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China's national nature reserve network shows great imbalances in conserving the country's mega-diverse vegetation

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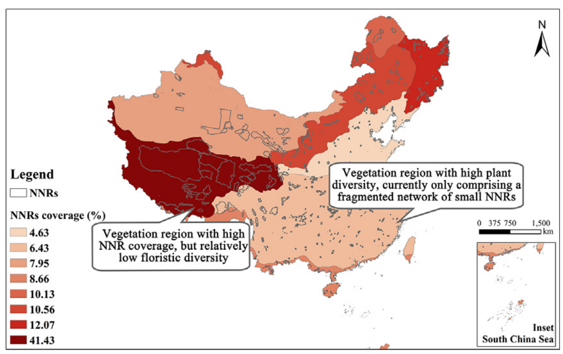
HIGHLIGHTS

- National Nature Reserves (NNRs) are central to China's biodiversity conservation.
- NNRs contain highly varying amounts of China's main vegetation types.
- Most phyto-diverse regions/habitats are strongly underrepresented in NNRs.
- Significant adjustments to the NNR network could increase its conservation efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

The National Nature Reserve (NNR) network forms a central element in China's governmental strategy to conserve the country's vast biodiversity and its varied ecosystems. Nonetheless, the effectiveness of the existing NNR network in protecting China's highly diverse habitats and the fauna and flora they contain has remained unclear. Here, we analyze how comprehensively the existing NNR network protects China's vegetation diversity, identifying potential gaps to inform future NNR designations. Covering ~15.7% of China's land area, the existing nature reserve network contains 18 main vegetation types and 26 sub-types. All main vegetation types are also contained in the National-level Nature Reserves (NNRs), but to highly differing degrees. NNRs cover ~24.0% of China's grasslands, but only ~3.3% of the country's monsoon forests. With regards to main vegetation regions, about 41.4% of the Qinghai-Xizang Plateau is covered by NNRs, in contrast to only ~4.6% of the region representing warm-temperate deciduous broad-leaved forests. In five main vegetation regions, NNRs cover <10% of the area and are scattered across a highly fragmented network, leading for example to China's highly biodiverse subtropical evergreen broad-leaved forests being conserved only in small, isolated NNRs. NNRs also greatly vary in the number of vegetation types they individually comprise, with only 64 NNRs (18.9%) individually containing >50% of the vegetation types in their respective region. Overall, NNR size increases and fragmentation decreases from China's south-east to its western provinces. The resulting, extremely uneven distribution of NNRs across China limits their effectiveness in protection the country's plant diversity treasure trove. The country's NNR network therefore needs significant adjustments to effectively conserve China's valuable natural resources for future generations.

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1. Introduction

Systematic governmental conservation planning is common practice around the world (Groves et al., 2012). Accordingly, the global protected area estate has grown significantly in recent decades (Venter et al., 2014), with nature reserves, national parks and other designated conservation areas updated and optimized in light of changing conservation priorities, climate and land-use changes, economic developments and the corresponding changes in legal and governance frameworks. Nonetheless, the degree to which protected areas provide positive conservation outcomes in protecting threatened species and ecosystems is being debated (Gaston et al., 2006; Helsen et al., 2011; Wu et al., 2011; Brugière and Scholte, 2013; Xu et al., 2014). In view of environmental challenges linked particularly to climate change and associated shifts in species' distribution ranges, the focus of conservation activities is increasingly shifting from species conservation to the conservation of entire landscapes containing habitat types of conservation concern that can support threatened species of plants and animals (Tukiainen et al., 2017). Nonetheless, few systematic assessments have analyzed the large-scale efficiency of entire PA networks in conserving the diversity of habitat types across large geographic regions (Guo et al., 2015). Gap analysis can highlight their deficiencies, and has already been used successfully in assessing species and landscape feature representation in PA networks (Sharafi et al., 2012), demonstrating the suitability of this powerful analytical tool to inform biodiversity conservation planning.

