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GEOGRAPHICAL PATTERNS OF *RAUNKIAERIAN* LIFE-FORM SPECTRA IN CHINA

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Abstract

The first quantitative picture of the geographical distribution pattern of plant life-form spectra in China using SPSS and ArcGIS is presented. Based on the plant species data in 147 nature reserves across China and *Raunkiaerian* life-form classification system, we classified those reserves into five clusters using the cluster analysis. We quantified the mean proportions of phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes in each cluster to capture the essential life-form spectrum and simulated its geographical pattern at the large-scale in terms of its favorable climate conditions. We found that consistent with the biomes of China, the biological spectrum dominated by phanerophytes was mainly distributed in the subtropical region, and the spectrum dominated by hemicryptophytes concentrated in the temperate region. This full regional picture of *Raunkiaerian* life-form spectra in China will be helpful in the comprehensive understanding of the flora composition in China and provide theoretical guidance for the forest management and biodiversity conservation in the terrestrial ecosystems.

Key words: Biological spectrum, Forest management, Life-form classification, Nature reserve.

Introduction

It is easy to find that plants growing under the similar climatic conditions are characterized by the similar structures and functions due to their interaction with the environment during their whole life processes (Gill *et al.,* 1999; Nikolić *et al.,* 2011). The adaption of plants to certain environmental conditions is widely accepted to be represented by the general appearance and growth of plants, i.e., life-form (Wang *et al.,* 2003). Raunkiaer proposed a standard for the classification of plant life-forms based on the adaption of buds and shoot tips to overcome the unfavorable climatic conditions (Raunkiaer, 1934). Because of its clarity and simplicity, *Raunkiaerian* life-form classification (i.e., phanerophyte, chamaephyte, hemicryptophyte, cryptophyte, and therophyte) has been widely used to delineate the flora and indicate the climate in a particular region (Becker & Müller, 2007). An array of relative contributions of multiple life-forms in a flora of a particular region is considered as the life-form spectrum or biological spectrum (Costa *et al.,* 2016). This spectrum has been widely used in the ecological elucidation of the vegetation and phyto-climate (López-García *et al.,* 2014).

Most previous studies gave a qualitative or quantitative description of life-form spectra within a particular or local floristic community (Khan *et al.,* 2016). However, there is still a lack of geographical delineations in life-form spectra at the large scale (Díaz *et al.,* 2016). In this study, we aimed to report a quantitatively life-form spectra of China so that the original picture of the geographical patterns of life-form spectra could be determined. 147 nature reserves relatively well protected from human activities were selected in China. The life-form of each species comprising each nature reserve was determined according to the *Raunkiaerian* system (Raunkiaer, 1934) and the life-form spectrum of each nature reserve was calculated. Cluster analysis was carried out to demonstrate the geographical patterns of life-form spectra in China. Studies like this are extremely useful for environmentalists, ecologists and those engaged in the forest management and biodiversity conservation studies (Grubesic & Murray, 2001; Khan *et al.,* 2016).

Materials and Methods

Data sources: We collected the plant species list of 147 nature reserves across China from published literature (e.g., (Cui & Xing 2009; Yuan & Song 1998)). Latitudes of nature reserves studied here ranged from 18.6°N to 51.6°N, and longitudes are from 82.9°E to 125.5°E (Fig. 1). The area of the nature reserves is 583,446 km^2, comprising 6.1% of China's total land area. The elevation range (i.e., maximum minus minimum elevation) of each nature reserve is more than 300 m, indicating all nature reserves characterized by the mountain environment (Kapos *et al.,* 2000). Plant species can be categorized into five life-forms (i.e., phanerophyte, chamaephyte, hemicryptophyte, cryptophyte, and therophyte) according to the *Raunkiaerian* classification (Raunkiaer, 1934). The number of species belonging to certain life-form divided by the total number of species was treated as the contribution of this life-form to the flora. The life-form spectrum was determined by the five life-forms expressed in the percentage. Mean annual temperature (MAT) and mean annual precipitation (MAP) was extracted from a global database WorldClim with a resolution of 1 km × 1 km (Hijmans *et al.,* 2005), which was widely used in the previous studies (McCain & Sanders, 2010).

Cluster analysis. A k-means cluster analysis was performed to classify 147 nature reserves into five clusters according to the 147 life-form spectra (Fielding, 2007). Each cluster had more than five nature reserves in order to allow a sound statistical analysis. The histogram distributions of life-form spectra of nature reserves falling within each cluster were plotted to show the life-form spectrum of each cluster. Therefore, five clusters could represent five essential life-form spectra. The ranges of latitude, longitude, MAT, and MAP of nature reserves falling within each cluster were calculated and then used to simulate the geographical pattern of certain essential life-form spectrum. The analyses were done using SPSS 19.0 and ArcGIS 10.3.

