21.07 and 13.47, respectively, but the dominance of the drought intolerant PFTs decreased from 4.97 to 3.35.

The dominance of the drought tolerant and middle type PFTs increased at the most parts of this transect (*Fig. 3*) while the drought intolerant PFTs decreased from the distance about 150 km.

There was net increment (λ) of each PFT in the research area (*Fig. 4*). There were higher net increments for all PFTs at 0–220 km than those at 220–410 km. On average the drought tolerant PFT had a slight higher λ ($\lambda = 1.52$) than that of the drought intolerant ($\lambda = 1.29$) and middle type PFTs ($\lambda = 1.15$). Negative λ concentrated around 150–350 km.

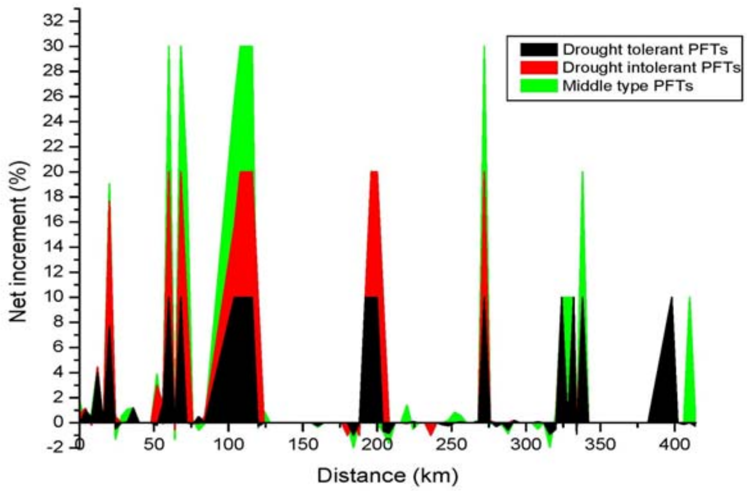

Figure 4. *The net increment (%) of three PFTs along NECT from 1986 to 1994.*

Spatial autocorrelation of each PFT in 1986 and 1994

The change of spatial autocorrelation for each PFTs from 1986 to 1994 was shown in *Fig. 5*. For the drought tolerant PFTs the pattern of spatial autocorrelation changed very little. For the drought intolerant PFTs there was a slight increment in the distance of spatial positive autocorrelation. For the middle type PFTs the positive autocorrelation decreased at 0–60 km, but it increased near 160 km.

The information entropy increased across scales for the drought intolerant PFTs from 1986 to 1994 while the other PFTs changed little (*Fig. 6*). The increase of information entropy of drought intolerant PFTs might be related its irregular spatial distribution change. This indicated that the spatial variability of drought intolerant PFTs was not mainly caused by local disturbances (such as windbreak) because information entropy increased at all scales. The local disturbances might cause change in PFTs at small scales. If change of land use occurred, then not only one of PFTs would change but all PFTs would be destroyed.

Interactions among three PFTs

The interactions among three PFTs were not statistically significant (*Table 2*), which might mean that the spatial variation of each PFTs was mainly due to environmental factors.

Table 2. *The slope of log (means of abundance) and log (variances of abundance) for each PFT in 1986 and 1994*

year	drought tolerant PFTs	drought intolerant PFTs	middle type PFTs
1986	3.31±1.11	0.33±0.09	0.33±0.27
1994	2.29±0.96	0.47±0.13	0.24±0.13

Discussion

Classification of plant functional types

The complexity of each species' response to environmental change can be obviously reduced by treating a smaller number of PFTs. Experience indicates that this grouping can work well for specific ecosystems but that the groups often have characteristics unique to the ecosystem under consideration [28]. The classification of PFTs is case specific, and there is no classification of plant function types which can meet criterion for all different researches [19]. The assumption which it is now generally agreed is that functional types must be defined by reference to both demographic criteria and those features of life history, physiology and biochemistry that determine the responsiveness of plants to soils, land use and climatic factors [16]. In this study, the classification of PFTs is largely based on their integrated drought tolerance because the environment gradient of NECT is mainly driven by moisture. The ecophysiological and morphological characters and the life history of each tree species, such as the occurring times during the succession, were used to qualitatively classify its drought tolerance. This classification was successful to study the possible response of this ecosystem after deleting or adding different species [8, 9].

