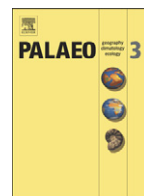




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Geographical elements of seed plants suggest the boundary of the tropical zone in China

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ABSTRACT

The distribution patterns of geographical elements of seed plants from 135 regional floras that cover southern China were used to reassess the extent and boundaries of the tropical zone. The areas for which tropical genera account for >80% of the total genera in the flora are south of 22°30'N in southern and southeastern China, which corresponds closely to the northern boundary of the tropical monsoon forest and rain forest in southeastern China. The line at c. 22°30'N is therefore suggested to be the northern biogeographical boundary of the tropical zone in south and southeastern China. This line exceeds the northern boundary of marginal tropical climate, which implies that the tropical zone could have extended further north in the geological past than it does today. The study supports the suggestion from palaeoecological studies that tropical and subtropical broadleaved evergreen forests in eastern China shifted north during the mid-Holocene. It also shows that there are climatic and biogeographical disparities between southeastern and southwestern China due to their different topography and geology.

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1. Introduction

The tropical region in China has generally been recognized to be the area on the northern edge of tropical Asia, including southeastern Xizang (Tibet), southern Yunnan, southwestern Guangxi, southern Taiwan, and Hainan Island (Zhu, 1997). Chinese meteorologist, Zhu Kezhen, suggested that south of the Nanling Mountains was the tropical area in China roughly south of 24°–25°N in southern China (Guangxi and Guangdong provinces) and up to 26°N in southeastern China (Fujian province), south of which there is no winter (Zhu and Wan, 1963). Chinese geographer, Ren Meie, suggested that vegetation and soil could be better indicators of bio-climate than a single climatic factor (Ren and Xiang, 1963; Ren and Zeng, 1991). He drew a demarcation line for the tropical area of China that generally corresponded with the Tropic of Cancer in southern China but extended north to 25°N in western Yunnan in southwest China and to c. 25°30'N at Putian in Fujian province in southeastern China, as well as including the whole of Taiwan. South of this line, there are 8–11 months with monthly mean temperatures >20 °C. Further south, a line at c. 21°30'N, with the annual effective accumulative temperature of 8000 °C, daily mean temperature >10 °C, and mean temperature of the coldest month >16 °C, has been suggested to be the climatic northern boundary of the tropical area in southern China (Institute of Geography, Chinese Academy of Sciences, 1959; Qiu and Lu, 1961; Qiu, 1986). The tropical areas in a narrow sense were suggested to be limited to southern

Hainan and the southern margin of Taiwan, with a mean temperature of the coldest month 18 °C and an annual biotemperature 25 °C (Fang, 2001; Fang et al., 2002). This agrees with the Köppen–Geiger climate classification of the equatorial monsoon climate (Kottek et al., 2006). These four suggested demarcation lines for the northern boundary of the tropical zone in China are largely based on bioclimatic and agroclimatic parameters or macro-level vegetation boundaries and vary from less than 20°N in Hainan in southern China, to 26°N in southeastern China. They were summarized by Tang (1964) and later used by numerous authors from different disciplines (Fig. 1). Although Holdridge (1947) suggested a life zone system using a three-dimensional bioclimate classification based on biotemperature, precipitation, and an aridity index, the life zone system is rarely used in Chinese vegetational and climatic classifications. From the updated Köppen–Geiger climate classification (Kottek et al., 2006; Peel et al., 2007), the tropical monsoon climate is limited only to southern Hainan and the southern margin of Taiwan, but on the newly published high-resolution bioclimate map of the world (Metzger et al., 2012), the whole of southern China falls into the category of hot and wet tropical conditions. This uncertainty concerning the northern boundary of the tropical zone in China hinders objective regionalization in agriculture and physical geography, especially for determining the areas for tropical crops.

It has been found that floristic patterns are strongly associated with geographical (particularly latitudinal) factors in local floras across China (Qian et al., 2003, 2006; Zhu et al., 2007). A line at c. 22°30'N was tentatively suggested as the northern boundary of the tropical zone in south and southeastern China from the biogeographical patterns of Chinese seed plants, south of which regional floras are

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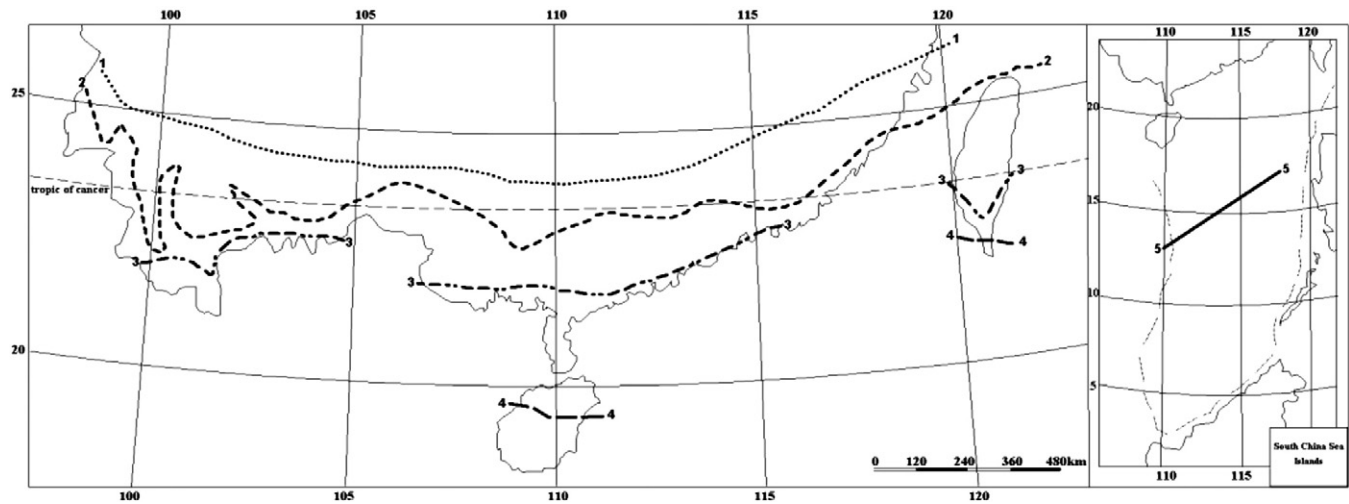


