Chapter 5

Conifers in Mountains of China

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Additional information is available at the end of the chapter

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Abstract

China has the largest area of mountains of all countries, with about 70% of land territory covered with mountains and plateaus. Thanks to vastness, mountainousness, highly heterogeneous habitats and long history of biological evolution, China boasts of extremely high biodiversity (more than 30,000 species of seed plants). The objectives of this chapter are to investigate conifer species and to analyze their multi-dimensional distribution in China. Our conclusions include: (1) China has 244 species of conifers belonging to 32 genera in 4 families (*Pinaceae, Cupressaceae, Podocarpaceae* and *Taxaceae*), accounting for 38.37, 49.29 and 66.67% of the global totals, respectively; (2) there are totally 115 conifer species endemic to China, falling in 23 genera of 4 families; (3) conifers and coniferous forests are widely distributed in China, from north to south and from east to west, more prominently in its numerous and high mountains and plateaus; (4) some conifer species appear even at very high elevations, e.g., *Juniperus tibetica* forests at 4800–4900 m above sea level in the southeastern Tibetan Plateau; and (5) China has established a large number of nature reserves and promulgated and implemented a series of laws and regulations to protect its rare and precious conifer resources.

Keywords: conifer, endemic species, Tibetan plateau, mountain forests, altitudinal zonation

1. Introduction

China is located in the southeast of the world's largest continent—the Eurasian continent, and characterized by vastness, mountainousness and high heterogeneity. With a land area of 9.6 million km^2, it is the third largest country in the world; about 70% of its land territory is mountains and plateaus, especially such high mountains and plateaus (**Figure 1**) as the

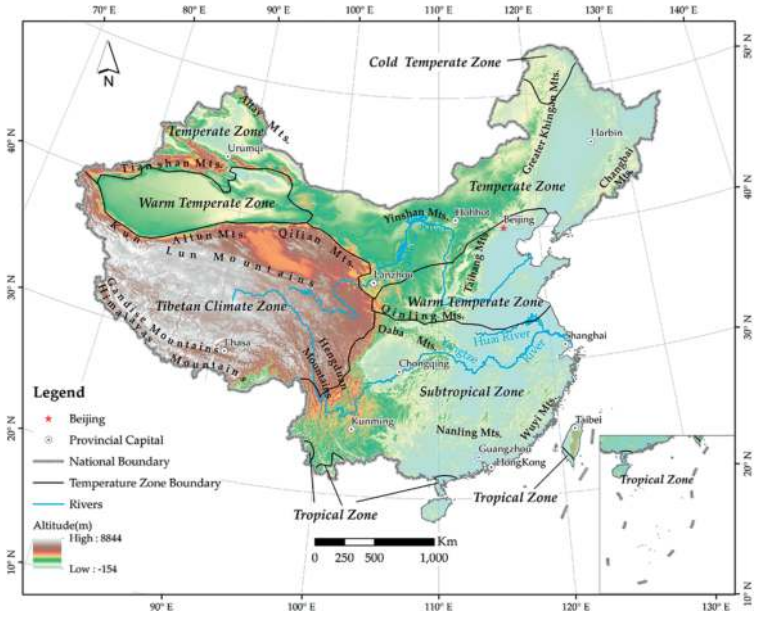

Figure 1. Distribution of the main mountain ranges in China.

Himalayas, the Kunlun Mountains, the Tianshan Mountains, the Tibetan Plateau, and so on. China is virtually a country with the largest area of mountains in the world. Its lowest point is at 154 m below sea level in the Turpan Basin of Xinjiang, and the highest point is the top of Mt. Everest (8844 m).

These many mountains, especially those extending east-west, contribute greatly to the climatic and landscape patterns of China. The Qinling Mountains form the boundary between temperate and subtropical climate regions; the Yinshan Mountains set apart temperate and warm-temperate climate in Inner Mongolia; the Tianshan Mountains are the natural border of temperate and warm-temperate desert areas in Xinjiang. While in Northeast China, the north-south stretching Greater Khingan mountains serve as the boundary between sub-humid and semi-arid regions. These mountains strengthen China's north-south and east-west areal differentiation, shaping its climate and vegetation patterns into their present states.

The most prominent feature of the geography of China is the differentiation of three realms: the eastern monsoon realm, the northwestern arid realm, and the Tibetan frigid realm (**Figure 2**). The formation of this pattern of three realms is mainly the effect of the Pacific monsoon from the southeast in the warm season and the Mongolian cold air flows in the cold season. The eastern monsoon realm is divided, by the Qinling-Daba Mts.-Huai River, into southern and northern parts. Therefore, the Qinling-Daba Mts. are also regarded as China's north-south transitional zone. To the south are subtropical and tropical regions, with an annual mean precipitation of 800–2000 mm. To the north are temperate areas with sub-humid and semi-arid moisture conditions, and their annual mean precipitation is only between 400

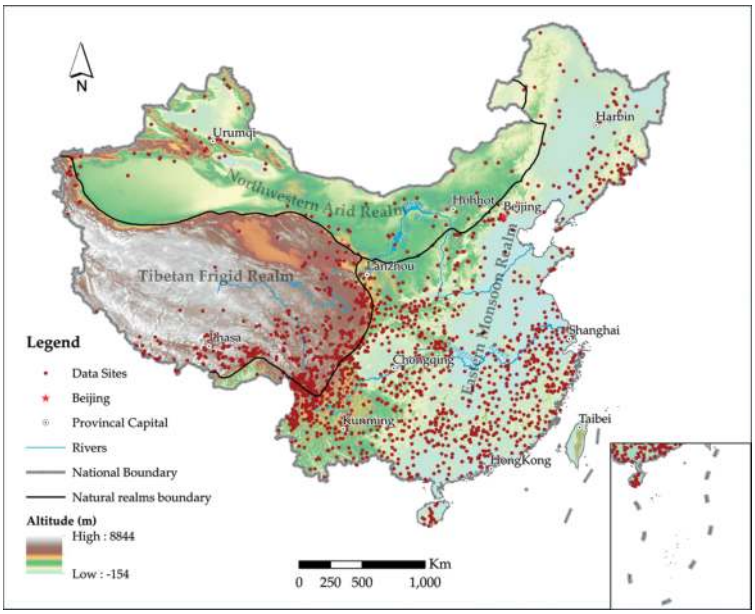

Figure 2. Conifer species occurrence in mainland China (data downloaded from gbif.org).

