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Vegetation-Climate Relationship and Its Application in the Division of Vegetation Zone in China

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Abstract: Distribution of vegetation is closely coupled with climate; the climate controls distribution of vegetation and the vegetation type reflects regional climates. To reveal vegetation-climate relationships is the foundation for understanding the vegetation distribution and theoretically serving vegetation regionalization. Vegetation regionalization is a theoretical integration of vegetation studies and provides a base for physiogeographical regionalization as well as agriculture and forestry regionalization. Based on a brief historical overview on studies of vegetation-climate relationships and vegetation regionalization conducted in China, we review the principles, bases and major schemes of previous vegetation regionalization and discuss on several contentious boundaries of vegetation zones in the present paper. We proposed that, under the circumstances that the primary vegetation has been destroyed in most parts of China, the division of vegetation zones/regions should be based on the distribution of primary and its secondary vegetation types and climatic indices that delimit distribution of the vegetation types. This not only reveals the closed relationship between vegetation and climate, but also is feasible practically. Although there still are divergence of views on the name and their boundaries of the several vegetation zones, it is commonly accepted that there are eight major vegetation regions in China, i.e. cold temperate needleleaf forest region, temperate needleleaf and broadleaf mixed forest region, warm temperate deciduous broadleaf forest region, subtropical evergreen broadleaf forest region, tropical monsoon forest and rain forest region, temperate steppe region, temperate desert region, and Qinghai-Xizang (Tibetan) Plateau high-cold vegetation region. Analyzing characteristics of vegetation and climate of major vegetation boundaries, we suggested that: 1) Qinling Mountain-Huaihe River line is an important arid/humid climatic, but not a thermal climatic boundary, and thus can not also be regarded as the northern limit of the subtropical vegetation zone; 2) the northern limit of subtropical vegetation zone in China is along the northern coast of the Yangtze River, from Hangzhou Bay, via Taihu Lake, Xuancheng and Tongling in Anhui Province, through by southern slope of the Dabie Mountains, to Wuhan and its west, coinciding with a warmth index (*WI*) value of 130 - 140 ℃·month; 3) the tropical region is limited in a very small area in southeastern Hainan Island and southern edge of Taiwan Island; and 4) considering a significant difference in climates between the southern and northern parts of the warm temperate zone, we suggested that the warm temperate zone in China is divided into two vegetation regions, deciduous broadleaf woodland region and deciduous and evergreen broadleaf mixed forest region, the Qinling Mountain-Huaihe River line being as their boundary. We also claimed that the zonal vegetation in North China is deciduous broadleaf woodland. Finally, we emphasized the importance of dynamic vegetation regionalization linked to climate changes.

Key words: China; dynamic vegetation regionalization; arid/humid climate; northern limit of subtropical zone; Qinling Mountain-Huaihe River line; thermal climate; vegetation-climate relationship; vegetation regionalization; vegetation zone

The vegetation-climate relationship is an old topic and new theme in both botany and geography. Its comprehensive study has been over one hundred years, from early classic studies such as the global mean temperature isotherm in the 19th century by Alex. v. Humboldt[1], temperature zone by Supan[2], climate classification by Koppen[3], classification of life-form-based plant climate zone by Raunkiaer[4], vegetation-climate classification based on water balance by Thornthwaite[5], life zone classification system by Holdridge[6,7], eco-climate classification by Kira[8,9], and classification system based on evapotranspiration processes by Budyko[10], to recent climate change approaches, for example, biogeographical model (BIOME1) proposed by Prentice *et al*[11] and biogeochemical model (BIOME3) of Haxeltine *et al*[12]. All these studies demonstrate that climate controls geographical distribution of vegetation and distribution of vegetation types reflects the regional climates.

It is said that the history of studies on vegetation-climate relationship in China can be restrospected to the 11th century BC[13]. However, application of the vegetation-climate relationship to vegetation regionalization was begun since the 1930s. Li[14] first proposed a scheme of vegetation regionalization of China. From then, several

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others were suggested by different authors[15, 16]. After foundation of the People's Republic of China in 1949, particularly during 1950s - 1960s, many studies had been conducted and several systems on principles, bases and schemes of China's vegetation regionalization had been proposed. Hou[17] compared and summarized these systems and developed the theories of vegetation ecology in China, which provided a basis for the book "Vegetation of China" published in 1980[13]. It was said that this period was a blooming stage of vegetation sciences in China. Few studies on vegetation regionalization were conducted during 1966 - 1976. At the beginning of the 1980s, this kind of study was refocused and developed[18, 19]. The application of computer technology has made the quantitative studies of vegetation-climate relationship possible and has become one of the focuses of vegetation sciences in China since the early 1980s[20 - 38].

In this paper, we will take overview on studies of vegetation-climate relationship in China, summarize major schemes of China's vegetation regionalization, and discuss some important vegetation boundaries. We also demonstrate the importance of dynamic vegetation regionalization linked to climatic changes. It should be note that the vegetation regionalization described in this paper refers primarily the division of vegetation zone or region, but not the classification of smaller vegetation units than vegetation zones.

1 Geographic Patterns of Vegetation and Climate in China and Climatic Factors Influencing Vegetation Distribution

1.1 Geographical patterns of vegetation and climate

China is strongly affected by the monsoon climate. In the eastern part of China, it is cold and dry in winter and warm and humid in summer, which is synchronous with the phonological changes of plants. The climate zone changes from tropical, subtropical, warm temperate, temperate to cold temperate in turn from south to north in eastern part of China. Corresponding to the climatic zones that are almost parallel with the latitude belt, distribution of vegetation in the eastern part of China also shows an obvious latitudinal zonality, i. e. tropical rain forest and monsoon forest, subtropical evergreen broadleaf forest, deciduous broadleaf forest, evergreen and deciduous needleleaf forest occur in turn from south to north, forming the greatest continuum of forest vegetation in the world and becoming a reference of vegetation-climate relationship studies and global latitudinal zonality. On the other hand, affected by the continental climate, it is dry in northwest China. With the changes from humid to arid climate from east to west, the vegetation type changes from forest, forest steppe, steppe and desert; this is termed as longitudinal zonality of vegetation.

China is a mountainous country, and more than half of the territory is occupied by mountains and plateaus[39]. Vertical zonality of vegetation which is closely related to horizontal zonality, is formed in a large amount of mountains, particularly in low latitudes, such as Mt. Qumurlangma (Everest), the vegetation zone changes from tropical rain forest to alpine meadow from the foot upwards[40]. In the arid zone of north China, close forest is formed on the middle and upper parts of the mountains, e. g. Mts. Tianshan and Qilian[41].

In addition, rising of the Qinghai-Xizang Plateau leads to a special plateau climate and thus forms a special pattern of vegetation distribution. Such a special vegetation pattern in the Plateau has been termed as "plateau zonality of vegetation" to distinguish horizontal zonality and vertical zonality of vegetation[42]. The plateau zonality has been formed by the Indian monsoon, the high pressure of Qinghai-Xizang Plateau and the "heating effect" of the plateau surface[42]. Although there are still different viewpoints on the vegetation distribution on the Qinghai-Xizang Plateau[43], the unique pattern of the plateau vegetation has been recognized by many studies[44 - 50].

The vegetation distribution of China can be characterized by the latitudinal zonality, longitudinal zonality, vertical zonality, and plateau zonality as described above. They constitute theoretical basis for vegetation regionalization of China.

1.2 Climatic factors affecting vegetation distribution

Temperature and precipitation are two major factors affecting vegetation distribution[51]. Precipitation or integrated water and heat conditions (moisture index) distinguish forest vegetation from non-forest vegetation (forest-steppe, steppe, deserts), while limiting factor for distribution of forest types is thermal climate. The quantitative relationship between distribution of forest types and thermal climate thus becomes the basis for division of thermal zones and latitudinal distribution of vegetation.

1.2.1 Moisture indexes affecting vegetation distribution In the period of 1950s - 1960s aridity index was used for division of the arid/humid climate zones of China[52, 53]. Because accumulative temperature was applied in the aridity index and because it could not reveal exactly vegetation distribution, an annual aridity index was proposed and used in the new climate regionalization[54].

A number of studies showed that Thornthwaite's moisture index (Im)[5] derived from water balance was regarded as a rational parameter for analyzing relationship between moisture condition and vegetation distribution[24, 27, 55, 56]. Chang[24] studied distribution of major vegetation types using Thornthwaite classification system and found that distribution of vegetation in China was strongly related to Im. Fang and Yoda[27] figured out that distribution of major vegetation types in China corresponded well to Im values, and humid forest (e. g. evergreen forest, rain forest), deciduous broadleaf forest, woodland, grassland and desert corresponded to the Im values of > 60, $60 - 0$, $0 - -20$, $-20 - -40$, and < -40, respectively. This provided quantitative criterion for vegetation division in China.