As the third-largest country in the world, China harbors megadiverse plant and animal communities. Its territory stretches 5200 km from east to west and spans 50° of latitude, covering five main climate zones from cold-temperate to tropical regions (Mittermeier, 1997). In addition, China's topography is highly variable and includes many of the highest mountains on the planet, but also extensive high- and low-elevation plains and large river basins. Given this topographic and climatic diversity, China harbors eight main vegetation regions that can be sub-divided into 29 distinct vegetation types and 54 subtypes (Wu, 1980).

China's rapid economic development in recent decades, that has seen the country become the second-largest economy in the world (Ma et al., 2017), has triggered massive biodiversity losses. These losses affect the stability of natural and semi-natural ecosystems across the country. To alleviate China's biodiversity crisis, restoring degraded ecosystems and safeguarding the ecological services they provide, the Chinese Government has implemented several ecological conservation programs. Among these, the Nature Reserve Development Program (NRDP) is of crucial importance, employing conservation biology principles to develop effective measures that protect biodiversity and ecosystem functions. By the end of 2016, China had established 446 national nature reserves (NNRs) covering an area of 0.94 million km^2, with a further 11 NNRs newly established in 2018 (MEE of China, 2011, 2018b). Like many other countries in the world, China has developed its NNR network in view of the AICHI criteria (Cooper et al., 2019), but the rapid associated expansion has led to distinct distribution imbalances – areas of low human population densities like arid regions seeing the establishment of particularly large PAs – and to problems associated with the consolidation and efficient management of the rapidly expanding reserves network (MEE of China, 1994).

Assessments of the direct effectiveness of PAs with regards to biodiversity and individual threatened species would require substantial systematic spatio-temporal inventories across the entire PA network. Existing threatened species lists are also routinely extremely biased towards species-poor taxa in vertebrates and vascular plants, while threatened species assessments and species richness-based conservation approaches routinely neglect invertebrates that represent the bulk of biodiversity. Furthermore, like in other mega-diverse countries, many Chinese invertebrate species are not even known to science, yet, while both, thorough inventories of vertebrate and vascular plant species and of their populations across the NNR network are widely lacking, too. Given the large prevailing data-gaps and taxonomic biases, in combination with the dynamic range shifts observed in many species in response to changes in climatic conditions, we decided to adopt an assessment approach for the efficiency of the NNR network that does not focus on individual species, instead investigating how well main vegetation types are represented within this network in China. We focus on NNRs since China only imposes strict spatial boundary demarcations at the national reserve level, and NNRs already represent a very large area proportion of the overall PA network (67.10%). We furthermore assume in our analysis that a strong representation of a specific vegetation type in an NNR will greatly enhance the chances of securing the survival of its core species pool in accordance with the Aichi Target 11 (https://www.cbd.int/sp/targets/), 17% area of an ecosystem under protection has commonly been used as benchmark, while it is also recognized that conservation of as much as 30% or more (Andren, 1994) of an ecosystem's distribution area might be required for some ecosystems to provide sufficient habitat for species maintenance. We acknowledged that our approach therefore can only provide an indication of conservation effectiveness, since particularly the conservation chances for locally endemic species cannot easily be established by this approach. We therefore also analyzed the NNR coverage specifically of China's main mountain region in Qinghai, since these high mountain ranges with their extreme variations in environmental conditions over short spatial scales harbor many of China's local endemics.

Overall, we tested the following hypotheses: 1. There is a strong imbalance in the NNRs coverage of different vegetation types across China that somewhat parallels their highly uneven regional distribution. 2. Vegetation units that harbor particularly high levels of species richness like many tropical forest types are particularly strongly underrepresented in the current NNR network, while vegetation types encountered in dry climatic conditions that comprise only a small fraction of China's biodiversity are overrepresented. 3. Vegetation types that are underrepresented in the NNR network are highly fragmented in their distribution across reserves.