Results

Five clusters: The k-means cluster analysis classified 147 nature reserves into five clusters: cluster I located in southern China, cluster II distributed in middle China, cluster III and IV scattered and dominated northern China, and cluster V contained only 6 nature reserves (Fig. 2).

Life-form spectra of nature reserves falling within the cluster: There was a large variation in the percentages of phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes for the nature reserves falling within each cluster (Figs. 3–7). The percentage of phanerophytes consistently decreased from cluster I (ranging from 74.68% to 97.75% with the mean value of 82.52%) to cluster II (ranging from 57.78% to 74.58% with the mean value of 65.97%), and to cluster III (ranging from 40.30% to 58.09% with the mean value of 48.87%), and to cluster IV (ranging from 24.55% to 41.54% with the mean value of 32.58%), and to cluster V (ranging from 10.60% to 26.09% with the mean value of 20.02%) (Fig. 3).

The proportion of chamaephytes increased from cluster I (ranging from 0 to 2.97% with the mean value of 1.00%) to cluster II (ranging from 0 to 5.45% with the mean value of 1.74%), and to cluster III (ranging from 0 to 18.75% with the mean value of 3.29%) (Fig. 4). The contribution of chamaephytes in the cluster IV flora ranged from 0.82% to 11.82% with the mean value of 2.99%. The cluster V had the highest percentage of chamaephytes (ranging from 1.63% to 5.91% with the mean value of 3.93%) comparing with other clusters.

The contribution of hemicryptophytes consistently increased from cluster I (ranging from 0 to 14.43% with the mean value of 8.00%) to cluster II (ranging from 11.76% to 25.71% with the mean value of 18.26%), and to cluster III (ranging from 19.78% to 36.30% with the mean value of 28.69%), and to cluster IV (ranging from 29.23% to 48.61% with the mean value of 39.26%), and to cluster V (ranging from 34.78% to 55.17% with the mean value of 45.83%) (Fig. 5).

The proportion of cryptophytes increased from cluster I (ranging from 0 to 12.50% with the mean value of 6.54%) to cluster II (ranging from 2.86% to 17.65% with the mean value of 10.22%), and to cluster III (ranging from 6.25% to 20.09% with the mean value of 12.83%), and to cluster IV (ranging from 11.27% to with 21.77% the mean value of 16.80%), and then decreased to cluster V (ranging from 9.09% to 18.21% with the mean value of 12.75%) (Fig. 6).

The percentage of therophytes consistently increased from cluster I (ranging from 0 to 6.07% with the mean value of 1.93%) to cluster II (ranging from 0 to 12.31% with the mean value of 3.82%), and to cluster III (ranging from 0 to 13.79% with the mean value of 6.33%), and to cluster IV (ranging from 3.23% to 21.54% with the mean value of 8.36%), and to cluster V (ranging from 6.40% to 23.19% with the mean value of 17.48%) (Fig. 7).

Five clusters represent five essential life-form spectra: There was a large difference in the percentages of phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes among five clusters. We can consider each cluster as one essential life-form spectra using the mean value of the percentages of phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes within each cluster (Fig. 8). On average, phanerophytes dominated the flora of cluster I (82.52%), II (65.97%) and III (48.87%). Hemicryptophytes contributed the largest proportion of the flora in cluster IV (39.26%) and V (45.83%). Chamaephytes took up the smallest percentage of the flora in all five clusters (I: 1.00%, II: 1.74%, III: 3.29%, IV: 2.99%, and V: 3.93%). Life-form spectrum I, II, and III had the same order of the percentages: phanerophyte>hemicryptophyte>cryptophyte>therophyte>chamaephyte; life-form spectrum IV had the order of hemicryptophyte>phanerophyte>cryptophyte>therophyte>chamaephyte; while life-form spectrum V had the order of hemicryptophyte>phanerophyte>therophyte>cryptophyte>chamaephyte.

