Spatial Patterns of Floristic Transition and the Biogeographical Implication in East China

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Abstract: Geographical patterns of organisms are key points in Biogeography. East China is an ideal place to explore spatial patterns of floristic transition with highly rugged mountains and great span in latitude. This study quantitatively investigated floristic transition's correlation with altitude, latitude and mean annual temperature based on documented information of flora and climate data from 15 study sites. In addition, we tentatively defined the floristic boundaries between major vegetation types. The results indicated that the ratios of tropic to temperate flora negatively correlated both with altitudinal and latitudinal gradients. Elevation where any given floristic transition occurred decreased against latitude when floristic transition was controlled, implicating energy requirement of any given floristic transition. Both altitude and latitude significantly shaped the geographical patterns of floristic transition, and its magnitude was obtained reliably through a regression model combining altitude and latitude. Floristic transition was strengthened first, and then decreased against mean annual temperature. Floristic boundaries between such pairs of vegetation types as rain forest and southern sub-tropical evergreen forest, northern sub-tropical evergreen forest and warm temperate deciduous forest, mixed needle-broad-leaved forest and temperate needle forest were tentatively assumed as floristic transition which was completely occupied by tropical elements, deuced by tropical elements and temperate elements, and entirely took up by temperate elements, in this order. Based on correlation between floristic transition and mean annual temperature, latitudinal boundaries of such pairs of vegetation types as rain forest and southern sub-tropical evergreen forest, northern sub-tropical evergreen forest and warm temperate deciduous forest, mixed needle-broad-leaved forest and temperate needle forest, were around 22.2° N, 34.5° N and of 47.6° N, with mean annual temperature around 22.70℃, 12.66℃ and 2.62℃, respectively. It supported the previous studies, and proposed a new idea and method in probing the zonation of vegetation.

Key words: floristic transition; biogeographical implication; spatial patterns; mean annual temperature; vegetation zone; East China

1 Introduction

A central goal of Biogeography and Ecology is to uncover and understand distribution patterns of organisms[1]. East China traverses 35 latitude degrees and covers various climate zones from north to south, and also we can observe a wide range of vegetation types, including tropical, subtropical, temperate and boreal forests along the latitudinal gradients[2]. In addition, there are huge altitudinal gradients in East China, ranging from sea level to more than 7,500 m, and it also holds complete vegetation spectrum in vertical gradients. Due to highly rugged mountain ranges, vast span of latitude and various climate zones, huge variation of floristic composition in geographical dimensions can be presumably predicted. Thus, East China is an ideal place to explore it.

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Flora (or florae) refers to all plant life occurring in an area or a time period, especially the naturally occurring or indigenous plant life. So, it's an interesting conception across time and space in Biogeography. In other words, flora implies essential information on plant's historical geographical distribution and evolution. Floristic transition, which means the inter-penetration between temperate and tropical flora and is expressed as the ratios of tropical to temperate flora (or its inverse), in some extents implicates the spatial variation of environmental factors and floristic composition of vegetation[3]. Thus, the investigation of floristic transition's spatial patterns and its biogeographical implication will throw bright light on floristic origin, distribution and migration. Nowadays, a major approach used to probe floristic transition in China was to group the taxa into two geographical types (tropical flora and temperate flora), according to a classification system compiled by Wu Zhengyi[4,5], in which genera of seed plants in China were grouped into 15 areal types (floristic types) based on the geographical range of taxa and floristic relationship between China and the rest of the world[4-6]. Peng (1996) examined the vertical patterns of flora in Mt. Wuliangshan at central Yunnan, China, and investigated the floristic equilibrium point (a particular case in floristic transition, a state when flora was equally shared by tropical elements and temperate ones) and its application in agricultural production[3]. Recently, Qian *et al* (2006) investigated the phytogeography of seed plant genera in China[7], and Zhu *et al* (2007) examined the biogeographical patterns of the genera of Chinese seed plants according to the Wu's classification system[8]. They found that variations in percentages of floristic elements of genera among the local flora strongly correlated with geographical and climatic factors[7,8]. More recently, Feng and Xu found (2008) that a latitudinal boundary dividing the vegetation in East China was obtained in terms of the biogeographical implication of flora equilibrium point and its correlation with mean annual temperature, and they also proposed that the study lent a new idea or method to investigate the North-south division boundary of vegetation in East China[9].

