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Seed plant features, distribution patterns, diversity hotspots, and conservation gaps in Xinjiang, China

Jihong Huang[1,2], Canran Liu[3], Zhongjun Guo[4], Keping Ma[5], Runguo Zang[1,2], Yi Ding[1,2], Xinghui Lu[1,2], Jiping Wang[6], Ruoyun Yu[1]

1 *Key Laboratory of Forest Ecology and Environment, the State Forestry and Grassland Administration, Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, #2 Dongxiaofu, Xiangshan Road, Haidian District, Beijing, China 100091, China* **2** *Co-Innovation Centre for Sustainable Forestry in Southern China, Nanjing Forestry University, #159 Longpan Road, Nanjing 210037, China* **3** *Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria 3084, Australia* **4** *Institute of Forest Ecology, Xinjiang Forestry Academy, #191 Anjunnan Road, Shuimogou District, Urumqi 830000, China* **5** *State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, #20 Nanxincun, Xiangshan, Haidian District, Beijing 100093, China* **6** *Research Center of Saline and Alkali Land of State Forestry and Grassland Administration, #2 Dongxiaofu, Xiangshan Road, Haidian District, Beijing 100091, China*

Corresponding author: *Jihong Huang* (northalluvion@caf.ac.cn)

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Abstract

The flora in Xinjiang is unique. Decisions about biodiversity conservation and management based on seed plant diversity hotspots and conservation gaps in Xinjiang are essential to maintain this unique flora. Based on a species distribution dataset of seed plants, we measured seed plant diversity using species richness and phylogenetic diversity indices. Five percent of Xinjiang's total land area with the highest biodiversity was used to identify hotspots for each index. In total, eight hotspots were identified. Most hotspots were located in mountainous areas, mainly in the Tianshan Mountains and Altai Mountains. Furthermore, we detected conservation gaps for Xinjiang's seed flora hotspots by overlaying nature reserve maps on to maps of identified hotspots and we designated priority conservation gaps for hotspots by overlaying global biodiversity hotspot maps on to hotspot conservation gaps maps. Most of Xinjiang's seed plant hotspots are poorly protected; only 10.45% of these hotspots were covered by nature reserves. We suggest that it is essential to promote network function of nature reserves within these hotspots in Xinjiang to conserve this unique flora.

Keywords
plant diversity, diversity hotspots, phylogenetic diversity, conservation gaps, Xinjiang

Introduction

Biodiversity is unevenly distributed; therefore, prioritisation is essential to minimise biodiversity loss (Brooks et al. 2006). Identifying priority areas or hotspots where biodiversity is most threatened is critical for effective conservation (Myers et al. 2000; Olson and Dinerstein 1998). Biodiversity hotspots are characterised by exceptional concentrations of endemic species that experience relatively high rates of habitat loss (Myers et al. 2000; Prendergast et al. 1999). This approach to defining hotspots has been used in many studies (Mittermeier et al. 2005). To adequately define a hotspot, its boundaries must be delineated. A predefined proportion of areas with large amounts of both endemic species richness and habitat loss was previously considered a hotspot (Orme et al. 2005; Prendergast et al. 1993). Recently, the definition of the term 'hotspot' for biodiversity has been generalised. In addition to the amount of endemic species and habitat loss, other aspects, including total number of species, number of threatened species and evolutionary history, have been proposed to identify hotspots (Cadotte et al. 2010; Forest et al. 2007; Rosauer and Laffan 2008). Researchers previously focused taxonomic diversity (Brooks et al. 2006; Reid 1998). However, more recently, many researchers focused on the evolutionary processes (Cadotte et al. 2010; Huang et al. 2016c; Xu et al. 2017). Phylogenies (evolutionary trees) have become increasingly important for identifying biodiversity hotspots. Phylogenetic diversity is often favoured because it shows relationships between extant species and provides more information about evolution over a long time-scale (Omland et al. 2008).