The insights gained by our analysis can directly be used not only to identify current conservation gaps, but in turn strongly inform a highly targeted expansion of the NR network.

2. Material and methods

2.1. Data

We established a database for all NNRs in mainland China that included PA area, broad classification (for example “inland wetland”, “forest”, “coastal”, “grassland”, “desert” “paleontological relic”, “geological feature”, as well as reserves designated for the protection specifically of a certain species of wild animal or plant), the specific foci or objectives of conservation (for example protection of specific habitats like primary or secondary forest types, threatened animal and plant species or species assemblages like migratory birds using an area during their migration), known plant species and establishment date. The explicit geographical spatial locations and boundaries of 339 NNRs were collected by referring to legal documents regarding the geographical distribution of NRs from government agencies, institutions, local government announcements, published papers and NR websites. Furthermore, a 1:1,000,000-scale vegetation map (Zhang, 2008) representing the hierarchical classification system of China's vegetation types, differentiated into 960 vegetation formations or sub-formations (including both natural and ‘artificial’ vegetation types) was used in our analysis. In addition, China's main eight vegetation regions were analyzed in our study: the Qinghai-Xizang plateau alpine vegetation; temperate desert; temperate grassland; tropical monsoon forests and rainforest; subtropical evergreen broad-leaved forests, warm temperate deciduous broad-leaved forests; temperate coniferous and deciduous broad-leaved mixed forests and cold temperate coniferous forests.

2.2. Analysis

Gap analysis was used to evaluate the effectiveness of NNRs in conserving the different vegetation types, considering regionalization and geographical distribution of each vegetation type (Jantke et al., 2011; Guo et al., 2015). The high-resolution maps of vegetation types and sub-types were overlaid with a spatial reserve layer in ArcGIS 10.4 to explore the representation of the different vegetation types in the NNR network. This was set into context with the size of both the area of each vegetation type under protection with its overall area in China.

In order to better express the spatial relationship of NNRs, we used Conefor26 software to calculate the Integral Index of Connectivity (IIC) to express the landscape connectivity of NNRs (Pascual-Hortal and Saura, 2006). This index ranges from 0 to1 and increases with improved connectivity. IIC = 1 represents the hypothetical case that all the landscape is occupied by protected habitat. Mathematically, the index can be expressed as:

$$\mathrm{IIC} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i a_j}{1+nl_{ij}}}{A_L^2}$$

where n is the total number of patches (here: NNRs), a_i and a_j are the area of the patches i and j, nl_{ij} is the number of links in the shortest path (topological distance) between patches i and j, A_L is the total area of the landscape. Different distance thresholds will directly affect A_L and therefore lead to different index results. In this study, we used the Number of Components (NC) indicator as the basis for judging the index results, assuming that the index reaches its maximum value for NC = 1.

Additionally, we weighted the importance of each NNR according to the known plant species richness it contained, using an integrative coefficient (Zuo, 1990):

$$S_i = \sum_{j}^{n}\left(x_{ij} - \overline{x_{ij}}\right)/\overline{x_{ij}}$$

where n is the number of different taxonomic units encountered at the three taxonomic levels j (family, genus and species), with x_{ij}representing the value for the taxonomic level j in the region i, while $\overline{x_{ij}}$ represents the average value for that taxonomic level across all regions. S_i represents the floristic richness coefficient in the ith region - the larger S_i, the species-richer is the vegetation in this region. The number of families, genera and species of higher plants reported from the different NNRs was plotted against the area of each NNR, represented on a logarithmic scale – following island biogeographic expectations for species-area relationships to show an increase in diversity with increasing $\log_{(area)}$. Since reliable and comprehensive data on vascular plant species was lacking from a large number of NNRs, our study used data from all 156 NNRs where this data was readily available.