and 600 mm and slightly higher in the northeast and in the upper parts of mountains. The northwest arid China features the alternativeness of high mountain ranges and desert basins or the mountain-basin systems, with an annual precipitation usually between 50 and 200 mm, but much higher (>500 mm) in its high mountains. The Tibetan frigid realm is characterized by high elevation of averagely 4500 m above sea level (a.s.l.) and alpine climate, and it shows great variation in moisture from southeast to northwest, namely, from humid to extremely arid conditions. This pattern was ever referred to as "Tibetan Zonation," a spatial dry-wet pattern just like that of China as a whole.

Thanks to extensiveness and numerous towering mountains, China shows not only sharp and complex areal differentiation but also outstanding altitudinal zonation in large mountains. In other words, zonal and azonal factors interplay to give rise to highly heterogeneous and varied habitats, landscapes and vegetation types. In the east, climate types transit in succession from cold temperate, temperate, and warm temperate in the north to subtropical and tropical climate in the south. From southeast to northwest, forest, forest-steppe, steppe and desert appear in succession. The frigid Tibetan Plateau shows, from southeast to northwest, an alternation of montane forest, alpine meadow, alpine steppe and alpine desert. In the northern flank of the long-stretching Tianshan Mts., such altitudinal belts could be clearly identified, from the bottom, montane desert, montane steppe, montane coniferous forests, alpine meadow, sub-nival and nival belts. In Mt. Namjag Barwa of East Himalayas, nine altitudinal belts can be recognized from tropical rainforest at the bottom upward to the nival belt at the uppermost part. In addition, the mass elevation effect leads to much higher air

temperature in the interior of the Tibetan Plateau than the free air on the same elevation above the lowlands around the plateau [1]. As a result, conifer forests could grow at elevations of up to 4800–6900 m a.s.l. in the southeastern Tibetan Plateau [2], that is, the globally highest forest, at least 1000 m higher than even in the southern flank of the Himalayas.

Thanks to large area, heterogeneous habitats and long history of biological evolution, China boasts of extremely high biodiversity (more than 30,000 species of seed plants), only next to Malaysia (45,000) and Brazil (40,000). As for the diversity of pteridophytes, China ranks No. 1, about 52 families, 204 genera, 2600 species. Gymnosperm has totally 13 families worldwide, of which only *Araucariaceae* and *Sciadopitys* are missing and other 11 families can all be recognized in China, including 42 genera and 323 species [3–5].

China's conifers amount to 244 species, occupying 66.67% of the total in the world. So, China has an outstanding position in global conifer diversity and protection. As for China itself, conifers have widespread distribution, especially up to surprising 4800–4900 m a.s.l. and are absolutely significant for its biodiversity conservation and ecological security.

The objectives of this chapter are to generalize conifer species, China-specific conifers and their three-dimensional distribution, to explain their distribution patterns, and to show China's effort in protecting its conifer diversity and resources. We first give a statistics of conifer family, genus and species in China, including those endemic to China, and briefly show their geographic distribution; then we display their characteristics in different temperature zones; next, we especially analyze the altitudinal pattern of conifers in China mainly by taking "mass elevation effect" into account; finally, we show what China has done to protect its diverse and precious conifer resources.

2. Conifers and endemics in China

2.1. Conifers in China

In terms of Christenhusz's taxonomy [3–5], China has 244 species of conifers (including subspecies, varieties and forms) belonging to 32 genera in 4 families (*Pinaceae*, *Cupressaceae*, *Podocarpaceae* and *Taxaceae*), accounting for 38.37, 49.29 and 66.67% of the global totals, respectively. The largest conifer family in China is *Pinaceae*, including 137 native species (56.14% of China's total) with 73 species endemic to China (63.47% of China's endemic conifer species) (**Table 1**).

2.2. Geographical distribution of conifers

Conifers are quite unevenly distributed in China. Their diversity is relatively low in Northeast China and high in Southwest. This distribution pattern is caused by many factors, including geologic histories, biotic histories and evolution, contemporary environments, and so on [6]. The major genera of conifers take on such geographical patterns as follows:

Pinaceae consists of 11 genera widespread in China, with the Himalayas-Hengduan mountain region as the center of distribution and differentiation. Comparatively, *Pinus*, *Picea* and *Abies*

Family name	Genera	Endemic genera	Species	Endemic species
Pinaceae	11	3	137	73
Cupressaceae	14	4	61	25
Taxaceae	5	1	28	12
Podocarpaceae	2	0	18	5
Sum	32	8	244	115

Table 1. Number of conifer genera and species in China.

are almost throughout the country; *Larix* is mainly in the northernmost, up to north latitude of 72–75°; *Pseudotsuga* and *Tsuga* are mainly distributed in the subtropical or tropical mountains in the Himalayas and south of the Qinling Mountains [7, 8].

Cupressaceae contains 15 genera in China, mostly occurring in the Hengduan Mountains of the eastern Qinghai-Tibet Plateau but scattered in the Northeast and Northwest of China. *Juniperus* has the largest number of species (33) in this family and more than half of these species are distributed in the Hengduan Mountains, Yunnan-Guizhou Plateau and the eastern Qinghai-Tibet Plateau [9].

Taxaceae includes five genera in China. *Cephalotaxus* is widely distributed in southeastern Tibet, Hainan and Taiwan. *Taxus cuspidata* is only seen in northeastern China. Other species of *Taxus* are found between the Qinling Mountains and the Pearl River, in eastern Taiwan and in western Tibet. *Torreya* trees are scattered in coniferous and broad-leaved forests in southern China. *Amentotaxus* can be found south of the Qinling Mountains, expanding from Taiwan westwards to southeastern Tibet and southeastern Yunnan [10].