Xinjiang Uygur Autonomous Region (Xinjiang hereafter) is a large (1.64 million km^2), topographically varied inland province in northwest China that extends from high mountains (8611 m above sea level) to lowland basins (156 m below sea level) and humid forest to grasslands and dry desert. Consequently, this region has an extreme arid and cold climate and exhibits striking climate, soil and vegetation patterns. Species richness patterns in Xinjiang were previously reported for woody plants (Zhang and Zhang 2014). The vegetation types in Xinjiang are mainly desert and grassland (including steppe and meadow) and forest covers relatively small areas. The constructive species of the grassland are Gramineae, Compositae and Leguminosae, whereas the constructive species of the forest include the coniferous *Larix*, *Picea*, *Abies*, and *Pinus*; broadleaved *Betula* and *Populus*; and the native fruit species of *Malus*, *Armeniaca* and *Juglans*, which are endemic to Ily Valley (Xinjiang Investigation Group of Chinese Academy of Sciences 1978). Although many studies have been conducted on Xinjiang's flora, data are still not sufficient to provide systematic guidance for regional biodiversity conservation.

In this paper, based on native seed plant species in Xinjiang, we identified seed plant hotspots using both species richness and phylogenetic diversity indices. Moreover, Xinjiang's seed plants conservation gaps, which are hotspot areas that are not covered by China's nature reserves, were detected by overlaying the seed plant hotspot map on a map of Xinjiang's nature reserves; and Xinjiang seed plant priority conservation gaps, which are areas within both Xinjiang seed plant hotspots and global biodiversity hotspots that are not covered by Xinjiang's nature reserves, were detected by overlaying the Xinjiang seed plant conservation gap map on a global biodiversity hotspot map. Finally, we discussed the potential causes of the patterns revealed in this study and proposed suggestions for Xinjiang flora protection.

Methods

Data sets

We compiled a species distribution database that included all seed plant species distributed in Xinjiang based on a large number of herbarium specimens (http://www.cvh.org.cn/), a list of Chinese seed plant species and distribution information at provincial level (Wu et al. 1994–2012) and other literature sources that mainly included Flora Xinjiangensis (Commissione Redactorum Florae Xinjiangensis 1992–2011), Sylva Xinjiangensis (Yang 2012), Desert Plants in China (Lu et al. 2012) and Rare Endangered Endemic Higher Plants in Xinjiang of China (Yin 2006). The county was used as the basic spatial unit for species distributions and geographical coordinates were included for each specimen. To improve the quality of the distribution data at the county level, we overlaid county distributions over altitudinal range distributions for each species. We divided the entire region into 50×50 km grids and then overlaid these grids on to the distribution polygons or points. Finally, we acquired presence/absence data for each species in each grid. In our study, data on 3715 seed plant species were obtained based on a total of 145781 occurrence records.

A georeferenced or spatially referenced dataset of 33 nature reserves in Xinjiang was constructed. The main body of nature reserves was downloaded from the World Database on Protected Areas (http://www.protectedplanet.net/). The global biodiversity hotspots dataset was downloaded from Conservation International (http://www.conservation.org/How/Pages/Hotspots.aspx).

Diversity measures and phylogenetic tree construction

To detect the distribution patterns of Xinjiang seed flora, we calculated seed species richness and phylogenetic diversity of seed plants. Phylogenetic diversity is a simple measure of evolutionary diversity that is determined based on the sum of the lengths of all branches that are members of the corresponding minimum spanning path (Faith 1992). The phylogenetic diversity equation is:

$$PD = \sum_{\{c \in C\}} L_c ,$$

where C indicates the set of branches in the minimum spanning path joining the species to the root of the tree, c indicates a branch in the spanning path, and L_c indicates the length of branch c. Phylogenetic diversities were calculated by using the phylogenetic diversity algorithm in PHYLOCOM (Webb et al. 2008).

PHYLOMATIC (Webb and Donoghue 2005) was used to construct a phylogenetic supertree for Xinjiang's seed plants. The backbone of the supertree in PHYLOMATIC was based on the latest plant phylogeny group classification. The BLADJ algorithm (Webb et al. 2008) was used to adjust the branch lengths of our phylogenetic tree by using known molecular and fossil dates (Wikstrom et al. 2001).