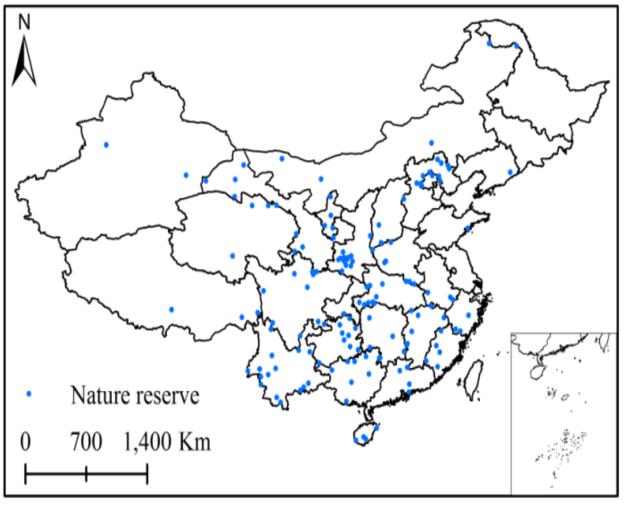

Fig. 1. Location of nature reserves used in this study.

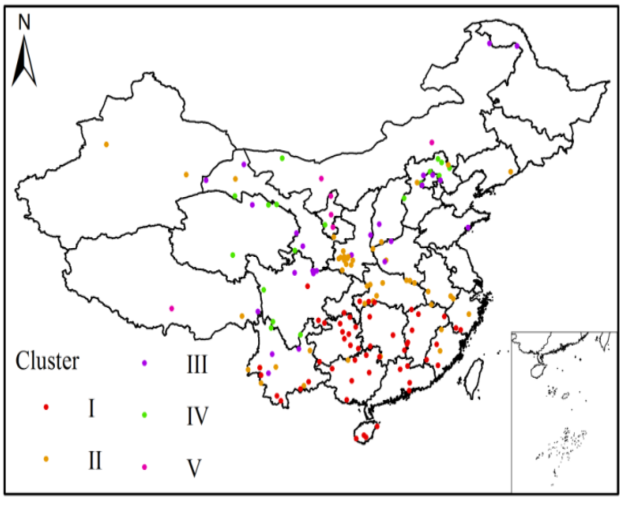

Fig. 2. Classification of 147 nature reserves into five clusters.

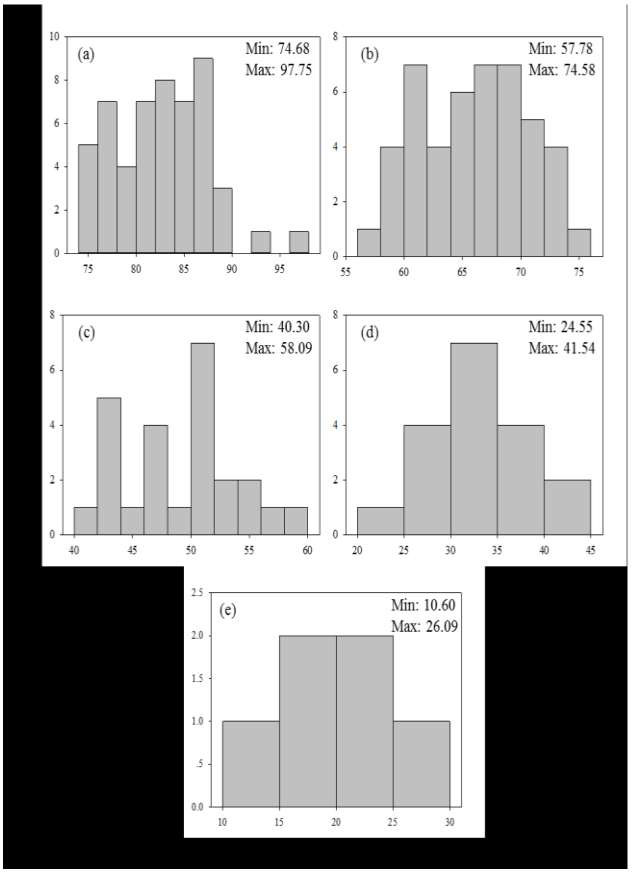

Fig. 3. Percentage of phanerophytes in the cluster (a) I, (b) II, (c) III, (d) IV, and (e) V flora.