Spatial variations of PFTs along NECT

The spatial variation of different PFTs at large scales can be used to indicate environmental change, such as soil moisture [1]. The local disturbances mainly occur at small scales and are impossible to change the spatial distribution of all PFTs across all scales. There were spatial variations for PFTs in the study area from 1986 to 1994 although the whole pattern was not totally changed from 1986 to 1994. There were higher covered areas in the eastern part than at the western part for the drought tolerant and middle type PFTs. The average percentage of the covered area increased significantly for the drought intolerant and middle type PFTs, also the covered areas changed at the different parts of the study area. In the eastern part the covered areas for all three PFTs increased, but at the western part the covered area of the drought intolerant PFT decreased while it increased for the drought intolerant and middle type of PFTs.

The dominance of the drought intolerant PFTs also decreased from the distance around 150 km, but the dominance of the other PFTs increased. Because the drought intolerant PFTs are tend to live at moisture area, and the drought tolerant PFTs are tend to grow at relative drought condition, the decreasing of the drought intolerant PFTs and increasing of the drought tolerant PFTs might indicate drought conditions at the research area. The drought intolerant PFTs may be vulnerable at the current climate change. The increase or decrease in the percentage of covered area and the dominance of each PFTs was mainly caused from its change in net increment. The negative net increment of three PFTs occurred mainly at 150–350 km. PFTs are strongly linked to climatic gradients [2]. The change of temperature in this area is not significant, but the change of precipitation has been dramatical in recent decades [7]. The spatial change of PFTs was mainly related with the high fluctuation of the gradient of annual precipitations in this area (*Fig. 7*). The change of precipitation gradient occurred mainly at the distance beyond 200 km. Because of the time delay in the response of tree species, the observed spatial variability of PFTs might be the result of the fluctuation of precipitation gradient along NECT for a long time. Changes in the frequency of very high temperature events may indirectly influence the relative abundances of different PFTs and for plant migration across the landscape at the regional scale [15]. Different PFTs in the arid area of NECT had different relationships with climate [22].