Hotspot identification and ranking and conservation gap analysis

Both diversity indices were calculated using two packages, Ape and Picante, in R 3.3.2 (R Core Team 2016) and the resulting maps were generated with ARCGIS 9.0 (ESRI, Redlands, CA, USA). The relationship between the patterns of diversity characterised with the different indices was calculated using Spearman's correlation coefficient for each pair of indices. Hotspots were identified with each diversity index as indicated hereafter. We accumulated all of the cells with the highest values of the two diversity indices until the total area reached 5% of Xinjiang's total land area. It was well known that complementarity (Vane-Wright et al. 1991) plays an important role in biodiversity hotspot identification (Zhang and Ma 2008). Here, we did not use complementarity (Vane-Wright et al. 1991) to identify hotspots, because our method ensures that all local areas (i.e. cells) within the hotspots have more species than any other areas outside the hotspots. Additionally, our grid cell size was 50km × 50km, which is large enough for local authorities to manage.

We then identified 'conservation gaps' (Huang et al. 2016a) and 'priority conservation gaps' (Huang et al. 2016a) for Xinjiang seed plants. We synthesised species richness, hotspot size, the proportion of protected areas that overlap with hotspots and global role in biodiversity conservation to rank all hotspots identified in our study for conservation. Species richness was calculated by species number in each hotspot; hotspot size was determined by the area of each hotspot; the proportion of protected areas that overlap with hotspots was calculated based on the each hotspot divided by the area covered by nature reverses; and global role in biodiversity conservation was calculated based on the area of each hotspot divided by the area covered by global biodiversity hotspots. These four indices were ranked and divided by total number of hotspots then summed to produce a total value. All hotspots were ranked according to their total value.

Results

Xinjiang seed plant features

Based on our data, Xinjiang has 3715 seed plant species (including 66 subspecies and 224 varieties), which account for 12.71% of all seed plant species in China. These seed

Table 1. Numbers of seed plant orders, families, genera and species in each geographical region of Xinjiang. Regional division of Xinjiang is shown in Fig. 1.

	Geographical regions										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Overall**
No. of orders	40	43	42	38	36	39	38	35	26	25	45
No. of families	92	104	95	76	72	79	83	64	42	40	113
No. of genera	572	629	569	365	315	378	403	251	130	153	767
No. of species	2291	2445	2110	1102	824	1163	1398	618	264	343	3716
Gymnosperms	22	30	25	17	12	17	18	9	2	2	41
Dicots	1820	1963	1708	870	630	881	1081	472	198	235	2994
Monocots	449	452	377	215	182	265	299	137	64	106	681

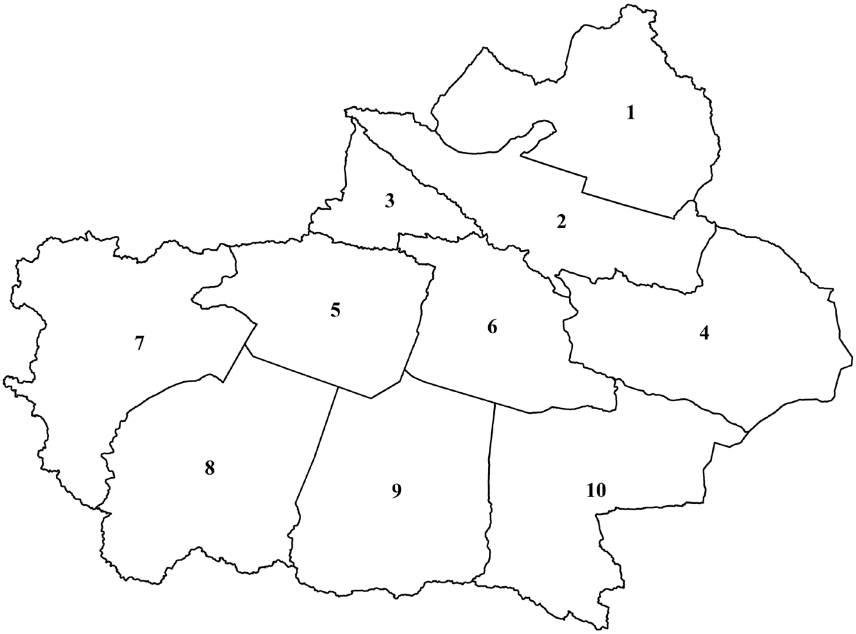
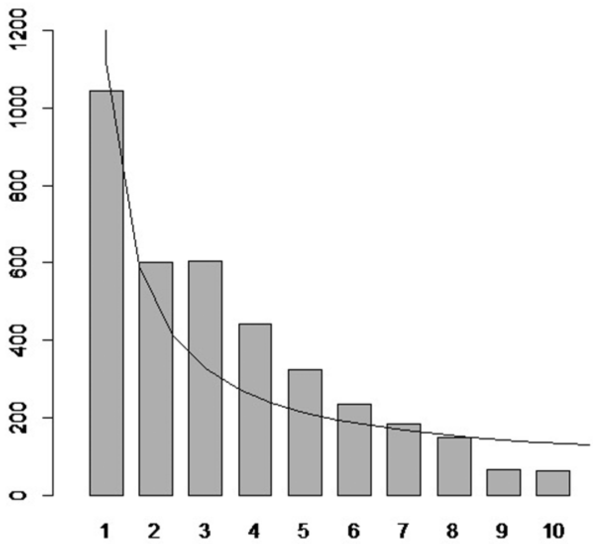