Fig. 1. Four suggested demarcation lines for the tropical zone in China (redraw from Tang, 1964). Line 1: Northern boundary of tropical zone in broad sense (without winter all the year round) (represented by Zhu and Wan, 1963; Tang, 1964). Line 2: Based on 8–11 months with monthly mean temperature over 20 °C (represented by Zeng, 1966; Ren and Zeng, 1991). Line 3: Based on effective accumulative temperature with > 10 °C daily mean temperature of 8000 °C and mean temperature of the coldest month > 16 °C (represented by Institute of Geography, Chinese Academy of Sciences, 1959). Line 4: Based on the lowest monthly mean temperature of 18 °C, annual biotemperature of 25 °C (Fang, 2001; Fang et al., 2002). Line 5: Equatorial tropic zone.

dominated by tropical genera (Zhu et al., 2007). This line corresponds well with the currently recognized northern boundary of the tropical monsoon and rain forests of China (Wu, 1980; Hou, 1981, 1988; Cao et al., 2006; Zhang, 2007; Zhang et al., 2010). It exceeds the northern boundary of the marginal tropical climate, and the local floras dominated by tropical elements are present in areas far north of the climatic tropics in southeastern China, which may imply that the tropical zone extended further north during geological history. In this article, we will discuss the boundary of the tropical zone of China biogeographically by analyzing the distribution patterns of geographical elements of seed plants from an updated database of regional floras in southern China. We will also discuss the palaeovegetation patterns of China from the implications of the distribution of geographical elements of seed plants.

2. Materials and methods

A database of 135 regional floristic works covering the areas of southern China south of 30°N was used to illustrate the distribution patterns of their floristic elements (see Appendix 1). The genera of Chinese seed plants were assigned to 15 distribution patterns, according to their worldwide geographical distributions, following the 15 geographical elements of Wu (1991). The genera from these regional floras were classified into 15 distribution types based on Wu's classification. For example, the flora of southern Yunnan consists of 1176 genera, which could be classified into 15 geographical elements (Zhu, 2008a), according to their worldwide geographical distributions, as follows: Cosmopolitan (59 genera), Pantropic (251), Tropical Asia and Tropical America disjunct (30), Old World Tropics (112), Tropical Asia to Tropical Australia (76), Tropical Asia to Tropical Africa (96), Tropical Asia (355), North Temperate (60), East Asia and North America disjunct (32), Old World Temperate (24), Temperate Asia (5), Mediterranean region, West to Central Asia (2), Central Asia (1), East Asia (62), and Endemic to China (11). Among these 15 geographical elements, six are tropical: (1) "Pantropic"—this distribution type includes the genera which are distributed throughout the tropics of the western and eastern hemispheres or those genera which have one or more distribution centers in the tropics, but with some species distributed in other regions. (2) "Tropical Asia and Tropical America disjunct"—included in this category are those genera which are disjunctly distributed in warm regions of America and Asia. (3) "Old World Tropic"—these are the genera which are distributed throughout the tropical areas of Asia,

Africa, Australia, and their adjacent islands. (4) "Tropical Asia and Tropical Australia"—this distribution type is the east wing of the "Old World Tropic" distribution. Its western boundary is sometimes in Madagascar but never in continental Africa. (5) "Tropical Asia to Tropical Africa"—this distribution type includes the genera which are distributed from tropical Africa to the Indo-Malaysia region, as the west wing of the "Old World Tropic" distribution. (6) "Tropical Asia (Indo-Malaysia)"—this distribution type includes the genera which are distributed throughout the Tropical Asian (Indo-Malaysia) region, and its eastern boundary reaches Fiji or the islands of the South Pacific, but never Australia, and the northern boundary mostly reaches Southwest and South China and Taiwan. These six tropical elements from the regional floras are significant indicators of tropical environments in southern China and were used in our study.

The ArcView software was used for making frequency maps of geographical elements from the regional floras. The frequencies were grouped into five classes that were classified by natural breaks with breakpoints between classes identified using a statistical formula, Jenk's optimization, a default classification method in ArcViewGIS 3.1 that reduces variance within classes and maximizes variance between them. Graduated symbols were used. The frequency of the tropical genera in total was also grouped into two classes, classified by natural breaks and by arbitrary breaks respectively, to discuss geographical demarcations.