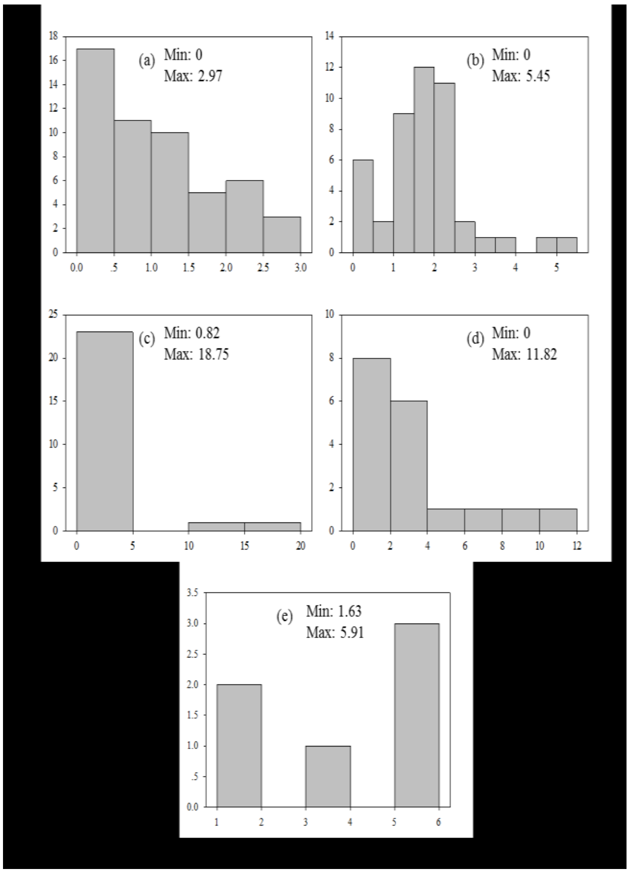

Fig. 4. Percentage of chamaephytes in the cluster (a) I, (b) II, (c) III, (d) IV, and (e) V flora.

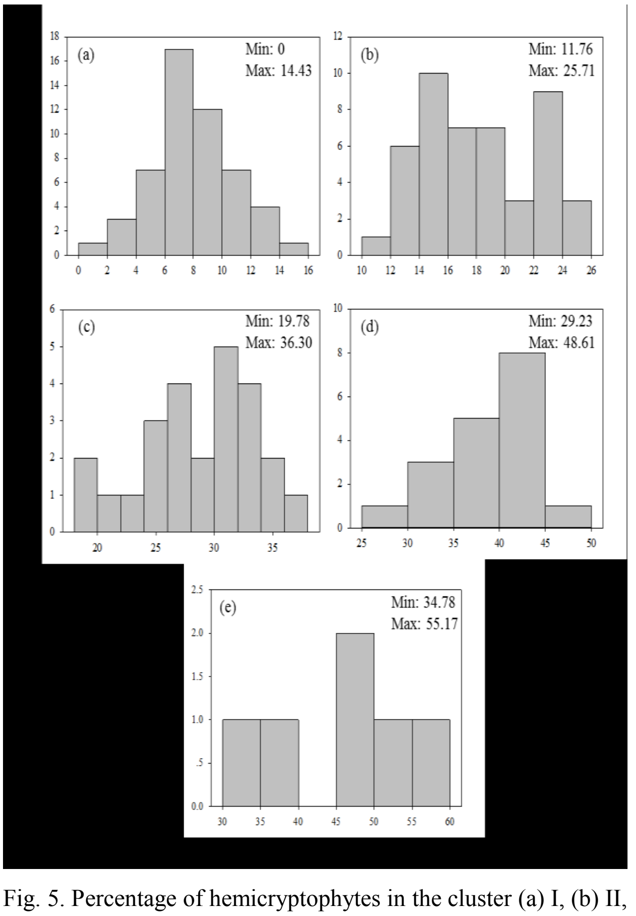

Fig. 5. Percentage of hemicryptophytes in the cluster (a) I, (b) II, (c) III, (d) IV, and (e) V flora.