Podocarpaceae has only two genera in China, with *Dacrydium* mainly distributed in Hainan Island and *Podocarpus* south of the Yangtze River and east of the Hengduan Mountains [10].

2.3. Conifers endemic to China

There are totally eight conifer genera endemic to China, and seven of which are monotypic genera except *Cunninghamia* [11]. *Pinaceae* contains three endemic genera, *Cathaya*, *Nothotsuga* and *Pseudolarix*. *Cupressaceae* contains four endemic genera, *Cunninghamia*, *Glyptostrobus*, *Metasequoia* and *Taiwania*. *Pseudotaxus* is the only endemic genus in *Taxaceae*. There are totally 115 conifer species endemic to China belonging to 23 genera of 4 families (**Table 2**). *Pinaceae* and *Cupressaceae* rank the top two families in terms of the number of endemic species, making up 63.47 and 21.73% of all endemic species, respectively.

2.4. Geographical distribution of conifer endemic genus

The complexity and diversity of regional climate and landform could affect directly or indirectly the speciation, differentiation, migration of Chinese endemic conifers [12]. Known for highly topographic heterogeneity, southwestern China is the hotspot of endemic conifers [11, 13]. The general distribution of endemic genera of conifers in China is as follows:

Family	Genus	Endemic species	Family	Genus	Endemic species
Pinaceae	*Pseudotsuga*	4(5)	*Cupressaceae*	*Cupressus*	5(6)
	Keteleeria	7(10)		*Chamaecyparis*	2(3)
	Abies	18(26)		*Juniperus*	12(33)
	Larix	7(11)		*Thuja*	1(2)
	Pinus	15(43)		*Glyptostrobus**	1(1)
	Tsuga	5(8)		*Taiwania**	1(1)
	Picea	14(26)		*Metasequoia**	1(1)
	*Pseudolarix**	1(1)		*Cunninghamia**	2(2)
	*Cathaya**	1(1)	*Taxaceae*	*Torreya*	4(6)
	*Nothotsuga**	1(1)		*Cephalotaxus*	5(10)
Podocarpaceae	*Podocarpus*	5(16)		*Amentotaxus*	2(4)
				*Pseudotaxus**	1(1)

Notes: genera with asterisk (*) are endemic to China; numbers in brackets mean the species number of each genus. Genera without species endemic to China are not shown in this table.

Table 2. Number of endemic conifers for each genus in China.

2.4.1. Cathaya

Cathaya, with only one species of *Cathaya argyrophylla,* is discontinuously distributed in southeastern Sichuan Basin, eastern Yunnan-Guizhou Plateau, and northeastern Nanling Mountains, usually between 900 and 1900 m a.s.l. Mostly seen on steep cliffs or in gaps of bare rocks, this species grows in communities or as mixed forests with *Quercus engleriana* and *Cyclobalanopsis glauca* [5, 9, 10, 14].

2.4.2. Nothotsuga

Nothotsuga is a monotypic genus (*Nothotsuga longibracteata*), usually growing in subtropical mountains with a warm, humid, cloudy and foggy climate, for example, in the Fanjing Mountains of Guizhou province, the Mang Mountains of Hunan province, and the Nanling and Wuyi Mountains of Fujian province. It appears on elevations between 400 and 2000 m a.s.l., and is mixed with *Tsuga chinensis* var. *tchekiangensis*, *Fokienia hodginsii* and other evergreen broad-leaved trees [5, 9, 10].

2.4.3. Pseudolarix

Pseudolarix, also a monotypic genus (*Pseudolarix amabilis*), is an ancient relic species. It ever grew in northern China between latitudes of 33°N and 52°N, but nowadays only appears on warm and rainy mountains in the warm regions of the middle and lower reaches of the Yangtze River. Its upper limit is 1500 m a.s.l., and it could be seen in coniferous or broad-leaved forests [5, 9, 10].

2.4.4. Cunninghamia

Cunninghamia contains two species. *Cunninghamia lanceolate* grows south of the Qinling Mountains, especially in the deep valleys of southwestern China. In the Dabie Mountains in the middle of China, it occurs only to 700 m a.s.l., but up to 1800 m a.s.l. in Mt. Emei of Sichuan Province. *Cunninghamia konishii* appears in central and northern Taiwan, taking on patches of pure forest or being scattered in *Chamaecyparis obtusa* forests [5, 9, 10, 15].

2.4.5. Glyptostrobus

Glyptostrobus has only one species of *Glyptostrobus pensilis*. It adapts to warm and humid environment below 1000 m in subtropical low mountains, appearing in a wide extent from Taiwan in the east to Yunnan province in the west and northwards to Shandong province [5, 9, 10].

2.4.6. Metasequoia

Metasequoia has also only one species of *Metasequoia glyptostroboides*. It is a relict species with strong adaptability, appearing in mountainous areas of moderate warm temperature, rainy climate and acidic yellow soil, with a very limited geographic distribution mainly in southwestern Hubei and little in Chongqing and Hunan [5, 9, 10].

2.4.7. Taiwania

Taiwania contains one species of *Taiwania cryptomerioides Hayata*. It grows in a cool and humid climate with fertile acidic soil, mainly in Taiwan and southwestern Asia, for example, the Gaoligong Mountains in northwestern Yunnan and the mountains in southeast Guizhou. Vertically, it is distributed in evergreen broad-leaved forests at an elevation of 1600–2800 m a.s.l [5, 9, 10, 16].

2.4.8. Pseudotaxus

Pseudotaxus is a monotypic genus, that is, *Pseudotaxus chienii*. Its distribution areas extend along the Nanling range, from southern Zhejiang in the east, to northern Guangxi in the west. It usually appears in subtropical evergreen broad-leaved forests at an altitude of 500–1500 m a.s.l [5, 9, 10].

3. Areal distribution of conifers in China

3.1. The spatial distribution of conifers in China

Conifers and coniferous forests are rather diverse and complex in China due to its vast and mountainous territory. They show quite different in different climatic zones. The cold-temperate coniferous deciduous mixed forest is composed of eight or more formations in China; the dark coniferous forest, mainly Spruce and Fir trees, has more than 26 common formations; while *Pinus*-dominant formations amount to 13 and could develop in several climatic zones.