3. Results

The genera of tropical Asia distribution are typical tropical elements and one of the dominant floristic groups in regional floras in southern China. They account for 42.3% of the total genera in the flora of southern Yunnan at c. 21.5°N in southwest China, contributing to the highest proportion in all the regional floras of southern China. They account for 32.4% of the total genera in the flora of Hainan at c. 19°N in southeast China (Fig. 2). The frequency of these genera is related to latitude, generally declining in proportion with increasing latitude. The tropical genera in total (including all tropical distribution types) make up a majority in regional floras in southern China. They account for 94.4% of the total genera in the flora of southernmost Yunnan, having a similar frequency pattern to the tropical Asian distribution (Fig. 3). However, these tropical elements decrease

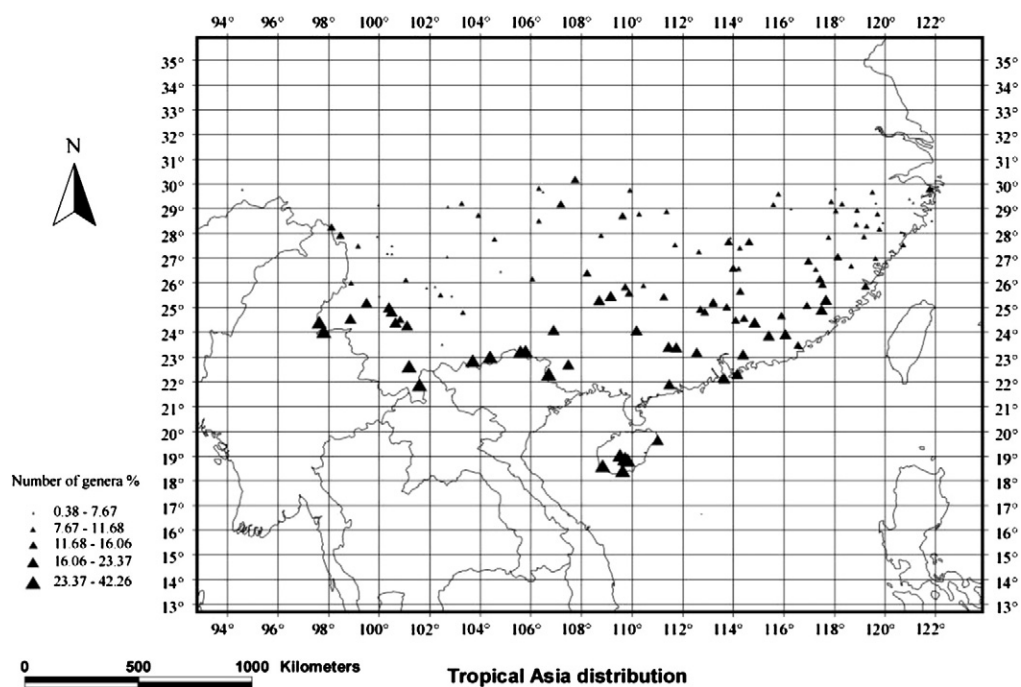


Fig. 2. Frequency of genera with Tropical Asian distribution (grouped into 5 classes, which were classified by natural breaks, identifying breakpoints between classes using a statistical formula: Jenk's optimization, a default classification method in ArcView).

more regularly with increasing latitude in southeastern China than in southwestern China.

The frequency of the tropical genera in total, grouped into two classes classified by a natural break, shows a demarcation, which is roughly 24°–25°N in Guangxi and Guangdong provinces in southern China, and up to 26°N in southeastern China (Fujian) (Fig. 4). In the areas south of the demarcation, tropical genera account to 60% of the total genera.

If the frequency of the tropical genera in total is grouped into two classes classified by arbitrary breaks at the breakpoints with the tropical genera accounting for more than 70% and 80% of the total genera, respectively, two significant demarcation lines could be illustrated (Figs. 5 and 6). The regional floras with tropical genera accounting for more than 70% of the total genera were found south of 23°–24°N in southern China and south of 25°N in southeastern China. The regional floras with tropical genera accounting for more than 80% of the total were found south of 22°30'N in southern China, but south of c. 26°N in deep valleys in southwestern China.

4. Discussion

4.1. Correlations with climate, vegetation zonation, and floristic regionalization in southern China

Correlations between annual mean temperature, accumulated air temperature ≥ 10 °C and the generic-level patterns of Chinese seed plants, were analyzed based on data sets of a total of 204 regional floras and 841 meteorological stations throughout China (Zhu et al., 2007). It was found that the distribution patterns have high correlations with mean annual air temperature and accumulated air temperature ≥ 10 °C. Tropical genera increase with increasing mean annual air temperature and accumulated air temperature ≥ 10 °C.

Tropical genera, accounting for 60% of the total genera when grouped into two classes classified by a natural break, look like a natural threshold. The line with the tropical genera accounting for more than 60% of the total genera is at 24°–25°N in southern China (Guangxi and Guangdong provinces) and up to 26°N in southeastern

China (Fujian). It more or less corresponds to the northern boundary of the tropical area in southern and southeastern China suggested by Zhu and Wan (1963) and Tang (1964). It also more or less corresponds to the northern boundary of the southern subtropical climate in southeastern China (National Committee of Atlas Compilations, 1999) (Fig. 4).