In addition, the *Im* was also used to document *vegetation-climate* relationship at regional scale. For example, Wang and Xiao[57] studied distribution of vegetation types along an *Im* gradient in the Loess Plateau. Ni[33] analyzed the relationship between distribution of evergreen broadleaf trees and the *Im* values. Holdridge's life zone system was also widely applied in study of the vegetation-climate relationship in China[58, 59]. However, because potential evapotranspiration rate (*PER*) of the Holdridge system[7] is the ratio of annual biotemperature to annual precipitation that is analogous to the arid/humidity index used in the early climate classification systems (e.g. Koppen system), its applicability is questioned.

1.2.2 Thermal indexes affecting distribution of vegetation types Mean temperature was adopted to identify the relationship between vegetation distribution and thermal conditions during the early stages. It was also used in the regionalization of China's vegetation and climate during the early stages[60-62]. After the 1950s, effective accumulative temperature was used as thermal parameter for division of thermal climate[52]. Chen[54] adopted the number of days of effective accumulative temperature as the thermal index for division of climate zones. Recently, Zhou and Zhang[37], based on Thornthwaite's potential evapotranspiration (1948), proposed a new index, regional potential evapotranspiration (*RPE*) to explore the climate-vegetation relationship, and applied it for the climate-vegetation classification of China for climate change study[38].

In China, Warmth Index (*WI*)[8, 9] and Coldness Index (*CI*)[9, 63] have been broadly used to explore the couplings between vegetation distribution and temperature conditions. The *WI* is a simplified effective accumulative temperature that uses monthly mean temperature, and is linearly related to the accumulative temperature and other temperature parameters[26]. The *CI* reflects the degree and its length of winter low temperature and indicates well the relationship between vegetation/plant distribution and limiting climatic factors in warm areas[9, 64, 65].

Hong and Li[20] first adopted Kira's *WI* and *CI* to a quantitative study of relationship between vegetation and climate in China. They found that distribution of major evergreen broadleaf trees in Jiangsu Province could be explained by these two variables. In the meantime, relationships between vegetation and moisture and heat conditions in Northeast China were also discussed by using the *WI* and *CI*[21, 22]. Li[66] discussed the relationship between the vertical forest zones and the *WI* in the Qinghai-Xizang Plateau. Fang and Yoda[26-29] and Fang[31] studied the relationship between vegetation distribution and *WI* values and defined the criterion for division of the thermal zones, i.e. *WI* < 15 °C·month for the arctic (alpine) zone, 15 - 50 °C·month for the subarctic zone, 50 - 90 °C·month for the temperate zone, 90 - 175 °C·month for the warm temperate zone, and > 175 °C·month for the subtropical and tropical zone. Fang *et al*[30] also discussed the vertical spectra and geographical differentiation of component genera along the 30°N in East Asia and found that the *WI* and *CI* values changed with continentality index, suggesting that continentality index should be taken into consideration in division of vegetation zone. Ni and Song[34, 35] found that Kira's indexes interpreted successfully distribution of evergreen broadleaf forests.

2 Major Principles, Bases and Schemes of China's Vegetation Regionalization

2.1 Principles and bases

The horizontal zonality (latitudinal zonality and longitudinal zonality) and the vertical zonality are theoretical bases for vegetation regionalization, of which the horizontal zonality is critical[19, 67]. Among the horizontal zonality, the latitudinal zonality is caused by different solar radiation and further thermal conditions on the earth surface from south to north, and thus indicates the zonation of thermal conditions, while longitude has no biological significance and means only the geographical coordinate and time. The longitudinal zonality demonstrates the moisture difference from oceanic to continental climate caused by the oceanic and inland distribution. The latitudinal zonality of vegetation indicates the changes of heat, while the longitudinal zonality shows difference in the moisture; combination of both is a basis for vegetation regionalization[31, 68]. In addition, the unique vegetation pattern of the Qinghai-Xizang Plateau should also be taken into consideration in vegetation regionalization of China. There are three major viewpoints about the bases of vegetation regionalization in China:

(1) Characteristics of zonal vegetation, composition of flora, and distribution of cultivated vegetation are primary bases. HOU Xue-Yu (HOU Hsioh-Yu) is a representative of this viewpoint. HOU[18, 67] deemed that zonal vegetation types are primary basis and indicator for vegetation regionalization, but semi-natural and secondary vegetation are also important in regions with strong human influences, e.g. the eastern part of China. He also stressed the role of composition and distribution of flora in indicating modern natural conditions. In areas with developed agriculture, distribution and growth of cultivated vegetation should be also considered as important indicator for vegetation regionalization. That is to say, he suggested the same significance of zonal vegetation, flora characteristics and distribution of cultivated vegetation. However, this viewpoint is difficult to practice. For this reason, he deemed that the existence of vegetation can not separate from the physiogeographical conditions, and as an alternative, geologic, topologic, pedalogic and hydrologic conditions were also taken into consideration in his vegetation regionalization scheme. In reality, his vegetation regionalization schemes[19, 69] were mostly based on climatic and topologic patterns. The similar viewpoints were also hold in Editorial Committee for Vegetation of China[13].

(2) Zonal vegetation is principal basis, and flora and distribution of cultivated vegetation are secondary fac-

tors. This viewpoint was hold by Xu[70], Lin[71], Zhou[72] and Song[73]. Xu[70] pointed out that natural vegetation and their secondary vegetation should be the chief indicator in vegetation regionalization. Cultivated vegetation can be used as reference. Flora analysis is of significance, but attention to the ratios of species and genera should be paid. Lin[71] argued that cultivated vegetation and agricultural system can only be used as auxiliary indicators. Zhou[72] pointed out that some researchers had over-emphasized the role of cultivated and introduced plants in vegetation regionalization. Song[73] demonstrated the importance of vegetation, particularly the natural vegetation and their secondary vegetation, and their flora composition and climatic conditions should also be referred. But Song[74] emphasized the same importance of vegetation types, flora and environmental conditions in vegetation regionalization later.

(3) Both vegetation and climate are critical to China's vegetation regionalization. Fang[68] argued that primary vegetation is undoubtedly important in the vegetation regionalization, but it is difficult to practice if only information on vegetation is used because primary vegetation has almost been destroyed particularly in eastern China. He argued that the most schemes of China's vegetation regionalization proposed so far were substantially similar to potential vegetation regionalization, thus basically these schemes were a kind of division of vegetation climax. That is to say, climatic factors, especially limiting climate factors that delimit the vegetation distribution, are critical to the vegetation division especially in the eastern China.

In fact, some climatic indexes, in most cases, single climate indices (e. g., mean temperature and precipitation) often were used in the vegetation regionalization, although this was not mentioned in their schemes[19, 75]. According to such an understanding, Fang[68] suggested that zonal vegetation types and their secondary types provide a base for identifying the vegetation-climate relationship of a region. Using the relationship and climate variables of the region, vegetation regionalization can be easily done. That is to say, both information on vegetation types and regional climate characteristics are of importance. This not only reflects the essence of vegetation-climate relationship, but also is easy to practice.

As for the role of flora in the division of vegetation zones, Fang[68] argued that it is not critical. Division of vegetation zones is a large-scale classification of vegetation landscape and differs from classification of plant communities, the former is controlled by modern environmental conditions, and the later is primarily influenced by geological history. Therefore, composition of flora is critical to classification of plant communities.

Regarding the role of cultivated vegetation, we agreed to the viewpoint claimed by Lin[71] and Zhou[72], who suggested that cultivated vegetation can only be served as auxiliary factor and its importance in vegetation regionalization can not be over-emphasized, because cultivated or introduced species can expand more widely than their natural range[71]. Moreover, the division of vegetation for agricultural purpose should be included in agricultural regionalization which is quite different from the vegetation regionalization.

In addition, some authors[76, 77] stressed the importance of the life-form of plants in vegetation regionalization, which is similar to the plant climate classification proposed by Raunkiaer[4].

2.2 Major schemes of vegetation regionalization

Since the first scheme of vegetation regionalization was proposed by Li[14], dozens of the schemes have been developed during the last 70 years. Table 1 lists the major schemes during different periods. The history of studies on vegetation regionalization in China can also be viewed from the Table 1.

Figures 1 and 2 illustrate the oldest[14] and the newest[85] map of vegetation regionalization in China. Of all the schemes listed in Table 1, that of Editorial Committee for Vegetation of China[13] and Hou[18, 19] is the most commonly used today in China. Another scheme proposed recently by Editorial Committee for Vegetation Atlas of China[85] is almost the same as that by Editorial Committee for Vegetation of China[13].

Comparing these schemes, we found that the early schemes were mostly linked to administrative regions, which is obviously in contradict to geographical distribution of vegetation because distribution of vegetation is irrespective of administrative boundaries. In addition, principles and bases of the regionalization and relationships among regions are not consistent in the earlier schemes. After the 1980s, although divergence of views on the name of the vegetation zones and the location of the vegetation boundaries still is found in different schemes, it has been commonly accepted that there are eight great vegetation regions in China, i.e. cold temperate needleleaf forest region, temperate needleleaf and broadleaf mixed forest region, warm temperate deciduous broadleaf forest region, subtropical evergreen broadleaf forest region, tropical monsoon forest and rain forest region, temperate steppe region, temperate desert region and Qinghai-Xizang Plateau high-cold vegetation region.