Figure 1. Map showing the 10 geographical regions of Xinjiang. Black number identifies geographical regions: **1** North of Junggar Basin **2** South of Junggar Basin **3** Ily Valley **4** Eastern zone of Xinjiang **5** West-North Tarim Basin **6** East-North Tarim Basin **7** West Tarim Basin **8** West-Central Tarim Basin **9** South-Central Tarim Basin **10** East-Central Tarim Basin.

plants belong to 767 genera and 113 families. Of these species, gymnosperms, dicots and monocots accounted for 1.10%, 80.57% and 18.33%, respectively, of all Xinjiang seed plant species (Table 1).

Xinjiang seed plants distribution and similarity at the regional level

Species richness at the regional scale generally increased with decreasing latitude in Xinjiang. In the 10 geographical regions (Fig. 1), region 9 (South-Central Tarim Basin) had



Figu 2. Species richness distribution for 3715 species in Xinjiang across the 10 spatial range classes. Spatial range was measured based on the number of geographical regions, without specific reference to particular regions. The line represents the least-squares regression using a hyperbola model with 61.07 and 1060.20 as the a and b parameters, respectively (R^2=0.89, P<0.001).

the lowest species richness (only 264 species) and region 2 (South of Junggar Basin) had the highest species richness (2445 species) (Table 1). In terms of regional occurrence, only 61 species (1.64% of total species) were found in each of the 10 geographical regions. By comparison, 1046 species (28.15% of total species) occurred in only one of the 10 geographical regions. The number of species that were present in a given number of regions decreased as the number of regions increased, which demonstrates that seed plants species with narrow spatial ranges were more common than those with wide or transcontinental spatial regions (Fig. 2). With the hyperbola model ($G=61.07+1060.20/RT$), where G was the number of species and RT was the total number of regions (Fig. 2), the spatial range of the genetic distributions of seed plants explained 89% of the variation in the number of species with varied distribution ranges.

The similarity indices for pairwise comparisons of regional species composition ranged from 0.07 to 0.58 (Table 2). In general, region 9 was the least similar to all other regions. This trend was, in part, due to the low number of species in this region. The lowest similarity indices were found between the regions 9 and 1 and 9 and 3, whereas the highest was found between the regions 1 and 2 (Table 2).

Diversity hotspots of Xinjiang seed plants

Distributions of Xinjiang seed plant species richness and phylogenetic diversity were uneven and concentrated in the northern regions of Xinjiang (i.e. north of the Tianshan

Table 2. Jaccard similarity indices for pairwise comparisons of geographical regions using all Xinjiang seed plant species. Regional division of Xinjiang is shown in Fig. 1.