The line at 23°–24°N in southern China and up to 25°N in southeastern China, with the tropical genera accounting for more than 70% of the total genera, more or less corresponds to the 7000 °C isotherm of the accumulated air temperature (the sum of daily temperature means > 10 °C), and the line of 20 °C annual mean temperature in southeastern China (National Committee of Atlas Compilations, 1999) (Fig. 5). This line also more or less corresponds to the northern boundary of the tropical area suggested by Ren and Xiang (1963) and Ren and Zeng (1991). It also corresponds to the northern boundary of the tropical area in Guangxi suggested by Qin (1995), which is at 24°30'N in western Guangxi and 23°N in eastern Guangxi. Furthermore, the line at 23°–24°N roughly corresponds to the northern border of the south subtropical evergreen broad-leaved forest in southeastern China (Wu, 1980; Hou, 1981, 1988) and the southern boundary of so-called subtropics (Corlett, 2013).

The line with tropical genera that increased to 80% of the total genera is at c. 22°30'N and corresponds closely to the northern boundary of the tropical monsoon forest and rain forest in southeastern China, although it is more or less corresponds to the 7500 °C isotherm of the annual cumulative temperature and the annual mean temperature of 22 °C in southeastern China (National Committee of Atlas Compilations, 1999).

The classification of climatic zones in China is mainly based on temperature factors, such as the annual cumulative temperature, the annual mean temperature, and the mean temperature of the coldest month (Wu et al., 2002). Huang (1991) defined the marginal tropics in China by the annual cumulative temperature > 8000 °C, the mean temperature of the coldest month > 15 °C. The 8000 °C isotherm of the annual cumulative temperature more or less corresponds to the line at 21°30'N, which was therefore suggested to be the northern boundary of the marginal tropics in China (National

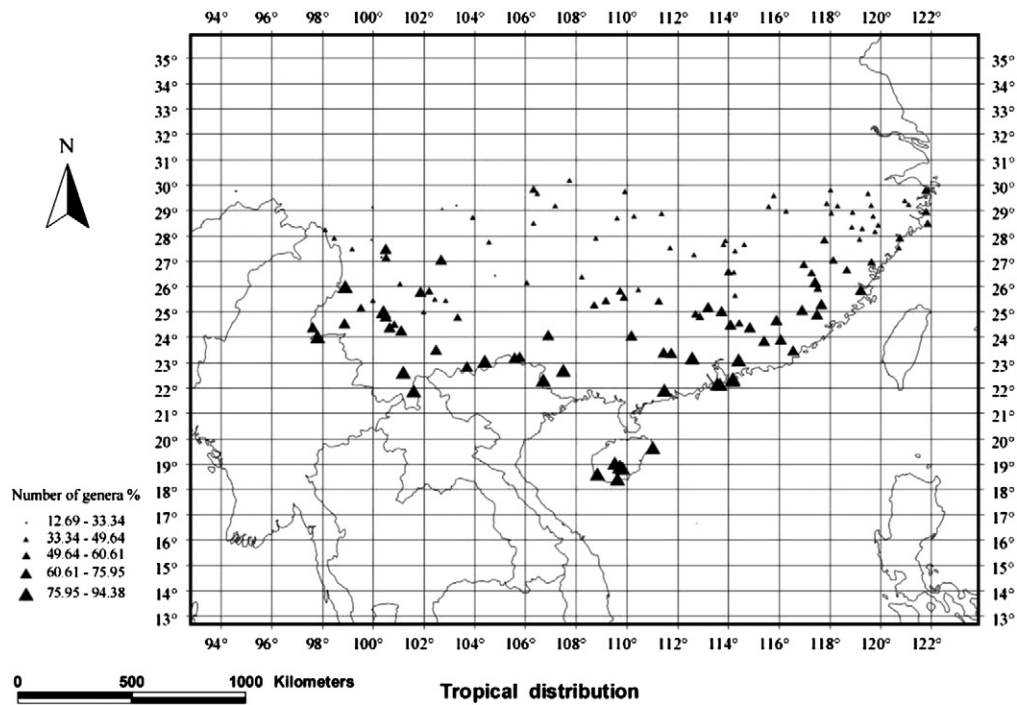


Fig. 3. Frequency of genera with Tropical distributions combined all types (same as in Fig. 2).

Committee of Atlas Compilations, 1999). The line at 21°30'N is also suggested to be the northern boundary of the so-called true tropical climate in southeastern China (Wu and Zheng, 2000).

Compared with the climatic marginal tropics defined by National Committee of Atlas Compilations (1999), although there is slightly lower annual cumulative temperature at the line with tropical genera accounting for more than 80% of the total genera, the strictly tropical lowland plants such as rubber could grow normally south of the line. The line (c. 22°30'N) roughly corresponds to the demarcation line of

tropical southern China suggested by Xu (1982), where the strictly tropical crops, such as coconuts, rubber, coffee, jackfruits, pepper, and pineapples, could generally survive in winter without cold protection. Tropical genera accounting for 80% of the total genera could also be a threshold for the boundary of the tropics in China biogeographically.

Although the boundary of the tropical climate is still uncertain, southern China does have a marginal tropical climate (Domroes, 2003). It is suggested here that 22°30'N could be the boundary of the tropical zone in south and southeastern China biogeographically.