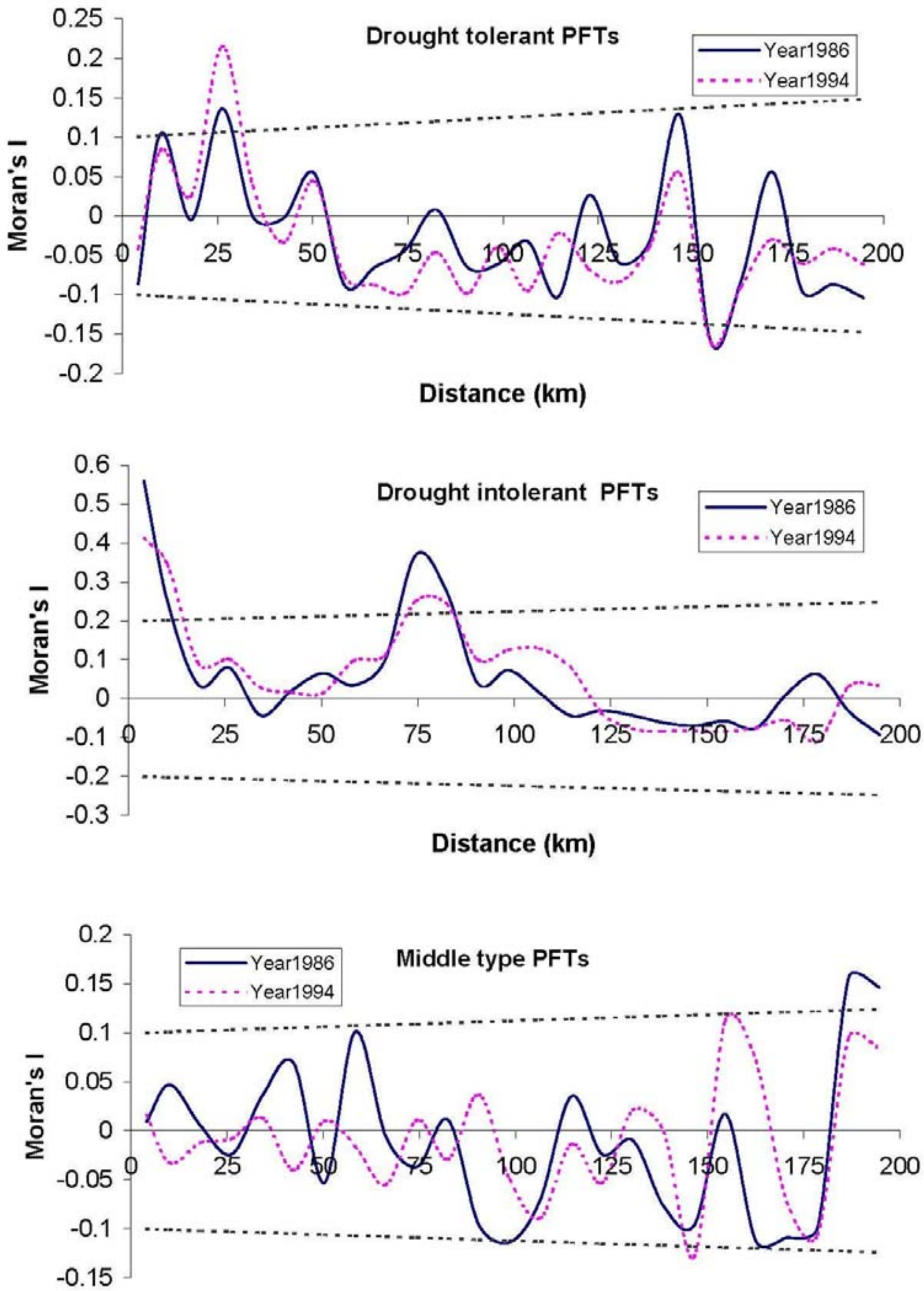

Figure 5. *Comparison of the spatial autocorrelation of three PFTs in 1986 and 1994 (outside of the two straight lines is 95% confidence area).*

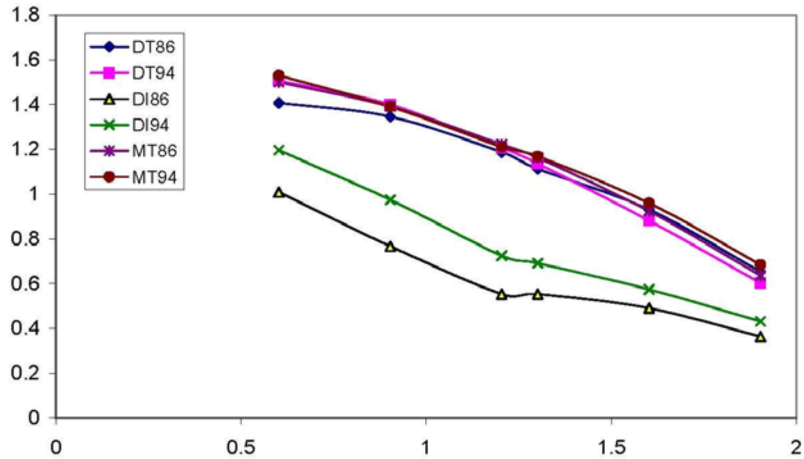

Figure 6. *Change of the information entropy across scales for each PFTs (DT: drought tolerant PFTs; DI: drought intolerant PFTs; MT: middle type PFTs)*