In China, it is always argued whether the Qinghai-Xizang Plateau is handled as a separated vegetation region. There exist two completely different viewpoints of yes or no. From the genesis of vegetation, it may be reasonable to divided the Qinghai-Xizang Plateau as a separated vegetation region, because the special geographical settings of the Plateau have lead to the special vegetation types and their distribution patterns. The hypothesis of the plateau zonality strongly supports this viewpoint. However, from a viewpoint of the modern vegetation-climate relationship, as a portion of China's vegetation the vegetation of the Plateau could not be separated, because the change of environmental factors is continuous, and the vegetation of the plateau is deeply related to those in surrounding areas, particularly in the northwestern part

Table 1 Major schemes of vegetation regionalization in China

Author	Major bases and variables used	Major zones or regions
Li[14]	Annual mean temperature and annual precipitation	Five groups: evergreen needleleaf forest, deciduous broadleaf forest, evergreen broadleaf forest, steppe, and desert
Huang[16]	Vegetation types	Twenty-six regions in the original scheme are combined into 11 regions in this paper (numbers in parentheses indicate the number of regions in the original scheme): Northeast China forest region (12), Northeast China steppe region (13), North China forest region (14), Loess Plateau steppe region (15), Middle and East China forest region (16, 17), Southwest China Forest Region (18-21), South China Forest Region (22-23), Steppe Region (2-4), Desert and Gobi Region (1), Qinghai-Xizang Plateau Region (5-11), and Azonal vegetation region (24-26)
Qian *et al*[78]	Vegetation types	Thirteen regions: subalpine needleleaf forest region, subcold needleleaf forest region, cold temperate mixed forest region, temperate summer green forest region, warm temperate mixed forest region, subtropical evergreen forest region, tropical and subtropical monsoon forest region, dry desert and semi desert region, plateau frozen desert region, steppe and grassland region, plateau grassland and scrub region, arid mountainous forest-steppe region, steppe and desert complex region
Hou *et al*[79]	Vegetation-soil relationships	Twelve regions: Da Hinggan Mountain needleleaf forest region, Changbai Mountain and Xiao Hinggan Mountain needleleaf and deciduous broadleaf forest region, North China deciduous broadleaf forest region, Northeast China and Jin-Shaan-Gan forest-steppe and steppe region, Middle China deciduous and evergreen broadleaf mixed forest region, Middle South-Southeast-Southwest China evergreen broadleaf forest region, South China tropical monsoon forest region, Southwest China alpine needleleaf forest and meadow region, Nei Mongol-Gansu dry steppe region, Meng-Xin-Qing desertified steppe and steppe region, Northwest China alpine needleleaf forest and steppe region, Qinghai-Xizang Plateau high mountains cold desert and scrubby meadow region
Qian *et al*[80]	Vegetation type	Fifteen regions: Da Hinggan Mountain needleleaf forest region, eastern Mandchuria needleleaf-broadleaf mixed forest region, Northeast China forest-steppe and steppe region, deciduous broadleaf forest and forest-steppe region, deciduous-evergreen broadleaf mixed forest region, deciduous forest region, tropical monsoon forest region, Southwest China mountainous vegetation region, western mountainous needleleaf forest region, alpine steppe-meadow-srub region, plateau cold desert and upper reach of the River basin region, Nei Mongol dry steppe region, semi-desert and desert region
Liu *et al*[81, 82]	Vegetation types, and as well distribution of plant taxa and climatic conditions	Thirteen regions: Da Hinggan Mountain larch forest region, Changbai Mountain needleleaf-broadleaf mixed forest region, North China pine and oak forest region, Middle China tropical evergreen forest region, Hainan and South China Sea Islands tropical evergreen forest region, Qinghai-Xizang Plateau desert-needleleaf forest complex region, Nei Mongol-Xinjiang desert region, Gansu-Nei Mongol steppe-semi desert region, Altay needleleaf forest region, Tianshan spruce forest region
Committee for Natural Regionalization[83]	Three macro-vegetation regions based on relief of macro-topography and monsoon climate; 7 vegetation zones were divided according to zonal vegetation types, and further divided into subzones for each zone	Three regions and seven zones: 1. Eastern China humid forest region: temperate needleleaf forest-needleleaf broadleaf mixed forest region-deciduous broadleaf forest zone, subtropical evergreen broadleaf forest zone, tropical monsoon forest and rain forest zone; 2. Qinghai-Xizang high cold plateau zone: subalpine needleleaf forest zone, meadow-steppe-scrub zone; 3. Nei Mongol-Xinjiang dry steppe and desert region: dry steppe zone, desert zone
Institute of Botany, The Chinese Academy of Sciences[84]	Zonal vegetation types	Three zones and ten regions: 1. Forest zones: cold-temperate needleleaf forest region, temperate needleleaf-broadleaf mixed deciduous forest region, warm temperate deciduous broadleaf forest region, subtropical evergreen forest region, tropical monsoon forest and rain forest region, equatorial coral reef vegetation region; 2. Steppe zone and alpine mountainous scrub-meadow-steppe zone: temperate and warm temperate steppe region, high cold mountainous scrub and meadow-steppe region; 3. Desert zone: temperate-warm temperate desert region, high cold desert region

Table 1 (continued)

Author	Major bases and variables used	Major zones or regions
Hou[67]	Zonal vegetation, distribution of plant taxa, and cultivated vegetation	Eight regions: northern Da Hinggan Mountain deciduous needleleaf forest region, Northeast and North China deciduous forest region, Middle and Southwest evergreen broadleaf forest region, South-Southwest China tropical rain forest region, Nei Mongol-Northeast China steppe region, Meng-Xin-Qing desert region, southeastern Qinghai-Xizang high cold meadow-steppe region, western Xizang high cold desert region
Hou[69]	Zonal vegetation, distribution of plant taxa, and cultivated vegetation	Eight regions: cold temperate deciduous needleleaf forest region, temperate deciduous broadleaf forest region, warm temperate deciduous broadleaf forest region, subtropical evergreen broadleaf forest region, tropical monsoon forest region, temperate steppe region, temperate desert region, and high cold vegetation region
Editorial Committee for Vegetation of China[13]; Editorial Committee for Vegetation Atlas of China, The Chinese Academy of Sciences[85]	Zonal vegetation and characteristics of climate and relief characteristics	Eight regions: cold temperate needleleaf forest region, temperate needleleaf-broadleaf forest region, warm temperate deciduous broadleaf forest region, subtropical evergreen broadleaf forest region, tropical monsoon forest and rain forest region, temperate steppe region, temperate desert region, Qinghai-Xizang Plateau high cold vegetation region
Hou[18]	Zonal vegetation, distribution of plant taxa, and cultivated vegetation	Eight regions: cold temperate needleleaf forest region, temperate deciduous broadleaf forest region, subtropical evergreen broadleaf forest region, tropical monsoon forest and rain forest region, temperate steppe region, high cold meadow-steppe region, temperate desert region, high cold desert region
Hou[19]	Zonal vegetation, distribution of plant taxa, and cultivated vegetation	Thirteen regions: cold temperate needleleaf forest region, temperate needleleaf-broadleaf mixed forest region, warm temperate deciduous broadleaf forest region, eastern subtropical (humid) evergreen broadleaf forest region, western subtropical (dry) evergreen broadleaf forest region, eastern tropical monsoon forest and rain forest region, western tropical monsoon forest and rain forest region, temperate steppe region, warm temperate steppe region, high cold meadow-steppe region, temperate desert region, warm temperate desert region, and high cold desert region
Fang[31, 32]	Eco-climatic parameters were used based on vegetation-climate relationship	Nine regions: cold temperate needleleaf forest region, temperate needleleaf-broadleaf deciduous mixed forest region, warm temperate deciduous-evergreen broadleaf forest region, warm temperate evergreen broadleaf forest region, subtropical and tropical monsoon forest and rain forest region, deciduous woodland region, steppe region, desert region, and high cold vegetation region
Editorial Committee for National Atlas of China[86]	Zonal vegetation and their secondary vegetation types, distribution of plant taxa, and cultivated vegetation	Thirteen regions: cold temperate needleleaf forest region, temperate needleleaf-broadleaf mixed forest region, warm temperate deciduous broadleaf forest region, eastern subtropical humid evergreen broadleaf forest region, western subtropical semi-humid evergreen broadleaf forest region, plateau and mountainous needleleaf forest and evergreen broadleaf forest region, eastern tropical humid monsoon forest and rain forest region, western tropical dry monsoon forest and rain forest region, temperate steppe region, warm temperate steppe region, high cold meadow-steppe region, temperate desert region, warm temperate desert region, high cold desert region
Song[73]	Zonal vegetation and their secondary vegetation types	Six zones from south to north in the eastern part of China: boreal forest zone, cool temperate needleleaf-broadleaf mixed forest zone, temperate deciduous broadleaf forest zone, subtropical evergreen broadleaf forest zone, tropical rain forest and monsoon forest zone
Fang[68]	Eco-climatic parameters were used based on vegetation-climate relationship	Six zones from south to north in the eastern part of China: cold-temperate needleleaf forest zone, temperate needleleaf-broadleaf mixed forest zone, warm temperate deciduous woodland zone, warm temperate evergreen-deciduous broadleaf mixed forest zone, subtropical evergreen broadleaf forest zone, tropical rain forest and monsoon forest zone

of the plateau.