However, we observed that the previous studies didn't pay much attention to investigate the geographical patterns of floristic transition and its biogeographical implication. Until now, the relevant investigations in floristic transition have been mainly focused on flora equilibrium point[3,9]. Therefore, the aim of this paper was to examine the biogeographical implication of floristic transition and its relationship with geographical and climatic factors coupled with flora lists and climate data in literature.

2 Material and Methods

2.1 Data Sets

Flora information was collected from reports covering 15 study sites (Figure 1) as flollows: Mt. Jianfenglin in Hai- nan[10,11], Xishuangbanna and Nangunhe Nature Reserve in southern and southwestern Yunnan province[12], Mt. Yaoshan Nature Reserve in northeast Yunnan[13], Mt. Laoshan in Guangxi[14], Mt. Mangdang in Fujian province[15], Mt. Tianmu in Zhejiang province[16], Mt. Fodingshan in Guizhou province[17], Mt. Shengnongjia in Hubei province[18], Maojingba in Hebei province[19], Changqing Nature Reserve in Shannxi province, at central Qingling Mountains[20], Pangquangou National Nature Reserve in Shanxi Province[21], Mt. Xiaoqingling in Henan Province[22], Mt. Changbaishan[23] and Mt. Daxing'anling in northeastern China[24]. These sites covered most of vegetation types in East China. The climatic data from 1951 to 1980 was collected from 496 meteorological observation stations throughout China[25].

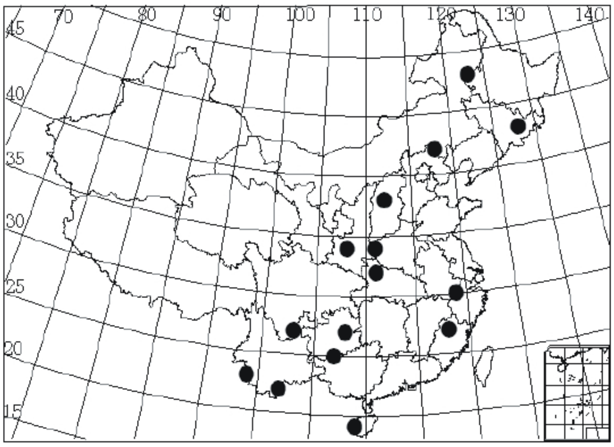

Figure 1. Location of the studied area

2.2 Data Analysis

Floristic elements were classified according to Wu's classification[1,5]. In terms of the Wu's classification system[1,5], tropical floristic types (T_{trop}) included "Pantropical"(T2), "Tropical Asia and Tropical America disjunct" (T3), "Old World Tropic" (T4), "Tropical Asia and Tropical Australia" (T5), "Tropical Asia to Tropical Africa" (T6) and "Tropical Asia (Indo-Malaysia)" (T7). And temperate floristic elements (T_{temp}) is composed of "North Temperate" (T8), "East Asia and North America disjunct" (T9), "Old World Temperate" (T10), "Temperate Asia" (T11), "Mediterranean, West Asia to Central Asia" (T12), "Central Asia" (T13) and "East Asia" (T14). In this paper, floristic transition was rendered as the ratio of the number of genera of tropic floristic types to that of temperate floristic types, or was abridged as T_{trop}/T_{temp}. The altitudinal pattern of floristic transition in each study site was calculated at the interval 100 m along altitudinal gradients. When T_{trop}/T_{temp} equaled to 1, floristic transition reached its maximum and meant the occurrence of floristic equilibrium point. When T_{trop}/T_{temp} equaled from zero to 1, it implied that floristic composition evolved from a state completely preoccupied by T_{temp} to floristic equilibrium point; when T_{trop}/T_{temp} equaled from 1 to infinity, it indicated that floristic composition developed from floristic equilib- rium point to a state predominated by T_{trop}. In order to fully reflect the magnitude of floristic transition, it must be noted that when T_{trop}/T_{temp} equaled from 1 to infinity, its inverse would be adopted. Hereby, floristic transition would not be greater than 1. In other words, the maximum of the floristic transition equaled to 1. Following the above methods, altitudinal patterns of floristic transition in each study site was calculated based on flora information from literature.

