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The biogeographical distribution of tree species-abundance and its relation to climatic factors in mass islands

LI Xiaoming[1], WU Chengzhen[2], GU Wu[1], YE Ran[3], ZHANG Haibo[3], QI Ping[1, 4], WANG Shengqiang[1], ZHOU Siying[3], WEI Yongjie[3], CAI Yanhong[3]*

[1] State Oceanic Administration , Beijing 100860, China

[2] Wuyi University, Wuyishan 354300, China

[3] Marine Environmental Monitoring Center of Ningbo, Ningbo 315012, China

[4] Marine Environmental Monitoring Center of Tianjin, Tianjin 300450, China

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Abstract

Tree species-abundance in forests is a function of geographical area and climate, although it is not clear whether such relationships apply to mass islands. We examined the spatial pattern of tree species in mass islands along the coast of Zhejiang, East China Sea using the Preston model, to identify the relationships between tree communities and climatic conditions. The results show that: (1) the biogeographical distribution of tree species-abundance conformes to Preston's log-normal pattern, and is in accordance with the findings in both tropical rainforests and estuarine forests; (2) the climatic factors related to tree communities in mass islands are similar to that of the subtropical zone, including the major species of evergreen needle-leaf, broad-leaf and deciduous broad-leaf forests. We conclude that the Preston model can be applied to the trees of mass islands and thus facilitate the systematic ecological researches of vegetation species' composition in subtropical zone.

Key words: mass islands, species-abundance, spatial pattern, log-normal model

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1 Introduction

There are more than 4 000 islands on the continental shelf of the East China Sea along the coast of Zhejiang, China, on which trees, shrubs and herbs are widely distributed with diverse abundance. The maximum length (north to south) and width (east to west) of these islands is 420 and 300 km, respectively. The areas of these islands range from 1×10^{-5} to 500 km^2. Most of them are within the 20 m isobaths and at elevations from 50 to 200 m, with the highest of 500 m.

In the last century, the pioneering studies of Williams, Preston, MacArthur, and Whittaker and colleagues sought to mathematically characterize the properties of biological communities and to interpret their spatial distribution patterns using a range of different mathematical models (see Brown, 1995). The study fields included terrestrial and aquatic ecosystems, from highvelds to forests (temperate, sub-tropical, tropical), often with a focus on plants, animals, and microbes. Consideration has been given to many relatively rare species and only a few very abundant ones. The study areas have been regarded usually as convenient ecological entities and /or considered as homogeneous in some intuitive sense, e.g., constrained to a taxonomic group (Pielou, 1975). Moreover, these studies have focused at the metacommunity level with the purpose of exploring the relationships between species and abundance.

Wu et al. (2001) and Li et al. (1996) all demonstrated that species abundance in subtropical zone accorded well with log-normal distributions using Preston Model. Given the fact that there were few researches on tree species-abundance and their relation to climatic factors in mass islands being carried out using mathematical approaches, in this study, we aimed to use Preston model to analyze the spatial pattern of tree communities and their response to climatic factors across clusters of islands.

2 Materials and methods

2.1 *Data sources*

Species data sets were derived from the "Investigations on Island Resources along Coastal Zhejiang Program" in the 1990s. Seven hundred and thirty five sampling plots, of 10 m×10 m, were randomly selected to investigate tree species composition and abundance. A range of climatic factors [i.e., mean annual temperature (T), mean temperature of the coldest month (Tc), annual precipitation (P), days above 10°C (D_{10}), active accumulated temperature ($\geqslant$ 10°C) (AAT_{10})] were recorded at each site (Fig. 1) by the Zhejiang Provincial Marine Environmental Monitoring and Forecast Centre (ZPMEMFC, 2010, unpublished data) during the period of 1971 to 2000.

2.2 *Data analysis*

2.2.1 *Log-normal distribution model*

The model was calculated using the following equation (Pre-

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*Corresponding author, E-mail: caiyh@eastsea.gov.cn

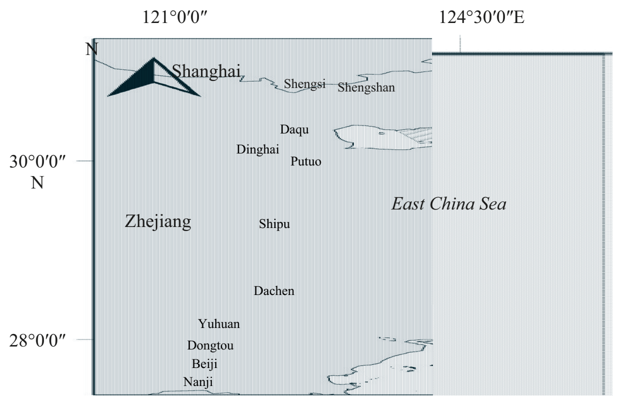

Fig. 1. Sampling sites for climatic factors. The shaded area referred to the mass islands across the whole study area.

ston, 1948):

$$S\,(R) = S_0 \exp\left[-a^2\,(R - R_0)\right], \tag{1}$$

where $S(R)$ is the number of species in the Rth octave from the model, S_0 is an estimate of the number of species in the modal octave, and parameter a is an inverse measure of the width of the distribution.