In addition, it is also worthy to note that the temperate and warm temperate steppe and desert zones in western China may not be further divided because the moisture condition is the primary limiting factor for distribution of these dry vegetation types and the thermal variables are not critical for their distribution.

3 Discussions on Some Horizontal Vegetation Zones and Their Boundaries

According to Botanical Society of China[87], there exist four main arguments on China's vegetation regionalization: 1) the boundary between tropical rain forest/monsoon forest and subtropical evergreen broadleaf forest;

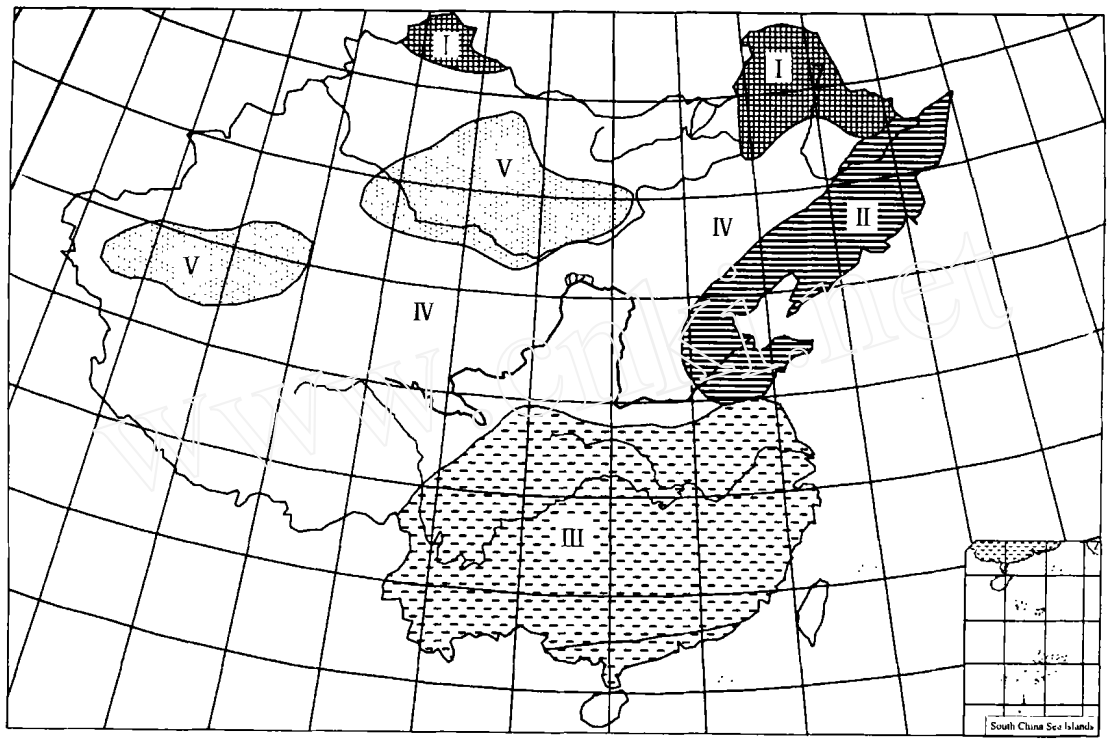

Fig. 1. The earliest scheme of China's vegetation regionalization[14].
I, evergreen needleleaf forest; **II**, deciduous broadleaf forest; **III**, evergreen broadleaf forest; **IV**, steppe; **V**, desert.

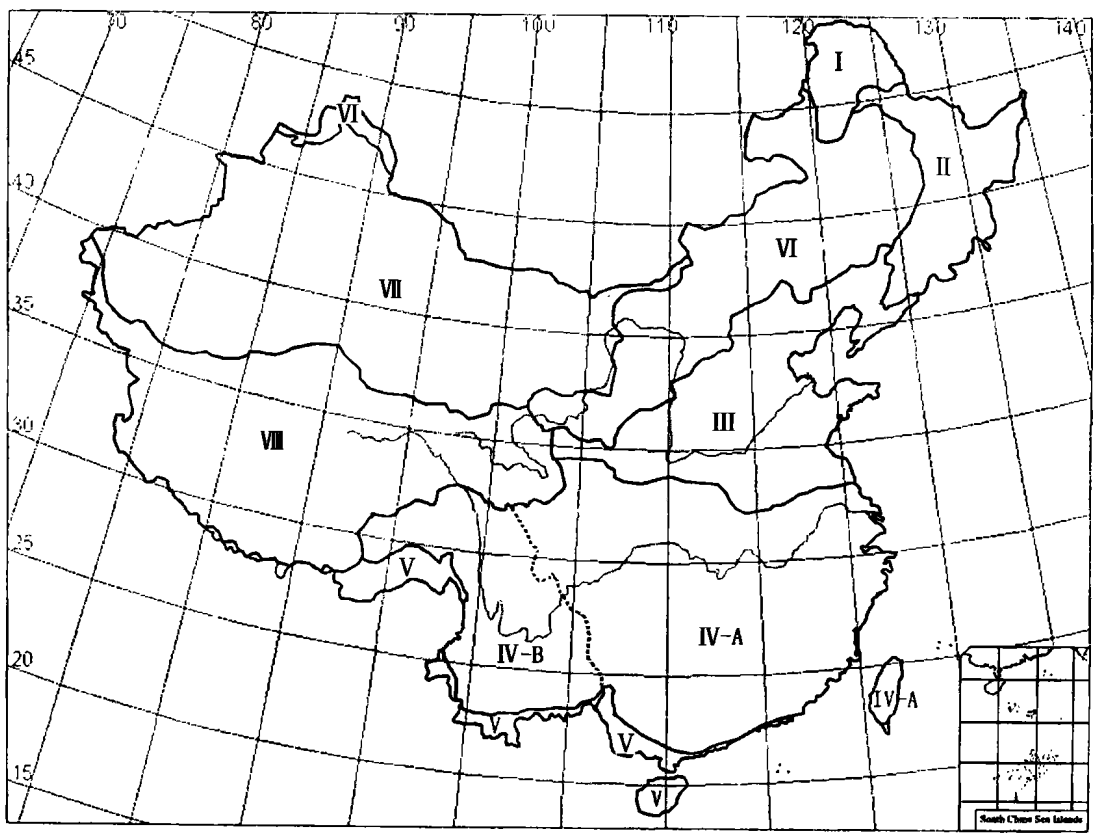

Fig. 2. The newest scheme of China's vegetation regionalization[85].
I, cold temperate needleleaf forest region; **II**, temperate needleleaf and broadleaf forest region; **III**, warm temperate deciduous broadleaf forest region; **IV**, subtropical evergreen broadleaf forest region (**IV**-A, eastern subregion; **IV**-B, western subregion); **V**, tropical monsoon forest and rain forest region; **VI**, temperate steppe region; **VII**, temperate desert region; **VIII**, Qinghai-Xizang Plateau high cold vegetation region.

Table 2 Major schemes of the boundary between tropical and subtropical vegetation zone

Major schemes	Location of the boundary	Climatic parameters	Authors
Boundary 1	From Fuqing, Longyan of Fujian Province, Meixian, Yingde, Huaiji of Guangdong Province, Donglan, Tian'e of Guangxi Autonomous Region, Luodian of Guizhou Province, turn west to Longwu, Changning, Baoshan of Yunnan Province	Frostless season	Chu and Wuan[89]; Tang[90]
Boundary 2	From northern Taiwan to Xiamen and Zhangpu of Fujian Province, along the Lianhua Mountain Range, Qingyuan of Guangdong Province, Nanning, Baise of Guangxi Autonomous Region, to Malipo, Pingbian and Lancang of Yunnan Province	8 - 11 months with monthly mean temperature over 20 ℃	Zeng[91, 92]; Jiang[93]; Hou[17]
Boundary 3	From Jiayi of Taiwan Province, Zhuhai, Maoming of Guangdong Province, Hepu, Dongxin of Guangxi Autonomous Region to Jinping of Yunan Province	Effective accumulative temperature with > 10 ℃ daily mean temperature of 8 000 ℃, and mean temperature of the coldest month > 16 ℃	Institute of Geography, The Chinese Academy of Sciences[94]; Qiu and Lu[95]; Xu[70, 96]; Qiu[97]
Boundary 4	From southern Taiwan, pass through northern and central Hainan Island	The lowest monthly mean temperature of 18 ℃, annual biotemperature of 25 ℃, *WI* of 240 ℃·month	Koppen[3]; Lu[98]; Yao[62]; Kira[9, 99]; Fang[68]; Ahti *et al*[100]

2) the boundary between warm temperate deciduous broadleaf forest and northern subtropical zone; 3) the existence or not of forest-steppe ecotone between temperate deciduous forest and steppe and their boundary; and 4) dividing the Qinghai-Xizang Plateau and its eastern high mountains as a separate vegetation region or not. In the present paper we are to focus on discussion about the first two arguments, namely, boundaries of forest vegetation zones.