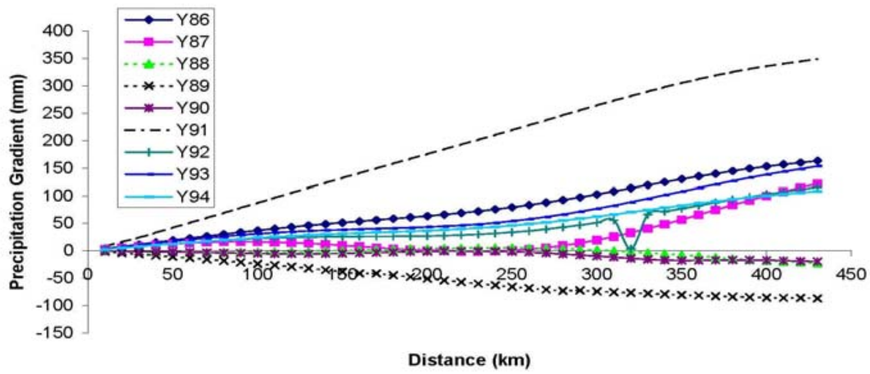

Figure 7. *The precipitation gradient at different distances at NECT from 1986 to 1994 (Y86, Y87, Y88, Y89, Y90, Y91, Y92, Y93 and Y94: Year of 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993 and 1994)*

The spatial autocorrelation was used to study the spatial distribution pattern of each PFTs. Only the drought intolerant and middle type PFTs changed in their distances of spatial positive autocorrelation. The increase of information entropy of the drought intolerant PFTs across scales indicated that climate, especially the fluctuations of precipitation gradient, might be the main factors to impact the spatial distribution of PFTs. This result is consistent with that *P. koraiensis* would be replaced by *Q. mongolica* under climate change and increased concentration of CO_2 [5], and the current broadleaved Korean pine forest is not ecological safety [6]. In principle entropy method is applicable to ecological research at landscape [21].

The possible causes for spatial variations of PFTs along NECT

This study indicated that interaction change among three PFTs was not significant. The effect from change of biological competition or ecological succession might be limited. The local disturbances were not possible to cause the spatial distribution change of some PFTs at large scales; and the change in land use might destroy all PFTs at one area instead of just replacing some kinds of PFTs. The distance of spatial autocorrelation would be decreased if there were strong local disturbances. Therefore, the spatial variation of each PFTs was

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mainly due to the fluctuation in the gradient of annual precipitations although it might be complicated by time delay in the response of tree species. The global climate change would change the regional climate [10], and this change would enhance the gradient of environmental factors and eventually change vegetation structure and distribution.

Conclusion

By analyzing the spatial pattern of PFTs of tree species along NECT with spatial analysis methods, we found the different spatial variation of three PFTs. From 1986 to 1994 the average percentages of the drought intolerant and middle type PFTs increased significantly along NECT. All three PFTs increased their covered area at eastern part of transect, and the drought tolerant and middle PFTs also increased their covered area at the western part of transect, but the covered area of the drought intolerant PFT decreased at 48% at the western part. The dominance of the drought intolerant PFT also decreased. Such decrease of the drought intolerant PFTs could be a signal of vulnerability to the occurring environmental change. There were higher net increments for all PFTs at 0–220 km than at 220–400 km and the negative net increments concentrated at 150–350 km. The spatial autocorrelation of the drought intolerant and the middle type PFTs changed slightly from 1986 to 1994. The impact from local disturbances was limited because of the increased spatial autocorrelation and the increased information entropy of drought intolerant PFT across large scales. The effect of interaction changes among three PFTs to their spatial variation was also limited. The spatial variation of PFTs was mainly caused by the fluctuation in the gradient of annual precipitation along this transect.

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