	1	2	3	4	5	6	7	8	9	10
1										
2	0.58									
3	0.55	0.58								
4	0.35	0.38	0.34							
5	0.26	0.28	0.28	0.36						
6	0.36	0.38	0.38	0.41	0.38					
7	0.33	0.36	0.34	0.35	0.38	0.40				
8	0.15	0.18	0.17	0.25	0.30	0.27	0.33			
9	0.07	0.08	0.07	0.13	0.17	0.14	0.15	0.27		
10	0.09	0.09	0.08	0.14	0.17	0.15	0.18	0.26	0.30	

Table 3. Seed plant diversity hotspots and conservation ranks in Xinjiang.

Code	Plant diversity hotspots	Number of species	Area of hotspots (km^2)	Proportion of area uncovered with nature reserves (%)	Proportion of area covered with global biodiversity hotspots (%)	Conservation rank
H1	Mountain areas in and around Altay city-Burqin County	1406	32500	94.21	0.00	2
H2	Mountainous areas in and around Urumqi city	1627	30000	88.5	63.06	3
H3	Mountainous areas in and around Yining city-Gongliu county	1084	15000	98.48	99.29	1
H4	Fuyun-Qinghe-Qitai-Jimsar Counties boundaries	969	10000	47.66	0.00	7
H5	Shihezi City and Shawan county	751	7500	100.00	42.39	4
H6	Tacheng City and Yumin county and Ermin county boundary	618	5000	100.00	0.00	5
H7	Bole City-Huocheng County and Wenquan County boundary	698	5000	94.68	99.08	6
H8	Karamay City-Hoboksar County-Shawan County boundaries	481	2500	92.19	0.00	8

Mountains; Fig. 3a–c). Both species richness and phylogenetic diversity indices calculated for each spatial unit across Xinjiang were highly significantly correlated with each other (R=0.99, P<0.0001). The diversity hotspots identified based on Xinjiang seed plant species richness were distributed in seven distinct centres: H1-H7 (Table 3, Fig. 3d). The diversity hotspots identified based on phylogenetic diversity included eight centres, which included all of the above seven hotspots and H8 (Table 3, Fig. 3e). All hotspots were located north of the Tianshan Mountains (Fig. 3f).