A regressive model was built with 30-years-averaged mean annual temperature (MAT) from records of 496 meteorological stations across East China and their geographical factors, including longitude, latitude and

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altitude. The model is rendered as follows:

$$MAT = 58.16 - 0.60 * Lat - 0.004 * Alt - 0.21 * Long \quad (R^2 = 0.97, P < 0.0001) \qquad (1)$$

The satisfied confidence (R^2 = 0.97, P < 0.0001) of equation (1) meant that MAT of 15 study sites across East China would be reliably estimated. According to equation (1), MAT on altitudinal gradients of each study site was predicted.

Another regressive model was built to show the floristic transition's correlation with altitude and latitude in terms of flora information and their latitude and altitude at 15 study sites. In the model, latitude and altitude was independent parameters, and T_{trop}/T_{temp} was dependent parameter. Then, we investigated the correlation between MAT and floristic transition based on MAT and floristic transition along the altitudinal gradients among 15 study sites. According to the floristic transition's correlation with MAT, we investigated three particular states of floristic transition (when T_{trop}/T_{temp} equaled to 1, T_{trop}/T_{temp} equaled to 0, and T_{trop}/T_{temp} equalled to infinity or T_{temp}/T_{trop} equaled to zero) and their biogeographical implications were tentatively interpreted. Above calculation and analysis were conducted with the help of SPSS (11.5), a widely accepted soft package in statistics. All figures in the article were done with Excel and CorelDRAW12.

3 Results

3.1 Correlation between T_{trop}/T_{temp} and Altitude, Latitude

According to partial correlation analysis between T_{trop}/T_{temp} and altitude, latitude among 15 study sites, T_{trop}/T_{temp} was negatively correlated both with altitude and latitude significantly (P < 0.001). It was consistent to the decreasing trend of energy along the altitudinal, latitudinal gradients and ecological characters of flora. As we would expect, T_{trop} preferred to warm environment and its proportion was decreasing with the increase of latitude and altitude; While T_{temp} was tolerant to cold climate and an increasing trend was observed. Based on floristic transition (T_{trop}/T_{temp}), latitude and altitude at each study site, a regressive model was built with high confidence (R^2 = 0.81, P = 0.0001, N = 165) (equation (2) and Figure 2). The model was rendered as following:

$$T_{trop}/T_{temp} = e^{(-0.157*Lat-0.002*Alt+10.13)}$$

(R^2=0.81, P=0.0001, N=165)

3.2 Relationship between Altitude and Latitude When Floristic Transition Was Controlled

According to the equation (2), when T_{trop}/T_{temp} was controlled, the relationship between altitude and latitude

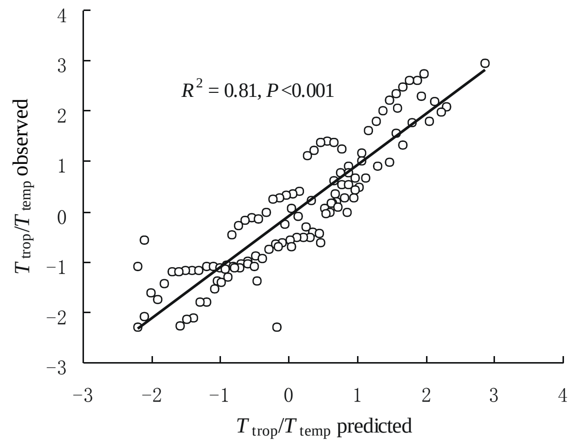

Figure 2. Comparison between T_{trop}/T_{temp} observed and predicted

was expressed as following formulation: Alt = A * Lat + B, in which the slope (coefficient A) was negative. In other words, when T_{trop}/T_{temp} was controlled, altitude where any given floristic transition occurred decreased with the increase of latitude.