3.1 Boundary between the tropical and subtropical zones

The tropical in China is located at the northern edge of the Southeast Asian tropical zone. It occupies a very little part of China. The rain forest which is an indicator of humid tropical zone is transitional in China[88]. Extensive discussions have been made on the boundary between tropical and subtropical vegetation zone, and four schemes can be summarized (Table 2; Fig. 3).

It is beneficial for discussing the tropical range in China to know the definition of the boundary between tropical and subtropical zone. Studying the vegetation distribution in Japan and its surrounding areas, Ahti *et al*[100] concluded that the northern limit of the tropical zone is consistent with the Holdridge's annual mean biotemperature (AMB) of 25 ℃. On the lowlands of lower latitudes, AMB value of 25 ℃ equals to Kira's *WI* of 240 ℃·month. Koppen[3], Wissmann[101], Trewartha[102] and Yao[62] defined the northern limit of the tropical zone with 18 ℃ of isotherm of the coldest month, which is almost equal to *WI* of 240 ℃·month. Therefore, climatically it is reasonable to use *WI* of 240 ℃·month as the boundary between the subtropical and tropical vegetation zone as suggested by Kira[9].

Typical tropical taxa can not be found in plant communities in the northern parts of this region. For example, only scattered individuals of *Vatica* among Dipterocarpaceae, a dominant family in the Southeast Asian tropical rain forests, occurred in Hainan Island. The genera and species of other typical tropical families, such as Burseraceae, Euphorbiaceae, Myrtaceae and Annaceae, are seldom distributed naturally in Hainan Island[103]. According to a tree plot study with a plot of 1 hm^2 at 820 m a.s.l. in mountain tropical rain forests of Jianfengling Nature Reserve in Hainan Island, the forest is dominated by species of Lauraceae, Fagaceae and Symplocaceae that are dominant elements of subtropical forests. Moreover, some temperate elements, such as *Betula alnoides* and *Carpinus lanceolata*, were also found in the plot. These suggested that forests in this region have species composition of typical subtropical evergreen broadleaf forests[68]. That is to say, this area is a transition from tropical to subtropical zone floristically. For this reason, Fang[31, 68] suggested that the *WI* of 240 ℃·month or AMB of 25 ℃ may be used as criteria of the southern limit of subtropical vegetation, or the northern limit of tropical vegetation.

Therefore, we agree with the scheme of the boundary 4 listed in Table 2, because this is not only commonly accepted and comparable internationally, but also coincident with the climatic characteristics of China and their relationship with agricultural practice. In China, the cold winter air mass from the north strongly influences plant growth and agricultural activities in the southern parts. Economically, perennial plants are used as primary cultivated crops in the southern areas and economical damages would be serious once cold disaster occurred[104]. This scheme is generally analogue to that in natural regionalization of China[105].

3.2 The vegetation boundary between subtropical and temperate zones

Chu[106] suggested that the northern limit of the subtropical zone in China run through the Qinling Mountain-Huaihe River-Bailongjiang River line, being almost parallel with 34°N in latitude. However, in the early 1950s, many authors handled the evergreen and deciduous

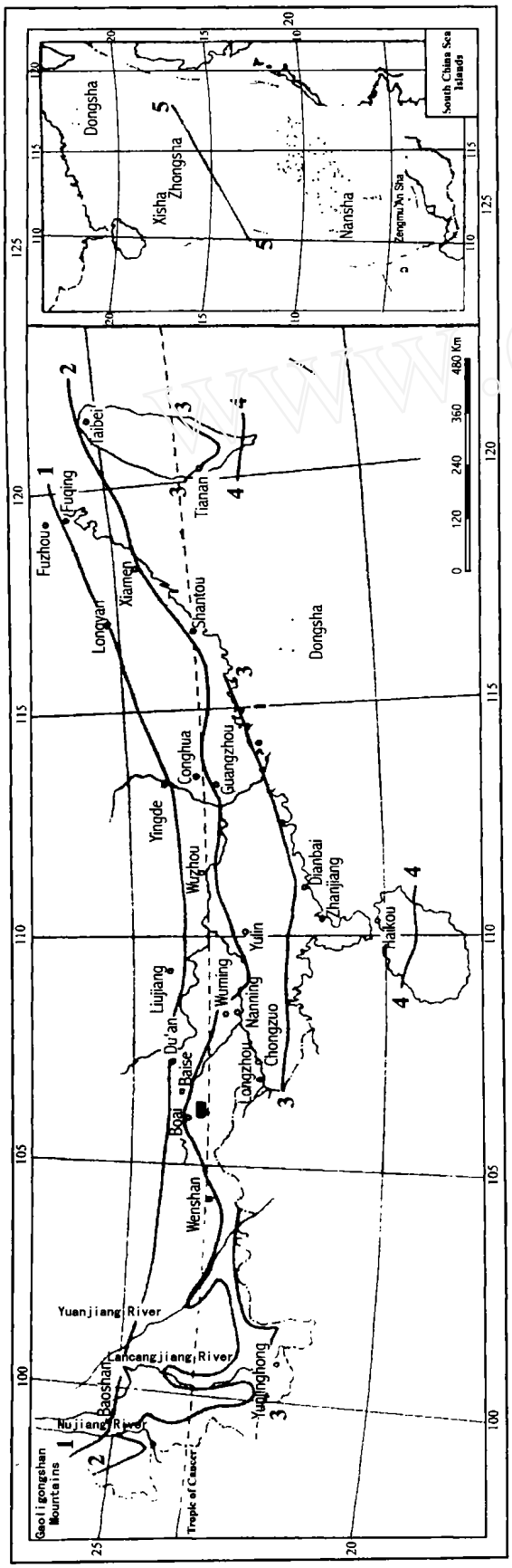

Fig. 3. Northern limits of tropical vegetation zone in China suggested by different authors.
For the boundaries 1 to 4, see Table 2.

broadleaf mixed forest as zonal vegetation of temperate and warm temperate. Some researchers also claimed that the southern limit of the warm temperate zone should be much more southward than that of the warm temperate suggested at present. Since the Qinling Mountain-Huaihe River line had been proposed as the northern boundary of subtropical zone by Chu[106], the evergreen and deciduous broadleaf mixed forest region was handled as subtropical zone, and this viewpoint has been adopted until now[107].

The northern limit of evergreen broadleaf forests expresses the northern limit of the subtropical zone and also the southern limit of the warm temperate zone. Therefore, it is necessary to make clear the characteristics of the evergreen broadleaf forest before discussing the boundary between the subtropical and warm temperate zone.

A number of authors have discussed about ascription of evergreen broadleaf forest[31, 56, 99, 108, 109, 110]. In China, although most researchers insisted that evergreen broadleaf forest belongs to subtropical vegetation type, some regarded it as zonal vegetation of warm temperate zone[107]. Not only almost all the Japanese researchers claimed that the evergreen broadleaf forest belongs to zonal vegetation of the subtropical, but European scientists who proposed the term "subtropical evergreen broadleaf forest" tend to use the term "warm temperate evergreen broadleaf forest"[102, 111, 112, 113]. Walter[113] described the evergreen broadleaf forest as zotal vegetation type of warm temperate zone. International Union for the Conservation of Nature (IUCN)[114] handled East Asian evergreen broadleaf forest as the temperate rain forest, and the Mediterranean sclerophyllous forest as Mediterranean broad-sclerophyll forest.