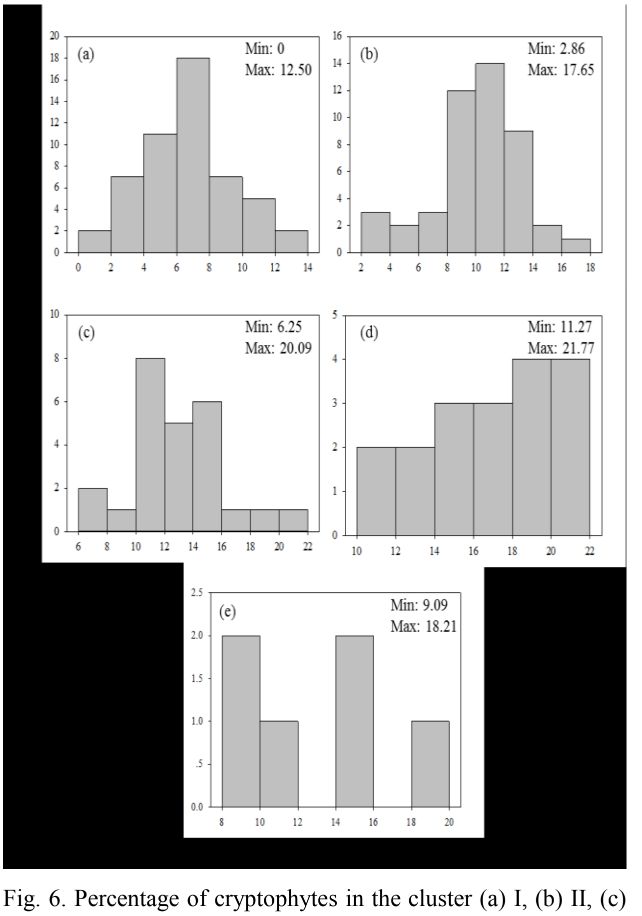

Fig. 6. Percentage of cryptophytes in the cluster (a) I, (b) II, (c) III, (d) IV, and (e) V flora.

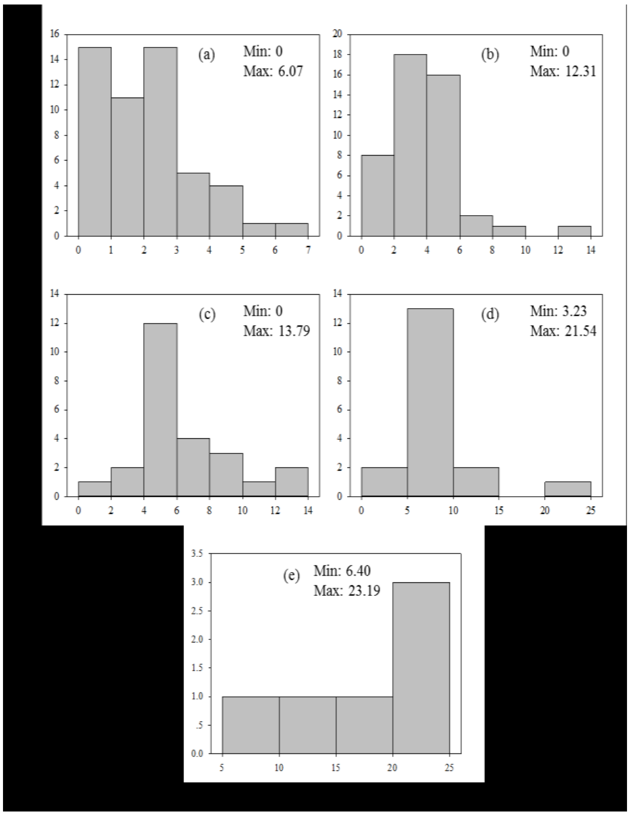

Fig. 7. Percentage of therophytes in the cluster (a) I, (b) II, (c) III, (d) IV, and (e) V flora.

Environmental characteristics of five clusters: There was a large variation in the geographical information and climatic conditions among five clusters (Table 1). Nature reserves belonging to the cluster I were located at the warmest and wettest region.

Geographical patterns of five essential life-form spectra: The simulated geographical range of each essential life-form spectrum covered the corresponding sampling nature reserve points (Fig. 9). Overlaying those simulated geographical patterns with the vegetation regionalization map of China (Editorial Committee of Vegetation Map of China, 2007a, 2007b) reflected the relationships between life-form spectra and bioclimatic conditions. Life-form spectrum I is mainly distributed in southern China, that is, in the subtropical broadleaf evergreen forest region, and the tropical monsoon rainforest and rainforest region (Fig. 9a). Life-form spectrum II had a large distribution in the south and east of China, which covered all the warm temperate deciduous broadleaf forest region, almost all the subtropical broadleaf evergreen forest region, the southern half of the temperate steppe region, the eastern part of the temperate desert region, a little part of the tropical monsoon rainforest and rainforest region, and a little part of the Qinghai-Xizang Plateau alpine vegetation region (Fig. 9b). Both life-form spectrum III and IV had a wide distribution, which included the subtropical broadleaf evergreen forest region, the warm temperate deciduous broadleaf forest region, the temperate steppe region, the temperate desert region, and the Qinghai-Xizang Plateau alpine vegetation region (Figs. 9c, 9d). Additionally, life-form spectrum III covered a larger part in all the same regions and also extra distribution in a little part of the cold-temperate needleleaf deciduous forest region, and the temperate mixed needleleaf and deciduous broadleaf forest region. Life-form spectrum V is mainly distributed in the temperate steppe region, and also sporadically distributed in the temperate desert region and Qinghai-Xizang Plateau alpine vegetation region (Fig. 9e).