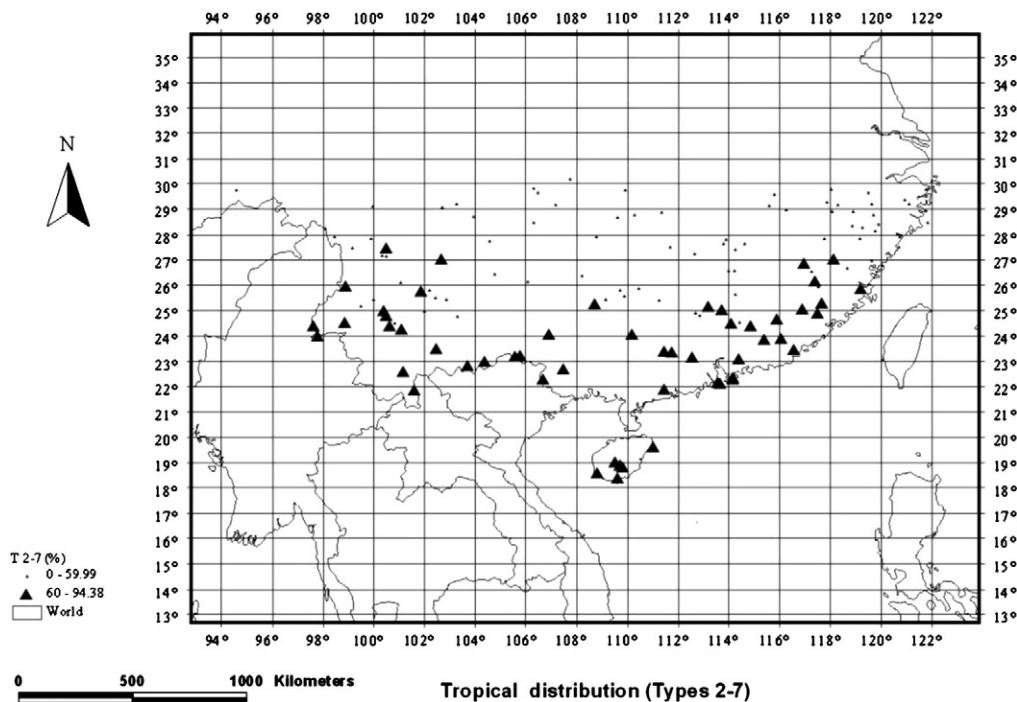


Fig. 4. Tropical distributions combined all types (grouped into two classes with natural breaks, showing the sites with tropical genera accounting for more than 60% of the total genera by big triangles).

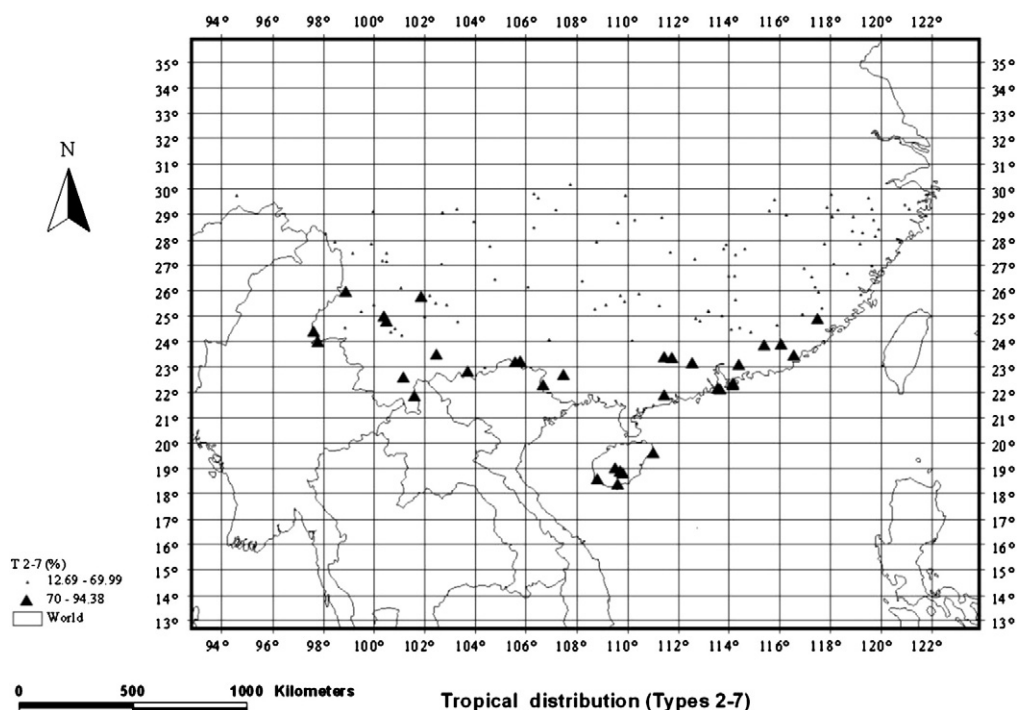


Fig. 5. Tropical distributions combined all types (grouped into two classes with arbitrary break at proportion of 70% of the total genera, showing the sites with tropical genera accounting for more than 70% of the total genera by big triangles).