3.3 Biogeographical Implication of Floristic Transition

Based on MAT and floristic transition among 15 study sites, MAT's effects on floristic transition were manifested by a regressive model as follows.

$$\text{Floristic transition} = e^{(-0.0187*MAT^2 + 0.4735*MAT - 3.4509)} - 0.1 \qquad (3)$$

(R^2 = 0.64, P = 0.0001, N = 165)

In equation (3), floristic transition was represented by T_{trop}/T_{temp} and if T_{trop}/T_{temp} was greater than 1, the inverse was adopted. It can be found that floristic transition showed significant correspondence to MAT (R^2= 0.64, P < 0.0001, N = 165) (Fig. 3). The floristic transition increased first, and then decreased against MAT gradients. In other words, when MAT was very low or high, the floristic transition was weak and floristic composition was predominated by T_{temp} or T_{trop}, respectively. But when MAT was moderate, the floristic transition was strong and was approaching to floristic equilibrium point where flora was equally shared by T_{temp} and T_{trop}. According to the equation (3), the MAT at intersection points A, B and C (Fig.3) were estimated, and they were 22.70℃, 2.62℃ and 12.66℃, respectively.

According to the floristic definition of vegetation zonation in Wu's classification system (Wu, 1980), biogeographical implications of floristic transition of the three points in Fig.3 were probed. Point A implied that when MAT was higher than 22.70℃, topical flora fully occupy the whole flora, and the corresponding vegetation was tentatively assumed as rain forest. Point B showed that when MAT was lower than 2.62℃, the flora was entirely dominated by T_{temp}, and cold temperate needle forests vegetation may be the corresponding vegetation. Point C (vertex of the parabola in Fig.3) indicated that when MAT was around 12.66, the flora was equally shared by T_{trop} and T_{temp}, and evergreen-deciduous broad-leaved forest was assumed. From point A to point C, it was assumed that the vegetations were subtropical evergreen broad-leaved forests, including southern subtropical monsoon evergreen forest, central subtropical evergreen forest and northern subtropical evergreen forest, respectively. From point C to point B, we tentatively assumed that the vegetations were temperate vegetations, including warm temperate deciduous broad-leaved forest, mixed needle-broad-leaved forest and temperate needle forest, respectively. Therefore, point A, B and C were assumed as the boundaries dividing such pairs of vegetation types as rain forest and southern monsoon subtropical evergreen broad-leaved forest, mixed needle-broad-leaved forest and cold temperate needle forest, mixed evergreen deciduous broad-leaved forest and warm temperate deciduous broad-leaved forest, and their MAT were 22.70℃, 2.62 ℃ and 12.66℃, respectively.

Also, According to the MAT around the intersection points in Fig.3 and the geographical patterns of isotherm in China[26], we found that the latitudinal boundaries dividing such pairs of vegetation types as rain forest and southern monsoon subtropical evergreen broad-leaved forest, mixed needle-broad-leaved forest and cold temperate needle forest, mixed evergreen deciduous broad-leaved forest and warm temperate deciduous broad-leaved forest were around 22.2^{o}N, 34-35°N and 47.6^{o}N, respectively, in East China.