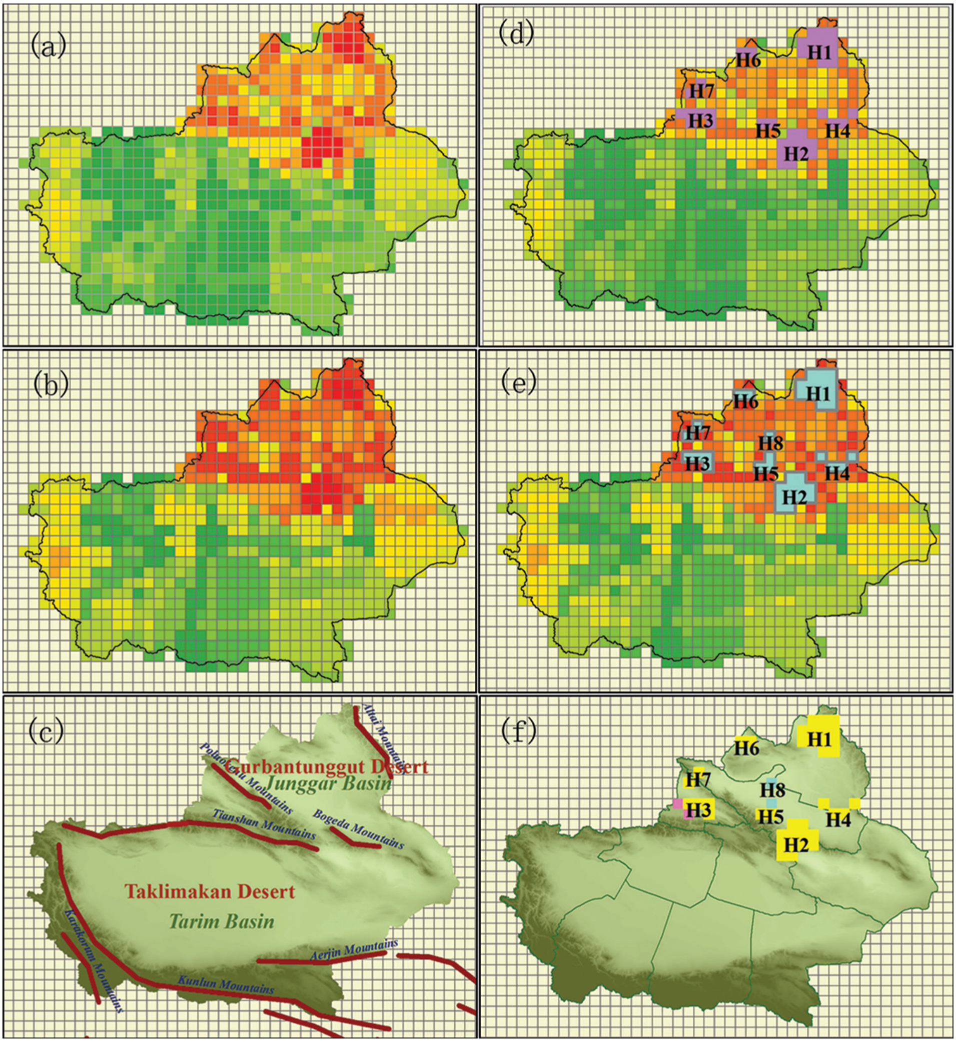


Figure 3. Geographic distribution of Xinjiang seed plant diversity patterns and hotspots and major mountains ranges in northwest China. **a** Geographic distribution of species richness **b** geographic distribution of phylogenetic diversity **c** major mountains ranges **d** diversity hotspots identified by species richness **e** diversity hotspots identified by phylogenetic diversity and **f** diversity hotspots identified by both species richness and phylogenetic diversity. Albers projection. Hotspot centre codes are consistent with those listed in Table 3.

Priority conservation gap areas for Xinjiang seed plant hotspots

The spatial distributions of 33 nature reserves and eight hotspots of Xinjiang seed plant species significantly differed (Fig. 4). These reserves and hotspots overlapped across 11238.63 km^2, which represented 4.18% of the total area of Xinjiang's nature reserves; 89.55% of the hotspot areas were not covered by nature reserves. Therefore, most of the seed plant hotspots are not well protected and thus represent conservation gaps (Fig. 4).