In our study, the floristic patterns in southern China correspond well also to vegetation and floristic regionalization. South of the line with the tropical genera accounting for more than 80% of the total genera there are tropical rain forests and a tropical Southeast Asian flora (Zhu, 1997, 2008a, 2008b; Zhu and Roos, 2004). The line corresponds well to the northern boundary of the tropical monsoon forest and rain forest in southeastern China (Wu, 1980; Hou, 1988) and also corresponds well to the demarcation between the East Asiatic Kingdom (Wu and Wu

1996) or Holarctic Kingdom and the Palearctic Kingdom in the floristic regions of the World (Takhtajan, 1978).

4.2. Implications for the palaeovegetation patterns of southern China

Geographical elements are expected to sometimes be more related to geological history than the present climate (Wu and Wu 1996; Quan et al., 2006). In our study, the regions with the tropical genera

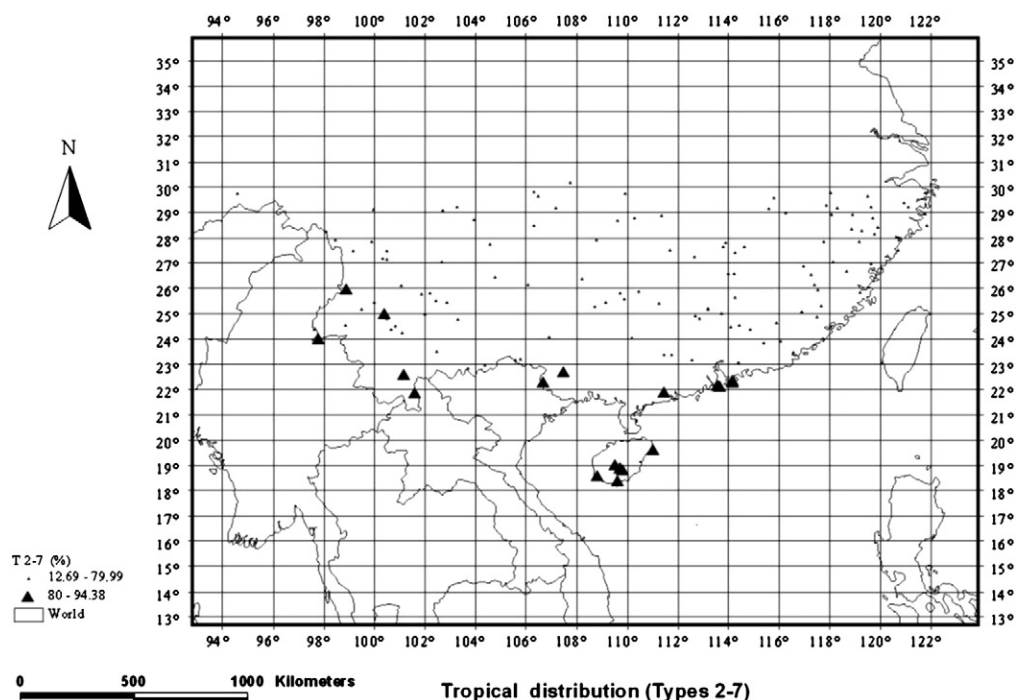


Fig. 6. Tropical distributions combined all types (grouped into two classes with arbitrary break at proportion of 80% of the total genera, showing the sites with tropical genera accounting for more than 80% of the total genera by big triangles).

accounting for more than 60% of the total genera extend to 26°N and with the tropical genera accounting for more than 70% of the total genera extend to 25°N in southeastern China. Although the line at c. 21°30' N with the annual effective accumulative temperature of 8000 °C was suggested to be the northern boundary of the tropical area in southern China climatically (Institute of Geography, Chinese Academy of Sciences, 1959; Qiu and Lu, 1961; Qiu, 1986), the regions with the tropical genera accounting for more than 80% of the total genera, and with disjunctively distributed tropical rain forest of Southeast Asia, extend further north than the climatic tropics in southern China. This suggests that tropical rain forest and tropical floras had a much wide distribution in the geological past in southern China, which is supported by the occurrence of fossil fruits of the strictly tropical Southeast Asian rain forest family Dipterocarpaceae in the middle Miocene at 24°12'N, 117°53'E in Fujian, southeast China (Shi and Li, 2010). Our results also support the suggestion from pollen data that tropical and subtropical broadleaved evergreen forests in eastern China occurred further north than today at 6000 ¹⁴C yr BP during the mid-Holocene (Yu et al. 2000) and are consistent with southern China being much warmer in the geological past than the present day (Editorial Committee for Physical Geography of China, 1984; Morley, 1998).

4.3. Climatic and biogeographical divergences between southeastern and southwestern China

Climate and biogeography differ between southeastern and southwestern China. Southwestern China has a mountainous topography with several deep valleys, where there is a tropical climate mainly due to the foehn effect, especially below 1000 m altitude (Wang, 2005). The climate corresponds more to altitude than latitude, as do the floristic elements in southwestern China. The tropical genera contribute a majority in local floras in deep valleys below 1000 m. For example, in the deep valleys of Lujiang in western Yunnan, where the annual mean temperature is 20.2 °C, the annual cumulative temperature (the sum of daily temperature means > 10 °C) is 7375 °C, and the mean temperature of the coldest month 15.7 °C (from a Meteorological Observation Station at 910 m at 25°52'N and 98° 51'E Yunnan Meteorological Bureau (1983), the tropical genera account for more than 80% of the total genera in the regional flora. It has been suggested that Yunnan is a huge tropical mountain with tropical areas below 1500 m (Liu et al., 1959; Ren and Xiang, 1963). Yunnan is indeed a region where tropical conditions with an annual mean temperature more than 20 °C and a mean temperature of the coldest month more than 15 °C prevail as well as tropical genera contribute to a majority at lower elevations (Zhu, 2008c).