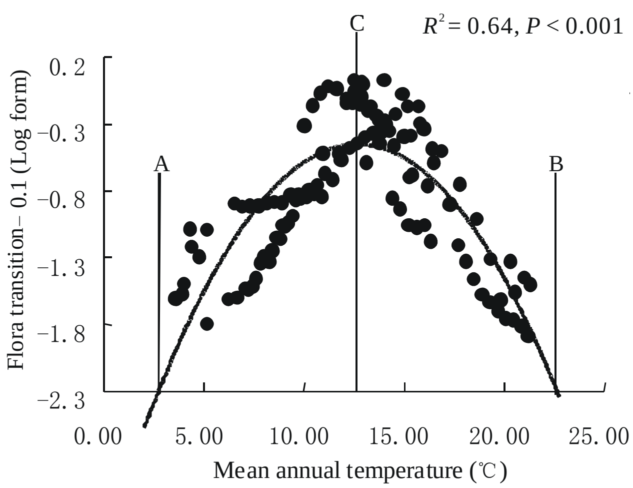

Figure 3. Correlation between MAT and floristic transition

4 Conclusions and Discussion

One of the cornerstones in our study was the identification of floristic elements according to the worldwide distributional ranges of the native taxa. However, there were various classification systems of floristic types in the world. In this paper, we adopted the Wu's classification system[1,5]. In the past, the Wu's classification system had been applied into the numerous studies, covering more than 400 regional, provincial and local areas across China[8]. Besides its application in China, the classification system also was adopted in the studies of the phytogeography of East Asia, including Japan, Russian Far East and the Korea peninsula[1]. Therefore, it was a widely accepted classification system of floristic elements, and may reliably identify distribution affinities among the floristic information in this study.

The results showed that the variation of floristic transition was explained by geographical factors and climatic factors (mean annual temperature). But we found that the amount of variation explained by geographical factors was more than that of climatic factors by 17%. It meant that geographical factors played much stronger roles in determining floristic transition than climatic factors. This may be in part because floristic elements were defined by their geographical range, rather than ecological distributions[7].

The results showed that when T_{trop}/T_{temp} was controlled, altitude where any given floristic transition occured decreasesd with the increase of latitude. What was the implication? In Ecology, the increase of latitude generally implied the decrease of energy in environment, while the decrease of altitude mainly indicated the increase of energy. So, we assumed that the decrease of altitude compensated the reduction of energy in environment induced by the increase of latitude. Therefore, when T_{trop}/T_{temp} was controlled, the decreasing trend of the altitude against the increase of latitude may suggest that the occurrence of any given T_{trop}/T_{temp} indicated certain energy requirement in environment. Recently, Feng and Xu (2008) found that the altitudes at floristic equilibrium points decreased against latitude, and MAT around floristic equilibrium points among 8 study sites didn't show any significant difference[9], which gave a evidence to support the result in this study.

Our study proposed the latitudinal and MAT's boundaries of major vegetation types in East China. It supported and refined Wu's classification and corresponded well with previously recognized boundaries dividing vegetation types, though methods in this study differed from them[2,27-29]. Recently, Zhu *et al* (2007) investigated the correlation between floristic elements and geographical, climatic attributes based on the flora lists across China through a way similar to this study, and got interesting conclusion[8]. Compared with that study, the boundary between rain forest and southern monsoon evergreen broad-leaved forest was further south by 0.3° latitude, which may be due to the different definition of floristic composition of rain forest. In Zhu's study, floristic threshold of rain forest was that the proportion of T_{trop} was greater than 80%[8]. But, in this study, floristic threshold of rain forest was constituted completely by T_{trop}, which may imply much more energy in environment and resulted in the further south of the boundary. Previous studies showed the threshold of MAT in rain forest was 20.℃ or 22℃ (Wu, 1980; Song, 1999)[2,27], while, in this study the threshold was around 22.70℃, which also may be attributed to different floristic threshold of rain forest.

Compared with the previous studies, we quantitatively investigated the relationship between floristic transition and geographical factors, MAT. It would be helpful to further our understanding in geographical patterns of flora and vegetation types. In the past, the zonation of vegetation had relied much on qualitative analysis of characters of plant species, ecological appearance and predominant species. However, in this study, the zonation of vegetation was mainly based on the quantitative analysis of floristic transition and its correlation with climatic factors, which may offer a new idea and method in the research of vegetation zonation.

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