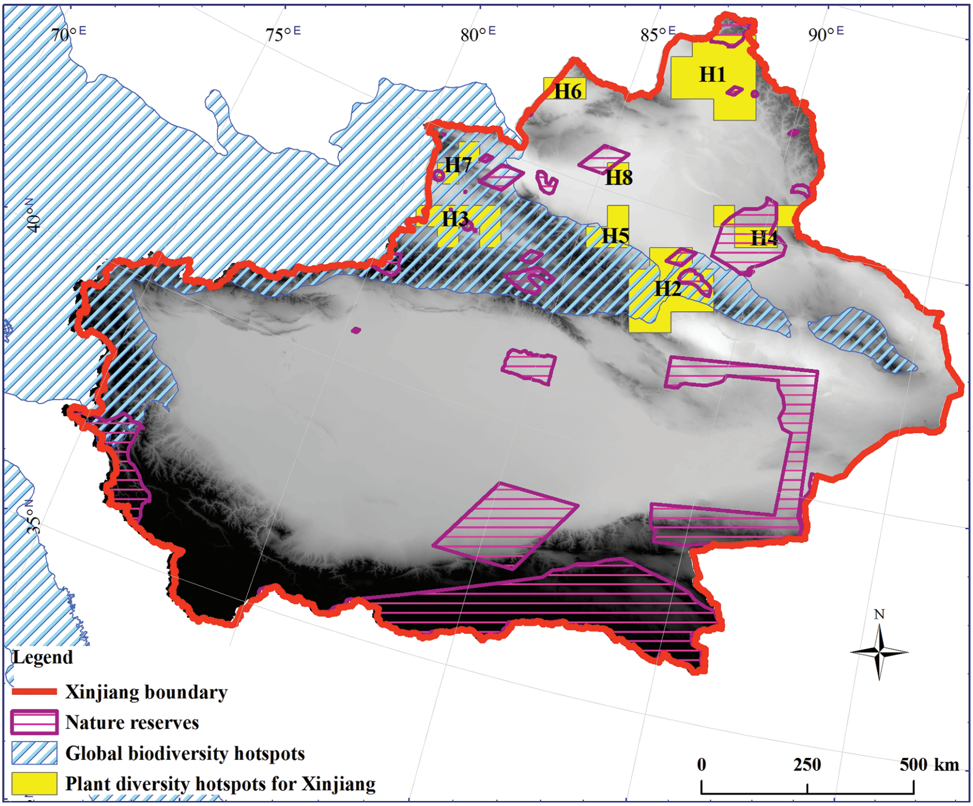


Figure 4. Geographic distributions of seed plant conservation and priority conservation gaps in Xinjiang, northwest China. Albers projection. Hotspot centre codes are consistent with those listed in Table 3.

Four of the eight hotspots overlapped with global biodiversity hotspots (H2, H3, H5 and H7; 60000.00 km^2); these overlapping areas accounted for 55.81% of the total area of all hotspots and contained 59.11% (2192 species) of all Xinjiang seed plant species. The remaining four hotspots harboured 1836 seed plant species, which accounted for 49.42% of all Xinjiang seed plant species. A priority conservation area that could alleviate Xinjiang seed plant conservation gaps is centre H5 (Fig. 4). Xinjiang's nature reserves, seed plant hotspots and global biodiversity hotspots overlap across 3319.79 km^2 and only account for 1.23% of the total area of Xinjiang's nature reserves.

Discussion

Xinjiang flora uniqueness and complexity

Xinjiang is located in the contact area of several natural geographical units, including the Altai Mountains, Tianshan Mountains, Pamirs, Kunlun Mountains, Altun Mountains and Northern Tibetan Plateau. Moreover, phytogeographically, Xinjiang also has intersections of Eurasian Forest, Eurasian steppe, Central Asian desert and Himalayan Chinese plant sub-regions. These characteristics have led to floral uniqueness and vegetation complexity in Xinjiang (Xinjiang Investigation Group of Chinese Academy of Sciences 1978). It was reported that there are 4081 species of vascular plants in Xinjiang (including subspecies), which account for 13.4% of the total number of plants in China (Yin 2006). Although, the number of species in Xinjiang is relatively low, the proportion of species that are locally endemic to Xinjiang is high (Huang et al. 2016b; Huang et al. 2014).

Xinjiang seed plant hotspots

Species richness is higher in Xinjiang mountains than basins (Li et al. 2013). The eight Xinjiang seed plant hotspots identified in this study cover key mountain ranges in Xinjiang, including both the Tianshan Mountains and Altai Mountains. Wang et al. (1993) proposed that these two terrestrial areas are key for conservation of China's biodiversity and these areas represent two of the 32 terrestrial priority areas for biodiversity conservation in China developed by the Ministry of Environmental Protection (Editorial Committee of China National Biodiversity Conservation Strategy and Action Plan 2011) and one of 19 centres of Chinese endemic seed plant hotspots (Huang et al. 2016a). Thus, Xinjiang seed plant hotspots encompass key areas for biodiversity conservation in China. This finding indicates that Xinjiang's seed plants represent a valuable group for identifying hotspots or priority areas that can be used to aid Xinjiang biodiversity conservation.