Based on the vegetation map of China and its geographic pattern (1:1,000,000) [17], the spatial distributions of conifers in China were divided into five vegetation types as follows:

3.1.1. Cold-temperate and temperate mountain conifer forests

The main species are *Larix*, *Abies* and *Picea* for the cold-temperate and temperate conifer forests of China, with 17 plant communities including *Larix gmelinii*, *Pinus sibirica*, and *Abies nephrolepis* forest. Its distribution areas extend from 53°33′N southward to the Qinling Mountains and the Dadu River in Sichuan, from the Changbai Mountains westward to the Tianshan Mountains, with the highest distribution at 4000 m a.s.l. They are mainly concentrated in mountains of Northeast China (Greater Khingan Mountains, Zhangguangcai Range, Changbai Mountains, etc.), of North China (Mt. Wulingshan, Mt. Wutai, Yanshan Mountains, Mt. Guandishan, Mt. Hengshan, etc.), and of Xinjiang and Inner Mongolia (Altay Mountains, Tianshan Mountains, Qilian Mountains, Helan Mountains and Yinshan Mountains), and in the Qinling- Daba Mountains of central China [10, 17].

3.1.2. Temperate conifer forests

Temperate coniferous forests are mainly distributed in the plain, hill or low mountain areas of the warm temperate zone in China, including the middle and lower reaches of the Yellow River and the Southern Xinjiang, roughly between the Yinshan Mountains in the north and the Qinling-Daba mountains in the south. The constructive species are *Pinus* and *Platycladus*, and the main communities *Pinus tabulaeformis*, *Pinus densiflora* and *Platycladus orientalis* forests. *Akamatsu* appears in the offshore of Shandong Peninsula, and *Pinus tabulaeformis* in the Qinling-Daba Mountains. *Platycladus orientalis* and *Juniperus* forests could extend up to an elevation of 2500 m in the mountains of the northwest arid China [10, 17].

3.1.3. Subtropical conifer forests

The subtropical coniferous forest can be subdivided into deciduous-coniferous mixed forest and evergreen-coniferous mixed forest according to their life forms. In the deciduous-coniferous mixed forest are mainly *Metasequoia glyptostroboides*, *Glyptostrobus pensilis*, *Pseudolarix kaempferi*, *Taxodium distichum* and *Taxodium ascendens*, occurring south of the Qinling Mountains. This type of forests is seldom in purely natural state. The evergreen-coniferous forest is widely distributed in subtropical and tropical regions of China, with dominant component of *Pinus*, *Picea*, and *Cupressus* and with such main communities of *Pinus massoniana, Cunninghamia lanceolata* and *Cupressus funebris*. Subtropical evergreen conifer forests are normally distributed below 1500 m in the eastern China and up to 2000–3000 m in the western subtropical areas [10, 17].

3.1.4. Tropical conifer forests

Tropical conifer forest is mainly distributed in the tropical flat ground, hills and low mountains in China, with a limited area in Hainan, southern Guangdong and southeastern Guangxi. *Pinus latteri* and *P. roxburghii* are the main species. *Pinus latteri* appears up to

600 m, at most to 800 m, in mountains, and only to 200 m in hills. *P. roxburghii* only occurs between 1800 and 2300 m in the Gyirong Basin of southeastern Tibetan Plateau [10, 17].

3.1.5. Subtropical and tropical mountain conifer forests

Distributed in relatively high mountainous areas south of the Qinling Mountains, generally from 1000 to 4500 m, tropical and subtropical mountain conifer forests include species of *Pinaceae, Taxodiaceae*, and *Cupressaceae* and about 30 types of communities such as *Pinus griffithii*, *Larix chinensis*, *Tsuga dumosa,* and so on [10, 17].

3.2. Main spatial limits for conifer distribution

Fourteen typical conifer associations from five vegetation types were selected to specify conifer spatial distribution limits. Associations 1–4 are from cold-temperate and temperate mountain conifer forests, association 5 from temperate conifer forests, associations 6–9 from subtropical conifer forests, association 10 from tropical conifer forests, and the other four (11–14) from subtropical and tropical mountain conifer forests [10, 17].

3.2.1. Larix gmelinii forest

The *Larix gmelinii* forest, mainly distributed in the Greater Khingan Mountains, is the largest larch forest in Northeast China and even in China. It is actually the southward continuation of bright coniferous forests in Eastern Siberia in Russia. It is zonal vegetation north of Yakeshi, Heilongjiang Province (49°20′N), but southward it turns into vertical zonal vegetation along the Greater Khingan Mountains. Further southward, it forms a transition zone with *Larix principis*, mixed with small patches of *Larix olgensis* and *Hailin larch* forest. *Larix gmelinii* forest also appears in the low-wetland as azonal vegetation between the Greater Khingan Mountains and the Lesser Khingan ridge. Further southward through Wandashan to Zhangguangcai mountains, near the Laoyeling Mountains (about 42°30′N), it forms a transitional zone with *Larix olgensis* and then is completely replaced by *Larix olgensis* forest. It is generally below 1200 m in the northern slope and below 1400 and 1550 m in the south slope of the Greater Khingan Mountains.

3.2.2. Larix olgensis var. changpaiensis forest

Larix olgensis var. *changpaiensis* is endemic to China and mainly appears in the Changbai Mountains in Jilin province, usually as stable pure forest. Just as *Spruce* and *Abies* in subalpine zone, it adapts to cold and humid climate and could also grow in low swamps or swampy areas where other tree species are difficult to grow.

3.2.3. Pinus sibirica forest

The *Pinus sibirica* forest is only distributed in the northwesternmost corner of Xinjiang which is virtually the southernmost limit of natural *Pinus sibirica* forest. As a cold-resistant continental species, it often appears at the upper parts and even upper limit of forest belts.