The Japanese Archipelagos bestride about 20 latitudes. The precipitation is plentiful across the country and plant growth is primarily affected by thermal conditions, thus the pattern of Japan's vegetation distribution is very important for identifying biotemperature zones of the world. According to studies in Japan, the *WI* value for evergreen broadleaf forest is 85 - 180 °C·month and *CI* value < 15 °C·month[63, 64]. That is to say, the forest appears from Sendai along the coastal area of the Pacific Ocean in the north to southern edge of Kyushu and Yakushima and Tanejima Island in the south. The present distribution of the evergreen broadleaf forest reaches 40.5 °N in its northernmost limit. This is to say, the northern limit of the subtropical zone in Japan should reach 40.5 °N if the evergreen broadleaf forest is regarded as zonal vegetation of the subtropical zone. The isotherm of *WI* 85 °C·month reaches north of Beijing, and the range with *CI* value of 10 - 15 °C·month is broader than the range of the current evergreen broadleaf forest. Therefore, the subtropical zone in China could be much broader if it was divided by the criterion described previously. This is not the truth. In China, the distribution of evergreen broadleaf forest is primarily restricted by moisture conditions as well as the low winter temperature[26, 29, 68]. Being this reason, Chu[106] claimed the Qinling Mountain-Huaihe River line to be the northern limit of the subtropi-

cal zone when some former USSR scientists suggested that North China, southern part of Northeast China and southern Xinjiang belonged to the subtropical zone in the early 1950s. Chu's viewpoint has been commonly accepted by most researchers in China. However, if this is true, then another question would be raised: evergreen broadleaf forest could be distributed in the most parts of North China if amount of precipitation was enough for its growth because thermal conditions was enough in North China. Therefore, should the northern limit of the subtropical zone move northward? If so, what should be the criterion of temperature zone, thermal conditions or precipitation? The division of temperature zones should eliminate the effects of moisture conditions because they are two different things. In another word, its division should be dependent on the vegetation pattern in those areas with abundant precipitation.

Although most researchers in China regard the evergreen broadleaf forest as zonal vegetation type of the subtropical and define Qingling Mountains-Huaihe River as its northern boundary, some disagree with this opinion. Zhou[107] argued that it was unreasonable to define the northern limit of the evergreen and deciduous broadleaf mixed forest as that of the subtropical vegetation. Han[115] pointed out that the northern limit of the subtropical zone in Anhui Province should put much more southern. Ahti *et al*[100] defined the biotemperature of subtropical zone as 18 - 25 ℃ and *WI* of 150 - 160 ℃·month. Fang and Yoda[29] and Fang[56] pointed out that Qinling Mountain-Huaihe River line is an important boundary of moisture climate rather than the boundary between two temperature zones, and a detailed discussion on this will be done in section 4.4 of the paper. Based on a study of flora and plant communities in Qinling Mountain area, Ying[116] demonstrated that the Qinling Mountain-Huaihe River line could not be regarded as the boundary between subtropical and temperate plants.

The major reason for the Qinling Mountain-Huaihe River line as the northern limit of the subtropical zone by Chu[106] was because the evergreen broadleaf forest occurred there. In reality, the evergreen broadleaf forest declared by Chu[106] was not forest community but only some individuals of evergreen trees being sparsely in some humid sites. Where is the real northern limit of the evergreen broadleaf forests? Deng *et al*[117] reported that *Castanopsis sclerophylla*, *Cyclobalanopsis glauca*, *Lithocarpus glabera*-dominated evergreen broadleaf forest was distributed in Huoshan and Jinzai of Anhui Province. *C. sclerophylla*, *C. glauca*, *Castanopsis carlesii* and *Schima superba*-dominated forest appeared in Yixing and Wuxian of Jiangsu Province[118]. These areas can be regarded as the northern limit of evergreen broadleaf forest in the eastern China. In comparison with the Qinling Mountain-Huaihe River line, this line is situated more southern, along 30°N latitude parallel. The *WI* values along this line are 120 - 130 ℃·month and *CI* < 10 ℃·month.

That is to say, the northern limit of the subtropical vegetation zone should be laid much more southern if the evergreen broadleaf forest is regarded as the zonal vegetation type of the subtropical zone. Song[73] and Fang[68] hence insisted that the northern limit of the subtropical zone in China is along the northern coast of the Yangtze River, from Hangzhou Bay, Taihu Lake, Xuancheng and Tongling of Anhui Province, southern slope of Dabie Mountains, Wuhan and westward, which is consistent with the *WI* values of 130 - 140 ℃·month.

3.3 Zonal vegetation type in the warm temperate zone

There are a large amount of discussions on the range and limits of the warm temperate vegetation zone, particularly on its southern limit. After Chu[106] adopted the Qinling Mountain-Huaihe River line as the northern limit of the subtropical vegetation zone in China, this line has also regarded as the southern limit of zonal vegetation of the warm temperate zone in China. As discussed above, botanical, climatological and ecogeographic evidence has supported that this line is not the northern limit of the subtropical vegetation zone and the southern limit of the warm temperate vegetation zone. Based on such an understanding, Song[73] and Fang[68] insisted that the southern limit of the warm temperate vegetation zone should be along the northern coast of the Yangtze River. As proposed in the previous studies, the northern limit of the warm temperate vegetation zone was along the Shenyang-Dandong line[68]. Therefore, the warm temperate vegetation zone in China would cover Shandong Peninsular, Liaodong Peninsular, North China and Jianghuai Plain and Hills. The zonal vegetation of the warm temperate vegetation zone can be distinguished into two types, deciduous broadleaf woodland and evergreen and deciduous broadleaf mixed forest, according to heat and moisture conditions[68].

3.3.1 Warm-temperate deciduous broadleaf woodland This type is distributed in the North China Plain and its southern limit is along the Huanhe River-northern slope of Qinling Mountain and the northern limit along the Shenyang-Dandong line in Liaoning Province. In case some evergreen trees can appear in deciduous broadleaf forests, but tall and closed forests can not formed in lower places due to dry climate. The Thornthwaite's *Im* value[5] in this area is - 20 - 0, implying a subhumid climate. The vegetation type is transitional from grassland to woodland according to Thornthwaite's water balance system[68].

There are different viewpoints about the zonal vegetation type in this area. For example, there are three understandings about the zonal vegetation in Beijing area. The first one is deciduous broadleaf forest, as suggested by Editorial Committee for Vegetation of China[13]. The second is woodland-steppe suggested by botanists[119] and climatologists[9, 62, 101]. The third is dry broadleaf forest suggested by Li *et al*[120]. Fang[68] suggested that the zonal vegetation type is the deciduous broadleaf woodland. This is supported by the early observations[121, 122]. That the woodland-steppe ecotone at the edge of the Nei

Mongol Plateau was only dozens of kilometer away from Beijing is also an evidence[123]. The climatological evidence for the characteristics of deciduous woodland in this area can be referred to a large amount of literatures[55, 98, 101, 124, 125].

3.3.2 Warm-temperate deciduous and evergreen broadleaf mixed forest It corresponds to the northern subtropical evergreen and deciduous broadleaf mixed forest of the scheme of Editorial Committee for Vegetation of China[13] and Hou[19], and warm temperate evergreen and deciduous broadleaf mixed forest of Song[73]. The northern limit is along the Qinling Mountain-Huaihe River line in the west and northward to Shandong Penisular in the east, and parallel to the Thornthwaite's *Im* value of 0. Its southern limit is also the northern limit of the subtropical zone and generally in consistent with the *WI* 135 °C·month line. The eastern part of this limit corresponds to the *Im* value of 60, which is regarded as the boundary between perhumid (rain forest) and humid (deciduous forest) climate in East Asia[28]. In some sites with better moisture conditions, evergreen broadleaf forest or deciduous broadleaf forest mixed with evergreen element is distributed. For example, in Shandong Peninsular, north of this zone, evergreen and semi-evergreen elements, such as *Machilus thunbergii* and *Camellia japonica*, are naturally distributed[126]. However, most parts of this zone are dominated by deciduous broadleaf forests due primarily to water deficiency and secondarily to low winter temperature. Many study have demonstrated that the extremely low temperature should not be lower than -15 °C for the northward distribution of evergreen broadleaf forests[51], and winter temperature might be down to -20 °C in some areas of this region. Fang[68] suggested to term the zonal vegetation as warm-temperate deciduous and evergreen broadleaf mixed forest because vegetation in this zone is dominated by deciduous broadleaf forest and evergreen elements are subordinate.

3.4 Significance of the Qinling Mountain-Huaihe River line in the division of vegetation zone

After Chu[106] proposed the Qinling Mountain-Huaihe River line as the northern limit of the subtropical zone, this line has become an important thermal boundary. In addition to vegetation regionalization, the climatic regionalization[124], integrated physiogeographical regionalization[94] and agricultural regionalization all use this line as the northern limit of the subtropical zone. Undoubtedly, this line has botanical, geographical and ecological significance as a transition from humid to semi-humid area. Nevertheless, it is worthy to be argued if this line is regarded as the boundary of thermal/heat zone.