R is given by (Ludwig and Reynolds, 1988)

$$R = \log_2\left(\frac{N_i}{N_0}\right), \tag{2}$$

where N_i is the species abundance in the ith octave, and N_0 is the species abundance in the modal octave.

a is given by (Ludwig and Reynolds, 1988)

$$a = \sqrt{\frac{\ln S\,(0)\,/S\,(R_{\max})}{R^2_{\max}}}, \tag{3}$$

where $S(0)$ is the observed number of species in the modal octave, and $S\,(R_{\max})$ is the observed number of species in the octave most distant from modal (indicated by $R_{\max}$).

S_0 is given by (Ludwig and Reynolds, 1988):

$$S_0 = \exp\left[\ln \overline{S\,(R)} + a^2\overline{R^2}\right], \tag{4}$$

where $\ln \overline{S(R)}$ is the mean of the logarithms of the observed number of species per octave, a is estimated from Eq. (3), and $\overline{R^2}$ is the mean of R^2.

The theoretical number of species available for observation, S^* is given by (Preston, 1948)

$$S^* = \sqrt{\pi}\,(S_0/a), \tag{5}$$

where a and S_0 are calculated from Eqs (3) and (4), respectively. π stands for circumference ratio.

2.2.2 *Parameter estimation (PE)*

Parameters a and S_0 could be estimated via Eqs (3) and (4), respectively. Model fitting would then be carried out after adaptability tests.

2.2.3 *Genetic algorithm (GA)*

GA is an artificial intelligence approach which facilitates the estimation of global optimum via parameter optimization. The key parameters comprise the initial population, crossover rate, mutation rate and fitness function, etc. In this study, the initial value of the population was set as 100, with crossover rate of 0.4 and mutation rate of 0.5. The minimum value of residual sum of squares (RSS) of the significance test was applied to assess the goodness of the functions (i.e., convergence function).

3 Results and discussion

3.1 *Species composition*

A diverse range of 143 tree species were recorded, both deciduous and evergreen broad-leaf. These species belong to 48 families and, 101 genera, mainly in *Dalbergia*, *Albizia*, *Quercus*, *Liquidambar*, *Aphananthe*, *Pistacia*, *Cinnamomum*, *Platycarya*, *Ilex* and, *Cyclobalanopsis*. The whole study area is within the Eastern Asia zone (14SJ), and can be sub-classified into mixed (needle leaf and broad leaf) forest and evergreen broad-leaf forest of the world's temperate to subtropical zones (Wu et al., 2011). Therefore, the families, genera, and species in mass islands of Zhejiang coastal can be accommodated in the future modelling of global tree distribution patterns because of their biogeographical characteristics.

3.2 *Analysis of species-abundance*

Results of both the PE and GA are listed in Table 1 and two species-abundance curves fitted by Preston's lognormal model are also shown in Fig. 2. It is clear that tree species-abundance complied with a log-normal distribution pattern, which is methodologically available in the study area. Meanwhile, the simulation results show that $a_{\text{E.A.}} > a_{\text{P.E.}}$, $\sigma_{\text{G.A.}} < \sigma_{\text{P.E.}}$ $\left(a^2 = \dfrac{1}{2\sigma^2}\right)$ (Preston, 1962), and both $\chi_{\text{E.A.}}{}^2$ and $\sigma_{\text{E.A.}}$ of GA are lower than those of PE'. This indicates, that the precision of GA is higher than PE in terms of model fitting. Meanwhile, the theoretical number of species calculated by Eq. (5) of GA and PE simultaneously reached 176, suggesting that 33 species may not have been found during the fieldwork. Given the higher precision of GA, 33 missing species might be attributed to sampling strategy. Therefore, more attention should be paid in future to sampling scale and numbers in terms of sampling design for biogeographical studies in this region.

From the ecological perspective, once the community consists of a relatively large assembly of species, the observed distribution of species relative abundance, $S(N)$, is almost always lognormal (May, 1981). Regarding the sampling processes in mass islands, they are randomly designed, and the spatial patterns of these species are the products of stochasticity. Therefore, the observed and fitted values in this study indicate that the tree communities studied conform to known patterns that can be characterized by suitable environmental conditions, high richness, and uniform patterns.

3.3 *Analysis on species in relation to climatic factors*

The distributions of vegetation communities are affected by a many factors including climate, soil, topography, historical events, and anthropogenic-driven activity. Nonetheless, climate is viewed as the key factor (Qian et al., 1956) as it facilitates abiotic environment zoning assessment and lays the foundation for systematic research on insular vegetation ecology.