5. Conclusions

The tropical geographical elements of seed plants contribute a majority to regional floras in southern China. Their frequencies decrease in proportion with increasing latitude. The frequency patterns illustrate several demarcations. The demarcation with tropical genera accounting for more than 60% of the total genera is roughly at 24°–25°N in Guangxi and Guangdong provinces in southern China and up to 26°N in southeastern China (Fujian). The demarcation with tropical genera accounting for more than 80% of the total is found at 22°30' N in southern China, but up to c. 26°N in deep valleys in southwestern China. These demarcations correspond more or less to those of climate and vegetation previously suggested in southern China.

The 60% line more or less corresponds to the northern boundary of the southern subtropical climate in southeastern China (National Committee of Atlas Compilations, 1999). The 70% line more or less corresponds to the northern boundary of the tropical area suggested by geographers Ren and Xiang (1963) and Ren and Zeng (1991), based on a combination of climate, vegetation, and soil, and it also roughly corresponds to the northern border of the south subtropical

evergreen broad-leaved forest in southeastern China (Wu, 1980; Hou, 1988). The 80% line at c. 22°30'N corresponds well with the northern boundary of the tropical monsoon forest and rain forest in southeastern China, and also the demarcation between the East Asiatic Kingdom (Wu and Wu, 1996) or Holarctic Kingdom and the Paleotropical Kingdom in the floristic regions of the World (Takhtajan, 1978). The line at c. 22°30'N is therefore suggested to be the northern boundary of the tropical zone in south and southeastern China biogeographically. South of this line, tropical plants, such as coconuts, rubber trees, coffee, jackfruits, pepper etc., could generally survive the winter without cold protection. The line is far north of the northern boundary of the marginal tropical climate, which implies that the tropical zone extended further north during geological history. It is concordant with the palaeoecological studies that suggested the northward shifts of tropical and subtropical broadleaved evergreen forest in eastern China during the mid-Holocene.

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.palaeo.2013.04.007>.

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References

- Cao, M., Zhou, X.M., Warren, M., Zhu, H., 2006. Tropical forests of Xishuangbanna, China. *Biotropica* 38 (3), 306–309.
- Corlett, R.T., 2013. Where are the Subtropics. *Biotropica*. <http://dx.doi.org/10.1111/btp.12028> (Article first published online: 14 FEB 2013).
- Domroes, M., 2003. Climatological characteristics of the tropics in China: climate classification schemes between German scientists and Huang Bingwei. *Journal of Geographical Science* 13, 271–285.
- Editorial Committee for Physical Geography of China, 1984. *Physical Geography of China—Palaeogeography*. Science Press, Beijing, p. 262 (Chinese).
- Fang, J.Y., 2001. Re-discussion about the forest vegetation zonation in eastern China. *Acta Botanica Sinica* 43, 522–533.
- Fang, J.Y., Song, Y.C., Liu, H.Y., Piao, S.L., 2002. Vegetation-climate relationship and its application in the division of vegetation zone in China. *Acta Botanica Sinica* 44 (9), 1105–1122.
- Holdridge, L.R., 1947. Determination of world plant formations from simple climatic data. *Science* 105, 367–368.
- Hou, X.Y., 1988. *Physical Geography of China—Plant Geography*. Part II, *Vegetation Geography of China*. Science Press, Beijing, pp. 112–113 (in Chinese).
- Hou, X.Y., 1981. A further discussion on the principle and scheme for vegetation regionalization of China. *Acta Phytocologica et Geobotanica Sinica* 5, 290–301 (in Chinese).
- Huang, B.W., 1991. Climatic division and physiogeographic division of China: retrospects and prospects. (Climatol. Notes) In: Yoshino, M. (Ed.), *Studies on Tropical and Subtropical Climates and Their Impacts*. 41. Univ. of Tsukuba, Japan, pp. 3–10.
- Institute of Geography, Chinese Academy of Sciences, 1959. *Integrated Physiogeographical Regionalization of China (Preliminary draft)*. Science Press, Beijing (in Chinese).
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World map of Köppen–Geiger climate classification updated. *Meteorologische Zeitschrift* 15 (3), 259–263.
- Liu, S.E., Feng, Z.W., Zhao, D.C., 1959. Some principles of vegetational regionalization in China. *Acta Botanica Sinica* 8 (2), 87–105 (in Chinese).
- Metzger, M.J., Bunce, Robert G.H., Jongman, Rob H.G., Sayre, R., Trabucco, A., Zomer, R., 2012. A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring. <http://dx.doi.org/10.1111/geb.12022> (Article first published online: 20 DEC 2012).
- Morley, J.R., 1998. Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate. In: Hall, R., Holloway, J.D. (Eds.), *Biogeography and Geological Evolution of SE Asia*. Backbuys Publishers, Leiden, pp. 221–234.
- National Committee of Atlas Compilations, 1999. *National Nature Atlas of People's Republic of China*. Map Press of China, Beijing, pp. 64–80 (116–120 in Chinese).
- Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen–Geiger climate classification. *Hydrology and Earth System Sciences* 4, 439–473.
- Qian, H., Song, J.S., Krestov, P., Guo, Q., Wu, Z., Shen, X., Guo, X., 2003. Large-scale phytogeographical patterns in East Asia in relation to latitudinal and climatic gradients. *Journal of Biogeography* 30 (1), 129–141.
- Qin, M.Z., 1995. The north-line division of tropical zone in Guangxi. *Journal of Nanjing University (Natural Sciences)* 31, 685–690 (in Chinese).
- Qiu, B.J., 1986. A new discussion on the regionalization of agro-climate in China. *Acta Geographica Sinica* 41, 202–209 (in Chinese with English abstract).