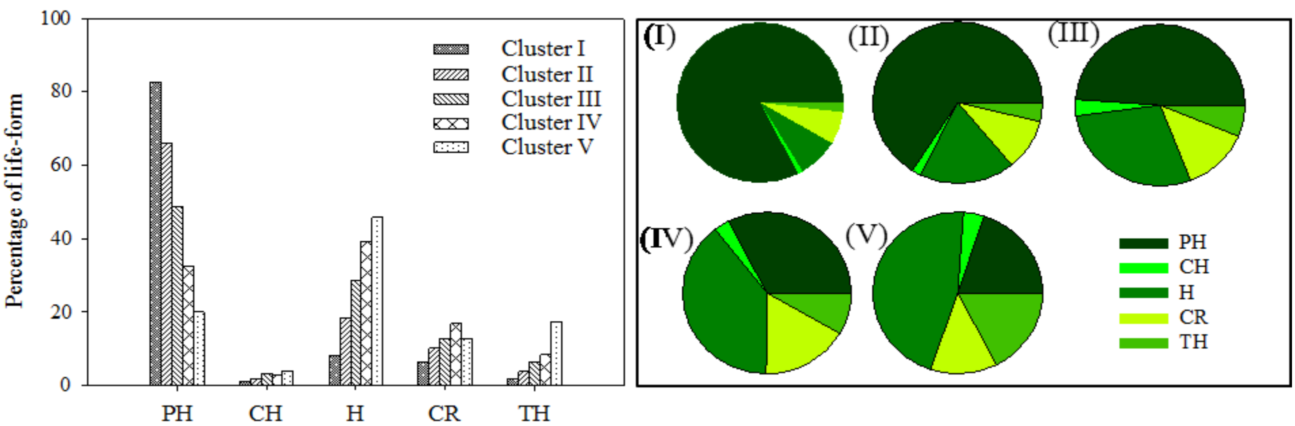

Fig. 8. Five clusters represent five essential life-form spectra. The length of columns (left) and area of pies (right) show the percentage of different life-forms (PH: phanerophyte, CH: chamaephyte, H: hemicryptophyte, CR: cryptophyte, TH: therophyte).

Table 1. The geographical and climatic characteristics of five clusters, including the range of latitude, longitude, mean annual temperature (MAT), and mean annual precipitation (MAP).

Cluster	Latitude (°)	Longitude (°)	MAT (°C)	MAP (mm)
I	18.63–31.33	98.85–119.66	7.94–24.27	1039.69–2272.82
II	23.03–43.15	82.98–124.85	0.82–20.59	30.21–2078.69
III	24.08–51.58	93.29–125.48	-6.48–17.03	22.22–1231.21
IV	27.29–42.00	96.07–118.50	-3.91–12.41	30.37–952.03
V	29.48–43.32	89.63–116.68	0.61–7.35	104.46–445.58