3.2.4. Picea schrenkiana forest

Picea schrenkiana is one of the most widespread forest species in the mountains of desert zones in Asia. In China, it appears in the northern flanks of the Tianshan and Western Kunlun and in the Western Junggar Basin. Usually as one-species pure forest, it appears on shadow slopes at elevations between 1600 and 2800 m in the northern flank of the Tianshan Mountains and 2500–3600 m in some valleys of the northern flank of West Kunlun.

3.2.5. Pinus tabulaeformis forest

Pinus tabulaeformis is endemic to China, widely distributed in the mountains of the warm temperate region in north China, namely, from the Yinshan Mountains southward to the Qinling Mountains. In the Qinling Mountains, it appears between 1400 and 2000 m. Further southward, it is replaced by *Pinus massoniana* forest.

3.2.6. Pinus massoniana forest

The *Pinus massoniana* forest is the largest and most widely distributed conifer community in subtropical China. Its distribution extends from the Qinling Mountains in the north to the Leizhou Peninsula in the south. It meets *Pinus yunnanensis* forest in its westernmost areas and tropical *Pinus latteri* forest in its southernmost distribution area. It can also be found in central Taiwan. It grows usually below 1000 m or even 800 m a.s.l.; further upward, it is replaced by *Pinus tabulaeformis*, *Pinus henryi* and *Pinus armandii* forests.

3.2.7. Pinus yunnanensis forest

Pinus yunnanensis is a common and important conifer species in the Yunnan-Guizhou Plateau. It is also a typical representative community of the western dry subtropics. Its distribution extends to Guangxi province and Tibetan Plateau. Mostly distributed between 1500 and 2800 m a.s.l., it can lower to about 1000 m and ascend to 3500 m. In the middle-south Yunnan Plateau, it is replaced by *Pinus khasya* forest.

3.2.8. Pinus taiwanensis forest

The *Pinus taiwanensis* forests are one of the representative communities in the subtropical mountains of east China. Mainly distributed in the subtropical mountains of Taiwan, Fujian, Zhejiang, Jiangxi, Anhui, Hunan and Hubei provinces, they especially can be met in the northern and southern flanks of the Dabie Mountains. Their most suitable distribution area is within 400 km off the coastline. Vertically, they occur on elevations above 600 and 800 m, at most up to 1750 m.

3.2.9. Pinus armandii forest

Pinus armandii constitutes a typical mountainous coniferous forest in the western subtropics of China. It is mainly distributed in Sichuan, Yunnan, Guizhou provinces and the Qinling-Daba Mountains. Its altitudinal distribution shows a trend of northward lowering, for example,

about 2500–3000 m in southwestern Sichuan and northwestern Yunnan, 2000–2500 m in western Guizhou, 1500–2400 m in the Qinling-Daba Mountains, and 1000–2200 m in the warm temperate zone.

3.2.10. Pinus latteri forest

This type of forest is a typical community in tropics. Mainly distributed in southern Guangdong, Hainan and southeastern Guangxi, its altitudinal range is normally below 600 m (800 m) a.s.l. in mountains, and even below 200 m in hills.

3.2.11. Larix chinensis forest

Larix chinensis forests are mainly distributed in the Qinling Mountains, especially in Mt. Taibai. Vertically, it is above the *Abies* forest and below alpine shrub-meadow, basically at elevations between 3100 and 3500/3600 m, and serves as treeline species in its distribution areas.

3.2.12. Larix potaninii forest

Larix potaninii is the main component of deciduous-coniferous forests in northwestern Sichuan, the Three-parallel-rivers areas, Tibetan Plateau, and the Taohe basin of Gansu province, roughly north of 30° north latitude. It appears on elevations of 3700–4200 m in west Sichuan and the southeastern Tibetan Plateau (down to 3000 m in some river valleys), and 2900–3300 m in the Taohe river basin of Gansu province.

3.2.13. Abies fargesii forest

The *Abies fargesii* forest is mainly distributed in the whole Qinling-Daba Mountains in central China. It is a special community of *Abies* in the subtropical mountains, with a relatively low elevation, normally between 2500 and 3000 m in central Qinling Mountains of Shaanxi province, at 2700–3052 m in Shennongjia of northwest Hubei province, at 2400–3600 m in Minshan, Micangshan and Dabashan of Sichuan Province, and at 1800–2100 m in the Funiu Mountain of Henan province. This indicates an increasing trend of its altitudinal distribution from northeast to southwest.

3.2.14. Abies spectabilis forest

The *Abies spectabilis* forests appear in the eastern and central Himalayas. In China, they are mainly distributed in Bomi, Nyingchi, Medog, Milin, Cuona, Yadong, Nyalam, and Gyirong of southeastern Tibet. Their altitudinal range is from 3400 (3200) to 4100 (4500) m.

4. Altitudinal distribution of conifers in mountains of China

China is the largest mountain country of the world, with about 70% of its land area being mountains or plateaus. Thanks to their extremely complex and varied environment, mountains usually provide quite diverse habitats for territorial plant species and, as a result, serve

as hotspots of biodiversity and endemic species [18]. Floras in mountains are relatively less disturbed by human activities in China, as in other countries. China's primary conifer forests are mainly distributed in mountains, and their altitudinal distribution is an important dimension to fully understand conifers of China. The following sections explore the conifer distribution pattern along elevation and its possible influencing factors by taking "mass elevation effect" into account.

4.1. Conifer species richness along elevation

Conifer records in mainland China (**Figure 2**) were downloaded from GBIF [19] using the *dismo* [20] package in R. After removing duplicate data and excluding data without position coordinates or scientific names, a total of 3158 records are used to analyze their altitudinal distributions (**Figure 3**). These records involve 215 species belonging to 34 genera in four families (*Cupressaceae*, *Pinaceae*, *Podocarpaceae*, *Taxaceae*). This type of data for mainland China from GBIF is less than the existing relevant data in China.