It is critical to the vegetation regionalization to understand difference and relationship between thermal and humid/arid (or moisture) climate zone. Fang[31, 68] pointed out that tropical, subtropical and temperate zone belong to division of thermal climate and thus without doubt their limits should be based on thermal conditions. The division of thermal zones should eliminate the effects of moisture conditions. In another word, the division of thermal zones should be based on vegetation in areas with abundant precipitation. This is why some authors[31, 68] emphasized the significance of the vegetation pattern in Japan on dividing thermal climate zone in China and in the world because moisture conditions are not limiting factor for plant/vegetation distribution in Japan. On the other hand, the division of moisture climate zone should be dependent on water conditions and combination of water and heat, and it reflects life form of plants and coverage of vegetation. It is particularly important to understand the relationship between the thermal zone and moisture zone in vegetation regionalization in China because both temperature and precipitation decline from south to north in the eastern part of China, and because this may cause a misunderstanding of vegetation morphology caused by these two factors. The confusion on the northern limit of the subtropical zone/the evergreen broadleaf forest zone in China might be induced by this misunderstanding[68].

Table 3 lists major thermal and arid/humid parameters around Qinling Mountain-Huaihe River line to analyze significance of the line. As shown in this table, thermal indices showed a large changes along the Qinling Mountain-Huaihe River line, e.g., *WI* from 103.0 to 131.0 °C·month with a mean of 121.1 °C·month; *CI* from 1.0 to 10.0 °C·month with a mean of 5.3 °C·month; annual mean temperature from 13.0 to 15.8 °C·month with a mean of 14.6 °C·month; mean temperature for the coldest month from 0.4 °C to 4.1 °C with a mean of 1.9 °C. The values of these indexes were all much larger than those at the northern limit of evergreen broadleaf forest in humid areas studied previously. Moreover, *WI* and annual mean temperature tended to an increase and *CI* to a decrease from west to east. This suggests that the more northward distribution of evergreen broadleaf forest is possible. On the other hand, changes in moisture indexes were relatively small, e.g. the annual precipitation from 700 to 900 mm with a mean of 817.2 mm; *Im* from -7 to 7 with a mean of -0.1. All these indexes showed that this line is the transition from humid to semi-humid climate and that water deficiency restricts the northward expansion of evergreen broadleaf forests. This further supports the conclusion of that Qinling Mountain-Huaihe River line is not the northern limit of the subtropical zone in China, but a pseudo-thermal limit caused by water deficiency[31, 68].

3.5 The significance of the Nanling Mountains line

The climatic indexes along the Nanling Mountains line are *WI* value of 170 - 180 °C·month and annual mean temperature of 20 °C, which corresponds to the northern limit of the subtropical zone of Kira[9, 127] and Ahti *et al*[100]. This line corresponds to the southern limit of southern subtropical monsoon evergreen broadleaf forest zone of Editorial Committee for Vegetation of China[13] and subtropical evergreen broadleaf forest zone of Song[73], and to the boundary between the tree species groups (e.g. *Castanopis hystrix*, *C. indica*) of typical subtropical evergreen broadleaf forest and those

(*Cryptomerya chinensis*, *Ficus* spp.) of the southern evergreen broadleaf forest identified by Fang[31, 56]. Accordingly, it can be understood that the northern part of the line is typical evergreen broadleaf forest and its south part is a transition from the subtropical to tropical. This viewpoint is coincident with claim of that the southern slope of the Nanling Mountains was the northern limit of southeast subtropical rain forests by He[128].

4 Climate Changes and Vegetation Regionalization

The current China's vegetation regionalization is actually a static division of biochimatic zone or potential vegetation zone. However, climate, especially, winter temperature, has remarkably changed in China during the last several decades. This should influence strongly distribution of vegetation and crops, and agricultural activities[129]. Corresponding to such changes in climate/plant distribution, it would be an urgent demand to develop a dynamic vegetation regionalization based on vegetation-climate relationships. To illustrate the importance of dynamic vegetation/climate distribution, two maps of the thermal and arid/humid climate zones derived from mean climatic variables of two periods of 1950 - 1979 and 1970 - 1999 are shown in Figs. 4, 5, respectively. The threshold values for the climate zones used in the figures are listed in Table 4.

Table 3 Major thermal and arid/humid indexes at major sites along the Qinling Mountain-Huaihe River line

Station	Latitude (N)	Longitude (E)	Altitude (m)	*WI* (℃·month)	*CI* (℃·month)	*AMT* (℃)	*MTCM* (℃)	*P* (mm/a)	*Im*
Bengbu	32°57′	117°23′	18.7	129.8	5.5	15.4	1.7	924.3	3.1
Suxian	33°38′	116°59′	25.9	124.4	8.5	14.7	0.7	836.7	-0.8
Shouxian	32°32′	116°35′	22.7	125.5	6.6	14.9	1.3	916.6	6.0
Fuyang	32°55′	115°49′	30.6	128.8	5.5	15.3	1.7	900.0	2.3
Boxian	33°52′	115°46′	37.7	123.9	8.8	14.6	0.5	780.0	-4.8
Xihua	33°47′	114°31′	52.6	120.8	8.9	14.3	0.6	761.7	-5.0
Baofeng	33°53′	113°03′	136.4	121.9	8.4	14.5	0.8	731.6	-7.5
Zaoyang	32°09′	112°45′	125.5	129.4	3.6	15.5	2.3	843.2	-1.8
Nanyang	33°02′	112°35′	129.2	124.5	6.5	14.8	1.4	762.3	-5.9
Xixia	33°30′	111°50′	250.3	123.9	4.3	15.0	2.2	843.7	0.0
Guanghua	32°23′	111°40′	90.0	128.7	3.3	15.5	2.5	843.4	-0.6
Yunxian	32°50′	110°49′	201.9	131.0	1.7	15.8	3.4	830.0	-3.1
Fangxian	32°02′	110°46′	426.9	116.2	5.6	14.2	1.8	833.0	0.9
Mulan	33°00′	110°25′	249.1	124.8	3.0	15.2	2.5	754.8	-6.6
Shangluo	33°52′	109°58′	742.2	102.9	9.8	12.8	0.4	676.2	-5.1
Zhen'an	33°26′	109°09′	693.7	102.9	7.2	13.0	1.4	767.6	1.9
Xikang	32°43′	109°02′	290.8	128.8	1.6	15.6	3.5	816.4	-3.2
Shiquan	33°03′	108°16′	484.9	116.8	2.9	14.5	2.8	873.9	9.1
Hanzhong	33°04′	107°02′	509.5	115.8	4.1	14.3	2.4	854.0	7.2
Lueyang	33°19′	106°09′	794.2	104.6	5.1	13.3	2.1	799.3	7.3
Pingwu	32°25′	104°31′	876.5	116.7	0.9	14.7	4.1	812.7	3.9
Mean				121.1	5.3	14.6	1.9	817.2	-0.1
SD				8.71	2.65	0.82	1.0	62.05	4.96

WI, warmth index; *CI*, coldness index; *AMT*, annual mean temperature; *MTCM*, mean temperature for the coldest month; *P*, annual precipitation; *Im*, moisture index.

Table 4 Critical climatic indexes for dividing vegetation region of China (Modified from Thornthwaite[5]; Thornthwaite and Hare[130]; Fang and Yoda[26-28]; Fang[68])

Thermal climate		
Climate type	Climatic index	Vegetation type at humid condition
Cold-temperate	$WI < 50$	Coniferous forest
Temperate	$50 < WI < 90$	Mixed coniferous and deciduous forest
Warm-temperate (northern subzone)	$90 < WI < 120$, $CI > 10$	Deciduous broadleaf woodland
Warm-temperate (southern subzone)	$120 < WI < 135$, $CI < 10$	Deciduous and evergreen broadleaf Mixed forest
Subtropical	$135 < WI < 240$	Evergreen broadleaf forest
Tropical	$WI < 240$	Rain forest and monsoon forest
Arid/humid climate		
Climate type	Climatic index	Vegetation type at warm condition
Arid	$Im < -40$	Desert
Semiarid	$-20 > Im > -40$	Grassland
Subhumid	$0 > Im > -20$	Woodland
Humid	$60 > Im > 0$	Deciduous forest
Perhumid	$Im > 60$	Evergreen forest

WI, warmth index (℃·month); *CI*, coldness index (℃·month); *Im*, moisture index.