- Qiu, B.J., Lu, Q.R., 1961. Agroclimatic division of tropical and southern subtropical regions in China. *Acta Geographica Sinica* 27, 28–37 (in Chinese).
- Quan, H., Wang, S.L., He, J.S., Zhang, J.L., Wang, L.S., Wang, X.L., Guo, K., 2006. Phytogeographical analysis of seed plant genera in China. *Annals of Botany* 98, 1073–1084.
- Ren, M.E., Xiang, R.Z., 1963. On some theoretical problems of the physical regionalization in China from a contradictory opinion—re-discussion on the physical regionalization in China. *Journal of Nanjing University (Natural Sciences)* 3, 1–12 (in Chinese).
- Ren, M.E., Zeng, Z.X., 1991. The extent of tropical zone in China. *Scientia Geographica Sinica* 11 (2), 101–108 (in Chinese with English abstract).
- Shi, G.L., Li, H.M., 2010. A fossil fruit wing of *Dipterocarpus* from the middle Miocene of Fujian, China and its palaeoclimatic significance. *Review of Palaeobotany and Palynology* 162, 599–606.
- Takhtajan, A., 1978. *Floristic reprints of the World*. Leningrad: Soviet Sciences Press. Chinese version, Translated by Huang G C, 1988. Beijing, Science Press. 203–229.
- Tang, Y.L., 1964. An analysis of boundaries of tropical zone. *Acta Phytocologica et Geobotanica Sinica* 2, 135–137 (in Chinese).
- Wang, Y., 2005. *Yunnan Mountain Climate*. Yunnan Sci. & Tech. Press, Kunming (p412 in Chinese).
- Wu, S.H., Zheng, D., 2000. New recognition on the boundary between tropical and subtropical zone in the middle section of eco-geographic system. *Acta Geographica Sinica* 55 (6), 689–697 (in Chinese with English abstract).
- Wu, S.H., Yang, Q.Y., Zheng, D., 2002. An index system for boundaries of eco-geographical regions of China. *Progress in Geography* 21 (4), 302–309 (in Chinese with English abstract).
- Wu, Z.Y., 1980. *Vegetation of China*. Science Press, Beijing, pp. 363–397.
- Wu, Z.Y., 1991. The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica Supp.* 4, 1–139 (in Chinese with English abstract).
- Wu, Z.Y., Wu, S.G., 1996. A proposal for a new floristic kingdom (realm)—the Asiatic kingdom, its delineation and characteristics. In: Zhang, A.L., Wu, S.G. (Eds.), *Floristic characteristics and diversity of east Asian plants*. China Higher Education and Springer Press, Beijing, pp. 3–42.
- Xu, X.H., 1982. On the demarcation line of tropical and subtropical zones in southern China. *Acta Phytocologica et Geobotanica Sinica* 6 (1), 74–77 (in Chinese with English abstract).
- Yunnan Meteorological Bureau, 1983. *Climatic Data of Yunnan Agriculture*. Yunnan People's Press, Kunming.
- Yu, G., Chen, X., Ni, J., et al., 2000. Palaeovegetation of China: a pollen data-based synthesis for the mid-Holocene and last glacial maximum. *Journal of Biogeography* 27, 635–664.
- Zeng, Z.X., 1966. Discussions on the tropical boundary of China from the distributions of cultivated plants. *Acta Phytocologica et Geobotanica Sinica* 4 (1), 141–154 (in Chinese).
- Zhang, L., Luo, T.X., Zhu, H.H., Daly, C., Deng, K.M., 2010. Leaf life span as a simple predictor of evergreen forest zonation in China. *Journal of Biogeography* 37, 27–36.
- Vegetation Map of the People's Republic of China. In: Zhang, X.S. (Ed.), *Geological Publishing House, Beijing* (12 in Chinese).
- Zhu, H., 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* 24, 647–662.
- Zhu, H., 2008a. The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Annals of the Missouri Botanical Garden* 95, 661–680.
- Zhu, H., 2008b. Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. *Tropical Conservation Science* 1, 34–42.
- Zhu, H., 2008c. Distribution patterns of genera of Yunnan seed plants with references to their biogeographical significances. *Advance in Earth Sciences* 23 (8), 830–839 (in Chinese with English abstract).
- Zhu, H., Ma, Y.X., Yan, L.C., Hu, H.B., 2007. The relationship between geography and climate in the generic-level patterns of Chinese seed plants. *Journal of Systematics and Evolution* 45 (2), 134–166.
- Zhu, H., Roos, M.C., 2004. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* 10 (2), 639–648.
- Zhu, K.Z., Wan, M.W., 1963. *Phenology*. Scientific Education Press, Beijing (in Chinese).