The elevational range of conifer species is from 0 to 4900 m, and 50 m is taken as an interval to acquire data of species numbers; and 98 elevational sections were divided to count species richness at each interval. The results are shown in **Figure 3(a**, **c)**. Species diversity decreases monotonically upwards, with a fluctuating rate. The diversity decreases fast below 1300 m a.s.l., remains roughly stable from 1300 to 3300 m a.s.l., and decreases relatively slowly above 3300 m a.s.l. Conifers of different families show varied altitudinal diversity patterns. The species diversity curve has a bulge between 2000 and 3500 m for *Pinaceae,* but the species diversity decreases continuously upwards for *Cupressaceae*, *Podocarpaceae* and *Taxaceae,* at varied rates.

Cupressaceae has the broadest altitudinal distribution, from 0 to 4900 m a.s.l. Its richness is relatively steady and small below 3000 m a.s.l., whereas a surge in richness occurred on the elevation of about 3000 m, and its richness occupies three quarters of the total at treeline ecotone. Pinaceae has a similar vertical range as Cupressaceae, making up about 20% of the total richness from 1800 to 4900 m a.s.l., and reaching the highest proportion at elevations between 2500 and 3500 m. Podocarpaceae has the narrowest vertical distribution, mainly below 2000 m. It accounts for about half of the total diversity below 200 m, but its relative contribution decreases upwards as Taxaceae's and Pinaceae's richness increases. Taxaceae contributes more than a quarter of the total species richness between 800 and 3000 m; yet, its contribution declines below and above these elevations.

4.2. Altitudinal distribution of conifer families

Conifers have different highest distribution elevations along latitude (**Figure 4**), achieving the highest roughly at 30° north latitude. *Pinaceae* can grow up to 4700 m at 28° north latitude, with *Abies* at the highest elevation. *Juniperus* of *Cupressaceae* appears even at 4900 m a.s.l., the highest treeline position, at approximately 30° north latitude. *Podocarpus* of *Podocarpaceae* can be up to 4000 m a.s.l. at 25° north latitude, but *Taxus* of *Taxaceae* to its highest elevation of only 2000 m a.s.l. at 28° north latitude.

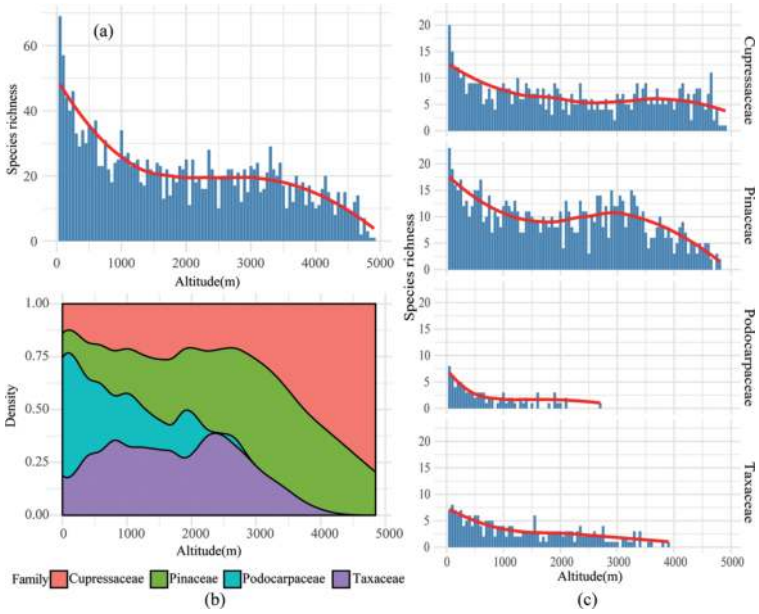

Figure 3. Species richness along elevation in mainland China. (a) The overall distribution pattern of conifers along elevation; (b) the percentage of different conifer families along elevation; (c) distribution pattern of four conifer families along elevation.

Figure 5 demonstrates that the four families all reach their highest distribution at around 100° eastern longitude. *Podocarpaceae* and *Taxaceae* appear only east of 95° east longitude; while *Pinaceae* and *Cupressaceae* are widespread with their highest distribution between 90 and 100° east longitudes.

4.3. Conifers in treeline ecotone

As is well known, leaves get smaller with increased elevation as a mean of adaptation to harsher environment. In other words, needle-leaved plants are comparatively more competitive than any other woody plants in treeline ecotone; so, treeline-forming species are almost all conifers [21, 22]. In China, at treeline ecotones are mainly *Pinaceae* and *Cupressaceae* [22]. In the eastern monsoon realm (**Figure 2**), *Larix*, *Picea* and *Abies* of *Pinaceae* constitute the main species of the upper treelines. In the north of the realm, *Larix*, such as *Larix gmelinii*, occurs in the Greater Khingan Mountains, *Larix principis-rupprechtii* in Mt. Wutai and the Taihang mountains, *Larix chinensis* on Taibai Mts. in the middle of the Qinling range; westwards from Taibai Mts. appears *Larix potaninii*. In the south of the realm, *Abies* of *Pinaceae* is the main treeline species in the Jade Mountains of Taiwan. In the northwestern arid realm of China, *Picea schrenkiana* forms the upper treeline species in the Tianshan, *Picea crassifolia* in the Qilian Mountain, and *Larix sibirica* in the Altay Mountains. In the Tibetan Frigid realm, all upper treelines are characterized by *Juniperus*, with *Juniperus tibetica* at the world-highest treeline site (4900 m) in the southeastern Tibetan Plateau [2].

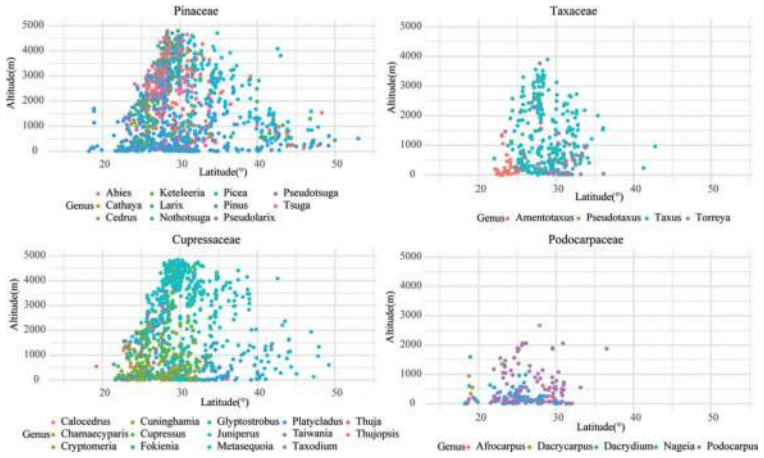

Figure 4. Altitudinal distribution of conifer families along latitude in China.