Table 1. Results of PE and GA

Octave	*R*	Observed	PE (a=0.142 0, S_0=14.058) Expected	PE χ^2	GA (a=0.150 1, S_0=14.857 6) Expected	GA χ^2
1	–4	5.5	10.179 9	2.151	10.361 9	2.281 2
2	–3	8.5	11.724 0	0.887	12.131 4	1.087 0
3	–2	13.5	12.968 3	0.022	13.577 5	0.000 4
4	–1	11	13.777 4	0.560	14.526 7	0.856 2
5	0	20.5	14.058 2	2.952	14.857 6	2.142 8
6	1	12	13.777 4	0.229	14.526 7	0.439 5
7	2	17	12.968 3	1.253	13.577 5	0.862 7
8	3	12	11.724 0	0.006	12.131 4	0.001 4
9	4	17	10.179 9	4.569	10.361 9	4.252 6
10	5	6	8.489 6	0.730	8.460 6	0.715 6
11	6	6	6.800 0	0.094	6.603 9	0.055 2
12	7	6	5.231 3	0.113	4.927 6	0.233 4
13	8	4	3.865 3	0.005	3.514 8	0.066 9
14	9	4	2.743 1	0.576	2.396 7	1.072 5
∑		143	138.487	14.148	141.956 2	14.067 4

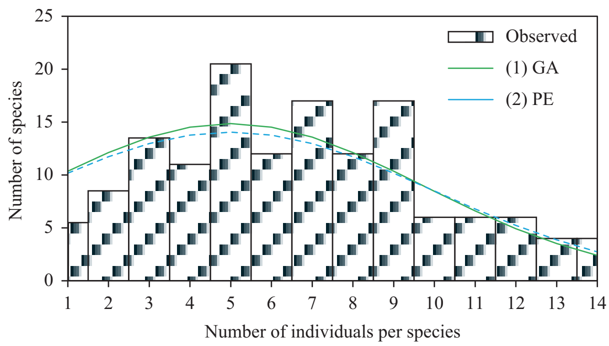

Fig. 2. Results of model fitting.

Given both the log-normal and stochastic distribution pattern of the whole study area, it could be inferred that all the tree species were influenced by similar climatic factors. The mean annual temperature only ranged from 15.6 to 18.1°C, the coldest temperature varied from 5.6 to 8.3°C, active accumulated temperature (above 10°C) spanned 4 758.0 to 6 100.4°C (236.9–274.3 days), annual precipitation extended from 1 001.0 to 1 442.5 mm (Table 2), and the frost period covered 1 to 28 days (ZPMEMFC, 2010, unpublished data). These environmental features are similar to those of evergreen broad-leaf forests in the mid-subtropical zone (Wu et al., 2011) and our study area thus accorded with the mid-subtropical zone in terms of climate regionalization (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (GAQSIQ), 1998).

Brown (1995) demonstrated that the majority of vegetation communities remain stable long-term and are characterized with spatial continuities and interspecies correlations without external disturbance. We also believed that tree communities in mass islands and adjacent lands remained stable over the long-term as there are considerable similarities between the vegetation communities of these areas. For example, there is 92.3%, 70.9%, 87.0%, and 86.3% genus level similarity between Zhejiang mass islands, and the adjacent mainland (Zhejiang Province and Jiangsu Province), Taiwan and Japan, respectively. This indicates that the floras, species compositions and distribution patterns of insular vegetation communities related closely with their surrounding circumstances (Chen et al., 1995). Therefore, mixed (needle leaf and broad leaf), deciduous and evergreen broad-leaf forests remained dominant in temperature and subtropical zones, respectively including common and relict species (Wu et al., 2011). Moreover, to some extent, the richness and spatial patterns of island vegetation communities could also reflect similar ecological conditions (Brown, 1995).

Table 2. Climatic factors of each site

Site	T/°C	T_c/°C	D_{10}/d	AAT_{10}/°C	P/mm
Shengsi	15.6	5.6	236.9	4 758.0	1 088.8
Shengshan	16.1	5.6	243.5	5 540.9	1 072.5
Daqu	16.3	6.0	243.9	5 060.3	1 001.0
Dinghai	16.2	5.6	241.5	5 067.4	1 442.5
Putuo	16.4	5.8	246.8	5 180.9	1 335.0
Shipu	16.3	5.8	245.3	5 643.5	1 412.8
Dachen	17.1	7.3	257.0	5 361.5	1 350.0
Yuhuan	17.0	7.2	253.7	5 881.4	1 350.2
Dongtou	18.1	8.3	274.3	5 809.1	1 390.2
Beiji	17.6	8.0	267.1	6 100.4	1 209.2
Nanji	17.5	7.9	265.7	5 422.9	1 201.5

4 Conclusions

The study shows that the spatial pattern of tree species in mass islands along Zhejiang conformed to the Preston model with the combination of PE and GA. The theoretical estimated values of both S^*_{GA} and S^*_{GA} reached 176, which implies that the tree communities are supported by suitable environmental conditions and high species richness. Results of the application of log-normal distribution model to the study area accord with their application in both tropical rainforests and estuarine forests. This in turn, indicates that the model is not only applicable for this study area, but also for similar plant communities. Additionally, our study suggests that the mass islands can be categorized as subtropical zones. Whilst the mixed (needle leaf and broad leaf), deciduous and evergreen broad-leaf forest species of mass islands relate closely to those of terrestrial Zhejiang Province and Jiangsu Province, as well as Taiwan and Japan, the island tree communities along coastal Zhejiang should be considered as an important part of the adjacent mainland communities which need further study in the context of possible speciation.

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