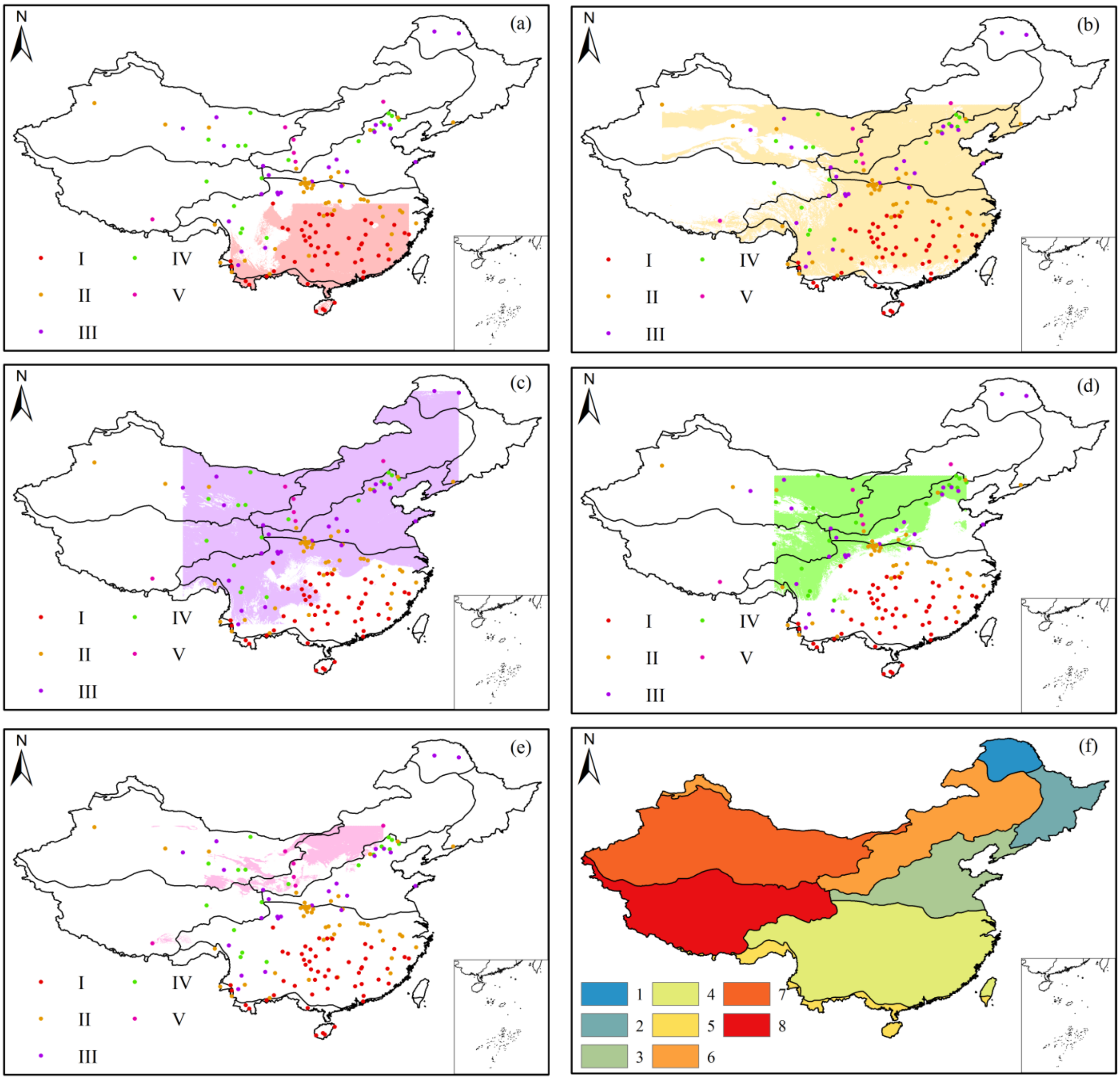

Fig. 9. Geographical patterns of five essential life-form spectra (a) I, (b) II, (c) III, (d) IV, (e) V, and (f) vegetation regionalization map of China (1: Cold-temperate needleleaf deciduous forest region, 2: Temperate mixed needleleaf and deciduous broadleaf forest region, 3: Warm temperate deciduous broadleaf forest region, 4: Subtropical broadleaf evergreen forest region, 5: Tropical monsoon rain forest and rain forest region, 6: Temperate steppe region, 7: Temperate desert region, 8: Qinghai-Xizang Plateau alpine vegetation region).

Discussion

The life-form of the plants is the physiognomic form reflecting the adaptation of plants to the climate of a region (Costa *et al.,* 2007; Mir *et al.,* 2017; Schmidt *et al.,* 2005).

According to the principles of position and degree of protection to parenting bud during the adverse seasons, Raunkiaer (1934) proposed the most compact and uniform life-form classification: phanerophyte, chamaephyte, hemicryptophyte, cryptophyte, and therophyte. The relative proportions of different life-forms in a given region are defined as its life-form spectrum or biological spectrum (Osman *et al.,* 2014). The deliberation of the life-form spectrum is helpful in the comparison of geographically separated plant habitats and the indication of the prevailing climate (Al-Hawshabi *et al.,* 2017; Batalha & Martins, 2004; Khan *et al.,* 2013).

Previous studies have focused on the description and analysis of the plant life-form spectrum in the certain local area (Batalha & Martins, 2002; van der Merwe & van Rooyen, 2011). However, there is a lack of studies aiming to give a full picture of geographical distribution patterns of plant life-form spectra at the large scale, e.g., the global, continental and regional scale. China is a home of a remarkably diverse plant life-forms (Fang *et al.,* 2012; Xu *et al.,* 2017, 2016), yet to our knowledge, no full picture of geographical patterns of plant life-form spectra in China is available. This full picture will provide a new way to study the plant life-form distribution and its underlying mechanism, indicate the bioclimatic and environmental conditions for certain typical life-form spectrum and also offer guidance to the practical work on the vegetation restoration and biodiversity conservation (Díaz *et al.,* 2016). The drawing of this picture is hence remarkably urgent, necessary and essential for the theoretical and practical studies in ecology and biogeography.