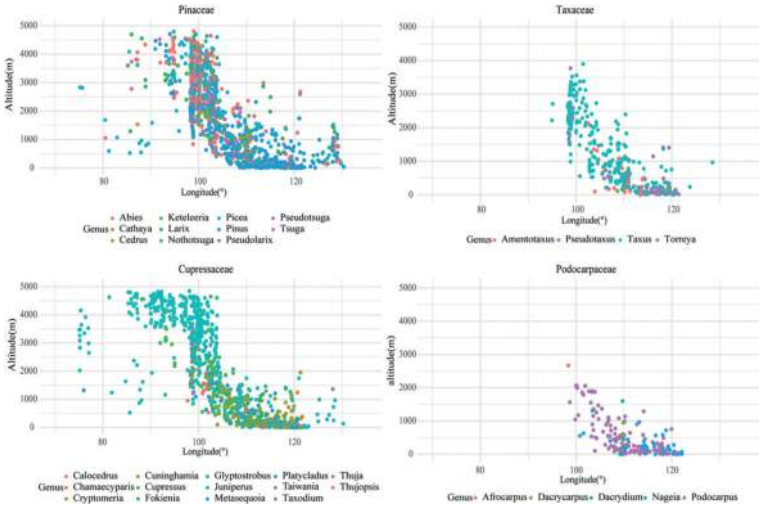

Figure 5. Altitudinal distribution of conifer families along longitude in China.

4.4. Mass elevation effect and the altitudinal distribution of conifer treelines

Mass elevation effect (MEE) is one of the most significant factors influencing the altitudinal distribution of treelines [23]. It is virtually the results of the thermodynamic effect of mountain masses or the heating effect of mountain massifs [24], leading to higher temperature in the interior than in the outside of mountain masses on the same elevations at similar latitudes. MEE is most prominent in the lofty and immense Tibetan Plateau (averagely 4500 m). Its magnitude is closely related with MEE intra-mountain base elevation (IMBE), and it can be quantified by developing a ternary linear regression model with IMBE, latitude and continentality as independent variables. It has been shown that IMBE, latitude and continentality

could together explain 92% of global treeline elevation variability, with IMBE contributing the most of 52.2% to the altitudinal distribution of global treelines [23]. Thanks to MEE, the 10°C isotherm for the warmest month and the warmth index of 15°C month, which roughly coincide with alpine treelines, are as high as 4600–4700 m a.s.l. in the southeastern Tibet Plateau [1], more than 1000 m higher than in surrounding lowland areas.

We collected 364 treeline sites of China from the dataset [23] to explore the contribution of MEE to the distribution of conifer treelines by developing a regression model with treeline elevation as the dependent variable and the other three variables (latitude, continentality and base elevation) as independent variables. The multiple regression model is as follows:

$$TL(m) = a \times Lat + b \times K + c \times BaseAlt + d \tag{1}$$

where TL is treeline elevation, Lat latitude, $BaseAlt$ Base altitude, K continentality; a, b and c are coefficients of independent variables, d is constant term.

Continentality is calculated based on Gorczynski's formulas [25]:

$$K = 1.7 \times A/\sin\phi - 20.4 \tag{2}$$

where K is continentality, ϕ latitude, and A the difference of mean temperature of the warmest and coldest months. Monthly mean temperature data were extracted from interpolated climate surfaces at a spatial resolution of 30 arcs (equivalent to 860 m) provided by the WorldClim database [26].

The regression is analyzed by using R, and the results are shown in **Table 3**.

The regression model is as follows:

$$TL(\mathrm{m}) = -24.77 \times Lat - 30.95 \times K + 0.54 \times BaseAlt + 4783.76 \left(R^2 = 0.7843, p < 0.001\right) \tag{3}$$

Variance inflation factor (VIF) is used to detect multicollinearity of the three variables, and the results showed low multicollinearity (**Table 3**). To analyze the prediction accuracy of the multiple regression model, Shapiro-Wilk normality test of standardized residual was performed. The result shows that $W = 0.9953$ and p-value = $0.3141 > 0.05$, proving the correctness of the regression model.

The contribution rate of base altitude is as high as 49.81%, showing that MEE contributes the most to the altitudinal distribution of conifers in China. Continentality and latitude are the second and the third influential factors with contribution rates of 33.28 and 16.90%, respectively. The contribution rate of base elevation we calculated is very close to the results by Zhao et al. [23] (52.2% for global scale and 50.4% for north hemisphere).

4.5. Conifer elfin forest in China

Conifer elfin forests develop under very severe environmental conditions, usually at the uppermost sections of treeline ecotones or pseudo-treelines with cold or harsh habitats. Most of conifer elfin forests are formed mainly by *Pinus pumila* in China [27]. *Juniperus* is another

variables	*C*1	*C*2	*CR* (%)	t value	p value
(Intercept)	4783.76	—		29.54	<0.001
Base altitude	0.54	0.51	49.81	17.82	<0.001
Latitude	−24.77	−0.17	16.9	−3.33	<0.001
continentality	−30.95	−0.34	33.28	−6.12	<0.001

Notes: *C*1 and *C*2 refer to Unstandardized Regression coefficients and Standardized Regression coefficients, respectively; *CR* is Contribution rate, is the respective proportion of absolute *C*2 to their absolute sum.

Table 3. Multiple linear regression model of treeline sites.

main component of elfin forests, such as *Juniperus squamata* scattered above the *Abies* treeline of the Jade Mountains, which can be compared with the *Abies*-formed treelines in the Tibetan Plateau, indicating the difference of dominant species between them.