Hotspots in major mountain ranges of Xinjiang

Seed plant species are unevenly distributed across Xinjiang; all their hotspots are located in mountain areas mainly within the Tianshan Mountains, Altai Mountains and western mountainous areas in Junggar. These areas approximately correspond to the montane forest and cold temperate coniferous forest in temperate steppe and temperate desert regions (Chen 2014). Mountainous areas were potentially important for shaping the distribution of Xinjiang seed plant species; the high level of heterogeneity in the physiognomy could have offered a diversity of environments and thus promoted formation of the substantial species diversity (Qian and Ricklefs 1999) and caused aggregation of seed plants in the mountain regions of Xinjiang. The Tianshan Mountains and Altai Mountains are two natural physical barriers that alter atmospheric movement and consequently cause changes in precipitation and temperature. These conditions maintain a greater variety of habitats and thus probably enhance speciation, differentiation and preservation of the species that live in these areas, because species diversity increases with habitat variation (Latham and Ricklefs 1993; Rosenzweig 1995). These natural physical barriers also restrict north-south and east-west plant migration and interchange by forming a geographically isolated area (Wu and Wang 1983), which thereby facilitates the speciation and differentiation of endemics. Alternatively, other factors may play prominent but not decisive roles in some local regions, such as transitional areas (Axelrod et al. 1996; Wu 1980; Wu and Wang 1983) and islands isolated from the continents (Lomolino et al. 2006). Consequently, the abundance of seed plant species in mountainous forests results from a combination of effects and is mainly attributable to the heterogeneous terrain, geological history and contemporary environments in this region.

Suggestions for Xinjiang flora protection

Xinjiang is the largest province in China and accounts for one-sixth of China's total areas (Xinjiang Investigation Group of Chinese Academy of Sciences 1978). Xinjiang has extensively varied geographical and topographical features and a complex and ancient geographical history. Although plants are not abundant (Yin 2006), Xinjiang has unique flora and complex vegetation. Therefore, it is necessary and urgent to protect plants in Xinjiang. Based on the results of this study, some suggestions for conservation of the Xinjiang flora are proposed.

Firstly, we need to create a unified conservation plan for the Xinjiang flora. Conservation biologists have proposed many conservation suggestions and schemes across China (Li et al. 1993; Liu et al. 2003; Sang et al. 2011; Wu et al. 2011). However, these suggestions have unfortunately not been perfected and implemented at the provincial level, mainly because solid data support for plant diversity conservation in Xinjiang is lacking. Although research on species diversity in Xinjiang is very limited, researchers have conducted a large number of taxonomic investigations on plants in Xinjiang (CRFX 1992 –2011).

Secondly, we need to establish a provincal georeferenced (spatially referenced) database for biodiversity that includes plant, animal and nature reserve distributions. In particular, efficient conservation of Xinjiang's plant resources requires accurate data on the current distribution and threat status of plant species in the country (Sang et al. 2011). A large amount of plant diversity information has been digitised in China, including through the National Specimen Information Infrastructure (http://www.nsii.org.cn/), Chinese Virtual Herbarium (http://www.cvh.org.cn/), Chinese Field Herbarium (http://www.cfh.ac.cn/), the Flora of China project (http://hua.huh.harvard.edu/china), Scientific Database of China Plant Species (http://db.kib.ac.cn/eflora/Default.aspx). Some datasets have also been published with Chinese administrative counties as the spatial units, such as in studies on wood plants in China (Fang et al. 2009) and Chinese endemic seed plants (Huang et al. 2014). Additionally, by the end of 2014, China established 2729 nature reserves (Ministry of Environmental Protection the People's Republic of China 2015). Although we produced a spatially referenced dataset of 2139 nature reserves (the World Database on Protected Areas: http://www.protectedplanet.net/), the boundaries of many nature reserves were not accurate, because they did not have clear boundaries. Moreover, although a vegetation map of China was published in 2008 (Editorial Committee of Vegetation Map China 2008), many vegetation field survey projects were completed 30–50 years ago. All of the described studies provide an important data for research on biodiversity conservation across China. However, the data provided by those projects could not meet the precision requirements for biodiversity conservation research at the provincial level; therefore, it is necessary to develop additional solid sources of information for Xinjiang plants.

Conclusions

Different diversity indices revealed similar distribution patterns of plant diversity in Xinjiang Province. A total of eight seed plant hotspots in Xinjiang were identified by species richness and phylogenetic diversity. All of these hotspots are located in the mountainous areas within the Tianshan Mountains and Altai Mountains. Most centres of Xinjiang seed plant hotspots are not covered by the current nature reserve system.

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