In this study, we tried to give such a full picture of China based on the plant database of 147 nature reserves. This database was compiled from published documents, literature, and monographs on nature reserves (e.g., (Cui & Xing 2009; Yuan & Song 1998)). Nature reserves are established to refuge species and main biodiversity based on the theoretical guidance and practical values (Zhao & Fang, 2006). Nature reserves hence contain the relatively well-protected forests, have more stable life-form spectra, experience more frequent investigations and more accurate original survey reports (Zhao *et al.,* 2006). Consequently, nature reserves provide the ideal experimental systems to study the floristic composition, structure, and function (Liu *et al.,* 2008). Those advantages of nature reserves provide a reliable data basis for our study.

The k-means cluster analysis divided 147 nature reserves into five clusters according to the relative proportions of five basic *Raunkiaerian* life-forms. On average, five clusters can be labeled as five essential life-form spectra. Cluster I, II, and III all exhibited a phanerophyte life-form spectrum, i.e., flora dominating by phanerophytes. Phanerophytes are produced high above ground exposed to the atmosphere and hence such plants are most abundant in warm and moist climates (Esmailzadeh & Hosseini, 2007; Nelson & Boots, 2008). As expected, the simulated geographical distributions of the life-form spectrum I, II, and III all covered the southern China where heat and water are abundant. Particularly, the dominance of phanerophytes in cluster I was the most significant ranging from 74.68% to 97.75% with the mean value of 82.52%. The simulated geographical pattern of the life-form spectrum I dominated the tropical monsoon rainforest and rainforest region. Close to our findings, the dominance of phanerophytes has also been found in the rainforests of Meghalaya, India (Khan *et al.,* 2016), sal-dominated lowland forests in Darjeeling, India (Shankar, 2001), equatorial rainforests of Malaya (Lee *et al.,* 2002) and rainforests of Xishuangbanna, China (Zhu, 1997).

The simulated geographical patterns of both life-form spectrum II and III additionally covered a large part of the subtropical and temperate regions, including the warm temperate deciduous broadleaf forest region, subtropical broadleaf evergreen forest region, temperate steppe region, and temperate desert region. A study on the Mount Huangshan of China exhibited the similar life-form spectrum as both cluster II and III in our research: phanerophytes> hemicryptophytes> cryptophytes> therophytes> chamaephytes, reflecting the unique features of mixed deciduous and evergreen broadleaf communities of northern subtropical vegetation in China (Qian *et al.,* 2014). The relative proportion of phanerophytes was smaller in the life-form spectrum III than that in the life-form spectrum II. Consequently, the simulated geographical pattern of the life-form spectrum III covered an extra region than the life-form spectrum II, i.e., the cold-temperate needleleaf deciduous forest region, indicating the lower temperature characterized by the lower percentage of phanerophytes.

The simulated geographical pattern of the life-form spectrum IV covered a less area and contracted to the temperate steppe region, temperate desert region, and Qinghai-Xizang Plateau alpine vegetation region. Hemicryptophytes contributed the largest in the life-form spectrum IV, confirming the previous finding that hemicryptophytes indicate the temperate zone. The simulated geographical pattern of the life-form spectrum V further contracted to a less area, i.e., the temperate steppe region. We found that the life-form spectrum V was shown in the order of hemicryptophytes> phanerophytes> therophytes> cryptophytes> chamaephytes, supporting the previous research that therophytes adapted to the dryness and rainfall shortage (Shimwell, 1971).

Generally, the simulated geographical variations of five essential life-form spectra revealed in our study were consistent with the biomes (i.e., large areas with relatively uniform climatic conditions) indicated by the vegetation regionalization map of China (Editorial Committee of Vegetation Map of China, 2007a, 2007b). Specifically, two or more essential life-form spectra coexisted in the same vegetation region due to the elevational gradient of climatic conditions in mountainous areas. This coexisting phenomenon was particularly obvious in the regions characterized by the large elevation variation. Notably, a similar picture of plant life-form spectra in China has been recorded in a previous research (Guo *et al.,* 1999), which gave the picture of plant life-form spectra in major Chinese forest communities based on 24 published monographs or references. While our study was based on more sampling points and provided a more comprehensive picture. This picture will provide theoretical guidance to the practical management of natural and planted vegetation (Bloch-Petersen *et al.,* 2006). For example, in the desert type of climates, the predominance of therophyte is an effective strategy to avoid water losses due to the water deficiency.

Acknowledgements

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