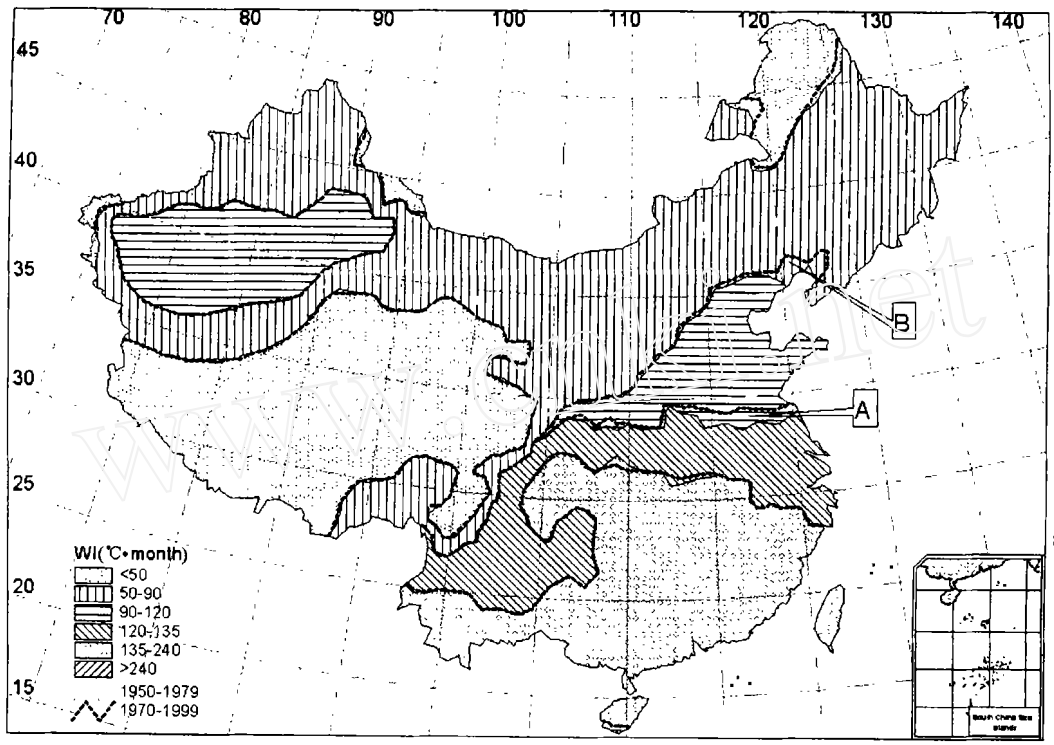

Fig. 4. Thermal climate zones of two periods of 1950 - 1979 and 1970 - 1999 in China.
All the boundaries of the thermal zones tend to move northward during 1970 - 1999 compared with period of 1950 - 1979 in the eastern part of China, of which the northern limit of the southern warm temperate zone (Qinling Mountain-Huanihe River-line) (A) and of the northern warm temperate zone (southern Liaoning Province) (B) remarkably moved northward.

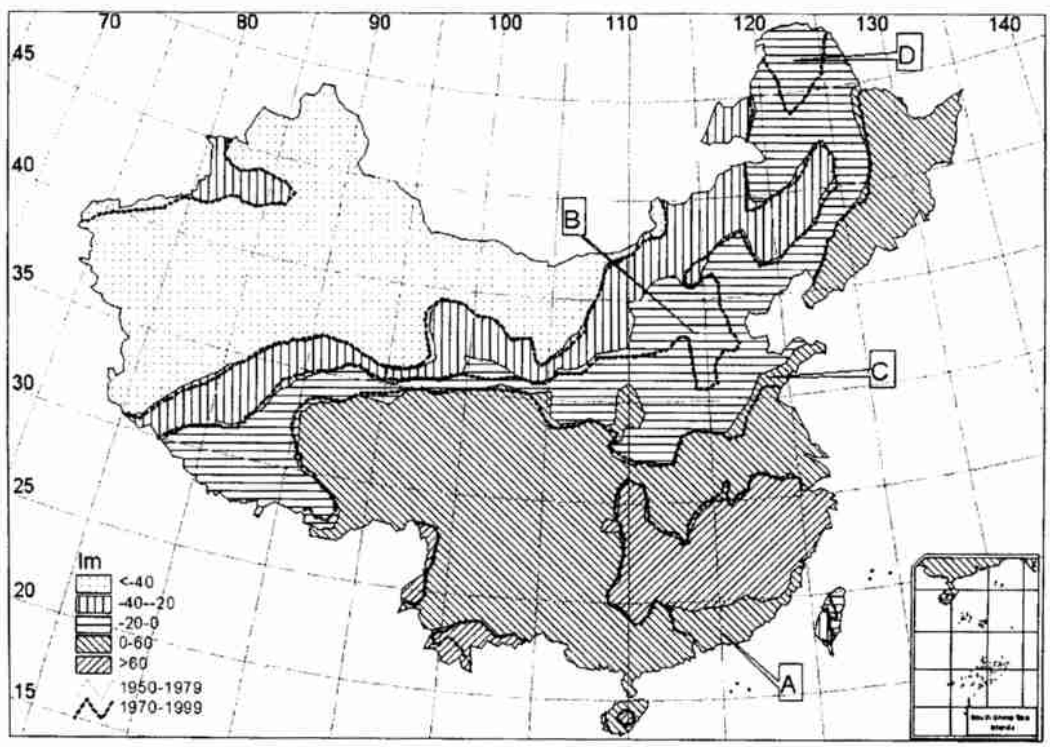

Fig. 5. Arid/thumid climate zones of two periods (1950 - 1979 and 1970 - 1999) in China.
Remarked change can be found in the following places: A, the range of evergreen broadleaf forest has expanded, particularly in area from Zhuhai (Guangdong Province) to the southern slope of the Nanling Mountains in the period of 1970 - 1999; B, the climate in North China has become drier, particularly in northwestern North China Plain, and a large area has become semi-arid (grassland) climate from semi-humid (woodland); C, Shandong Peninsular is becoming drier and this has led to a southward movement of the northern limit of the warm temperate deciduous broadleaf forest; D, the Da-xing-an-ling Mountains became more humid.

Clearly, all the boundaries of the thermal zones tend to move northward during 1970 - 1999 compared with period of 1950 - 1979 in the eastern part of China, of which the northern limit of the southern warm temperate zone (Qinling Mountain-Huanihe River-line) (Fig. 4A) and of the northern warm temperate zone (southern Liaoning Province) (Fig. 4B) remarkably moved northward (Fig. 4). On the other hand, boundaries of the arid/ humid climate zones in these two periods revealed a significant variation. In comparison with the period of 1950 - 1979, the changes during 1970 - 1999 can be summarized as follows (Fig. 5): 1) the range of evergreen broadleaf forest expands in the period of 1970 - 1999, particularly in area from Zhuhai (Guangdong Province) to the southern slope of the Nanling Mountains (Fig. 5A); 2) the climate in North China has become drier, particularly in northwestern North China Plain, and a large area has become semi-arid (grassland) climate from semi-humid (woodland), and this has resulted in an increase of grassland area (Fig. 5B); 3) Shandong Peninsular is becoming drier and this has led to a southward movement of the northern limit of the warm temperate deciduous broadleaf forest (Fig. 5C); and 4) part of the Da-xing-an-ling Mountains became more humid (Fig. 5D).

In closure, vegetation pattern will change with climatic variation. However, vegetation and climate data used in the previous vegetation regionalization of China were almost obtained before the 1970s or 1980s, and therefore the vegetation regionalization could not reflect the current distribution of either vegetation or climate. How vegetation regionalization reflects the dynamic climate and the dynamic vegetation-climate relationships is an urgent theme that vegetation ecology is facing.

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植被气候关系与我国的植被分区

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摘要: 气候制约着植被的地理分布,植被是区域气候特征的反映和指示,两者之间存在密不可分的联系。揭示植被与气候之间的关系是正确认识植被分布的前提,是进行植被区划的理论基础。植被区划是植被研究的归纳和总结,是其他自然地理区划和农林业区划的基础。本文在简要回顾中国植被气候关系及植被分区的研究历史的基础上,对我国以往的主要植被分区原则、依据和方案进行了评述,对有争议的主要植被界线进行了讨论。我们认为,在当今我国大部分地区的原生植被已遭到破坏的现实情况下,根据原生植被及其衍生植被类型的分布,确定其分布与限制性气候因子的关系,以此来进行植被带(区)的划分,不仅反映植被气候间密不可分的关系,在实践上也便于操作。尽管在一些植被带的命名、具体界线的划定上有分歧,但最近的中国植被分区方案大都认为我国基本的植被区有 8 至 9 个,即针叶林、针阔叶混交林、落叶阔叶林、常绿落叶阔叶混交林、常绿阔叶林以及雨林季雨林、草原、荒漠以及高寒植被。通过分析主要植被带附近的植被、气候等特征,本文认为,1) 秦岭淮河线是一条重要的水分气候带,而不是温度带,不是亚热带植被的北界;2) 我国亚热带植被的北界基本上沿长江北岸,从杭州湾经太湖、安徽宣城、铜陵经大别山南坡到武汉往西,与 *WI* 值 130 - 140 ℃·月一致;3) 我国热带区域的面积极小,仅分布在海南岛的东南部和台湾南端及其以南地区; 4) 我国东部地区暖温带的水热条件南北差异甚大,建议以秦岭淮河为界,将暖温带划分为两个植被带,即落叶阔叶疏林带和落叶常绿阔叶混交林带;华北地区的地带性植被为落叶阔叶疏林。最后,本文还强调了对应于气候变化进行动态植被分区的重要性。

关键词: 中国; 动态植被区划; 水分气候; 亚热带北界; 秦岭淮河线; 温度气候; 植被气候关系; 植被分区; 植被界线

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