5. Conifer protection in China

5.1. Evaluation and directory of endangered species

In the 1980s, Chinese government introduced the criteria of conservation status developed by the International Union for the Conservation of Nature (IUCN) to evaluate the situation of endangered native species. The National Environmental Protection Bureau of the PRC[1] and the Chinese Academy of Sciences jointly published the *List of Rare and Endangered Species in China* in 1987, which evaluated 388 endangered species including 65 species of coniferous trees in terms of IUCN's grades of endangered species (endangered, rare and vulnerable) [28]. In 1991, *China Plant Red Data Book* (vol. 1) was published to expound in detail the characteristics and endangerment causes of all listed species [29]. In 1999, the State Council issued the *List of National Protected Wild Plant*s (vol. 1), covering a total of 285 species and 51 conifer species. Its second volume, already under discussion, will include further 1615 species.

The Ministry of Environmental Protection released the *Red List of Biodiversity in China* in 2013, which evaluated the endangerment level of almost all wild higher plants in China. The list involves 202 species of conifers, of which 109 are endemic to China; a total of 16 species are critically endangered (CR), half of which are the *Pinaceae*; 29 species are endangered (EN), 10 near threatened (NT), 56 vulnerable (VU). In addition, some national protected species of class I are still in critical condition, such as *Abies beshanzuensis*, *Abies yuanbaoshanensis* and *Pinus squamata*, most of which are still endangered, such as *Cathaya argyrophylla*, *Abies fanjingshanensis*, *Taxus fauna,* and so on, and the rest are vulnerable. However, among the 45 conifer species in CR and EN, 9 in CR and 13 in EN are still not in the national protected list. To further

[1]The National Environmental Protection Bureau of the PRC (1984–1998) was predecessor of Ministry of Environmental Protection (2008–2018), and now the Ministry of Ecology and Environment.

strengthen species protection, the government launched the Rescue and Protection Program for Plant Species with Extremely Small Populations (PSESP), and carried out a 5-year rescue for 120 species, including 14 conifer species, mostly in CR or EN.

5.2. Conifer protection

5.2.1. On-site conservation

China has established a large number of protected areas to conserve its high biodiversity, especially its all rare or endangered species, including nature reserves, forest parks, national parks, scenic areas and geo-parks. By 2015, nature reserves of different levels amount to 2740 in mainland China, covering an area of about 1.4659 million km^2, about 15.31% of the total land area. A total of 256 nature reserves involves the protection of conifers and covers an area of 47, 200 km^2, 64 (about 1/4) are at the national level and occupy 50.25% of the total area. Geographically, conifer-related nature reserves cover almost all China's provinces. Heilongjiang province in Northeast China possess the most (23), followed by Hunan (22) in the middle south, Guizhou (22) and Yunnan (20) in the southwest (**Figure 6**).

5.2.2. Off-site conservation

The introduction and cultivation of rare and endangered species in botanical gardens and their specialized gardens (areas) are considered an effective method of species conservation, a supplement to on-site conservation. China has developed 164 botanical gardens, about one-fifth of the global total, to nurture about 20,000 species, some 60% of its whole flora [30]. Approximately half of conifer taxonomy in China are rare species and need off-site conservation. The repeated cultivation of species in different botanical gardens can effectively reduce the transmission of pests and diseases caused by larger populations [31]. China's main six botanical gardens (South China Botanical Garden, Wuhan Botanical Garden, Beijing Botanical Garden, Nanjing Botanical Garden, Guilin Botanical Garden and Lushan Botanical Garden) have covered almost all rare conifer species, especially *Taxus chinensis*, *Cathaya argyrophylla*, *Pinus kwangtungensis*, *Pseudotaxus chienii,* and so on [30, 32].

5.3. Laws and regulations

In order to protect forest ecosystems including conifers, China has promulgated and implemented Environmental Protection Law, Forest Law, Grassland Law, Nature Reserve Regulations, Regulations on the Protection of Wild Plants and so on, which have formed a relatively comprehensive legal system. The State Council issued in May 1987 the Chinese Program for Natural Protection, the first macro guidance document for protecting natural resources and environment in China [33]. In December 1993, China became the member of the State Parties of the Convention on Biological Diversity (CBD). The government even formulated and implemented the "China Action Plan for Biodiversity Conservation", "Outline of National Ecological Environment Protection Plan", "National Plan for the Protection and Utilization of Biological Species Resources ", and has organized a series of key plant protection projects [34].

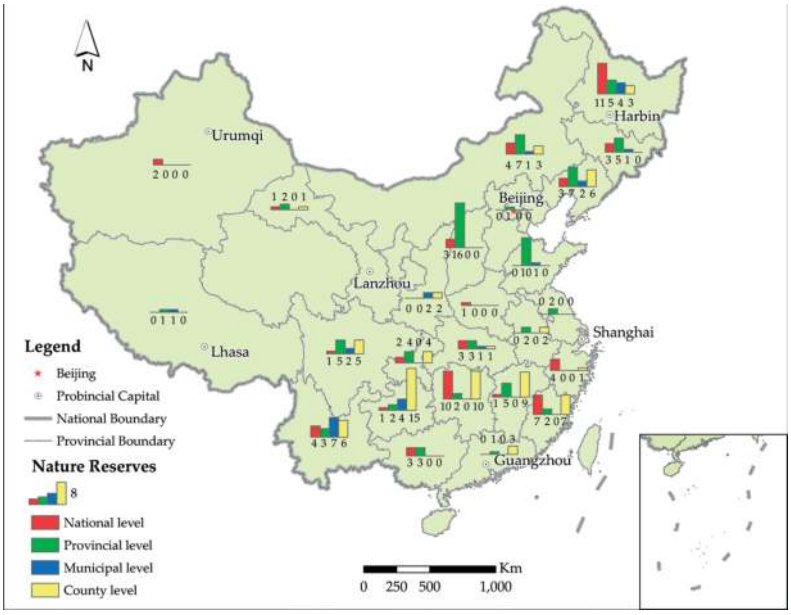

Figure 6. Number and distribution of conifer-related nature reserves in mainland China.

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