3. Results

3.1. The coverage of China's vegetation types in its existing NNR network

In 2016, the area protected within all nature reserves in China accounted for 15.32% of the country's terrestrial area, with the highest level protected areas, the NNRs, already covering >95 M ha (9.92% of the land area) and containing 18 vegetation types, differentiated into 26 sub-types. The area and number of NNRs varied markedly between different parts of China, with few, extremely large NNRs found in western China, whereas the opposite trend – many small, fragmented NNRs – observed for eastern China (Fig. 1). Of the main vegetation types, grasslands showed the highest level of protection, with ~24% of all grassland ecosystems being covered by the existing NNR network. As the other extreme, only 3.3% of the subtropical monsoon forest area is currently protected by NNRs (Table 1). Following the general distribution and extend of the NNR network in different parts of China, vegetation types dominating in western and northern areas of China also had a high proportion of their overall distribution area covered by the reserve network, whereas natural vegetation types of north-eastern and especially south-eastern parts of the country are generally less well protected (Fig. 1, Table 1).

3.2. Coverage of different vegetation regions by the NNR network

A very small number of NNRs account already for a large proportion of the area protected by the network. Thus, a large number of nature reserves in a region does not generally reflect an effective protection of a region's vegetation. This is clearly illustrated by the fact that the Qinghai-Xizang Plateau alpine vegetation region, that has the highest coverage (41.4%) of area under protection, also harbors the least fragmented reserve network with an overall low number of NNRs (Table 2; Fig. 2). In contrast, the subtropical evergreen broad-leaved forest region contains 151 NNRs, whereas the total protected area only accounts for 6.4% of the vegetation region. The smallest percentage of protected area was recorded for the warm temperate deciduous broad-leaved forest region, with the 51 regional NNRs covering <5% of that region. The NNRs in warm temperate deciduous broad-leaved forest and subtropical evergreen broad-leaved forest regions were not only small, but also highly fragmented. This is illustrated by the IIC that reaches values for warm temperate deciduous broad-leaved forest and subtropical evergreen broad-leaved forest regions of 0.22 when only considering NNRs, and of 0.27 once all biodiversity priority protected areas are considered in the analysis. The NNRs currently preserve highly isolated patches of these habitats with populations of threatened species being widely isolated from other protected populations, resulting in limited potential for genetic exchange and re-colonization once a species has become locally extinct.

3.3. Protection efficiency of vegetation types by the NNR network in different vegetation regions

In different vegetation regions, the number and proportion of vegetation types covered by NNRs varies greatly. While many vegetation regions have vegetation types that are not currently protected at all, this is not the case in the temperate needle broad-leaved mixed forest region, the tropical monsoon forest and rainforest region and the Qinghai-Xizang plateau alpine vegetation region. Among the remaining regions, the warm temperate deciduous broad-leaved forest region shows the largest number (4) and proportion (29%) of unprotected vegetation types, with examples of these unprotected forest types including warm broad-leaved and conifer mixed forest and the evergreen coniferous shrub.

Based on the general results described above, we found that the subtropical evergreen broad-leaved forest region contained the largest number of NNRs and of different vegetation types, while the NNRs of the Qinghai-Xizang plateau alpine vegetation region have the highest areal coverage and different vegetation types, as well as representing a known key area for local species endemism. Therefore, we decided to focus on these two vegetation regions in more detail.

The Qinghai-Xizang plateau alpine vegetation region was the only region where all 12 natural vegetation types reached a coverage of >10% by the NNR network. Despite this high coverage, there were distinct differences between vegetation types. Grassland was the dominant natural vegetation type in this region, with a total area of 861,230 km2, 44.7% of which is currently protected. Warm coniferous forest covered the smallest area (57 km2), but this entire area was included in NNRs. Evergreen coniferous shrub had the lowest coverage of 13.3% (Tables 3 and 4; Fig. 3).

In contrast, the subtropical evergreen broad-leaved forest region contained the highest diversity of vegetation types (18), but only

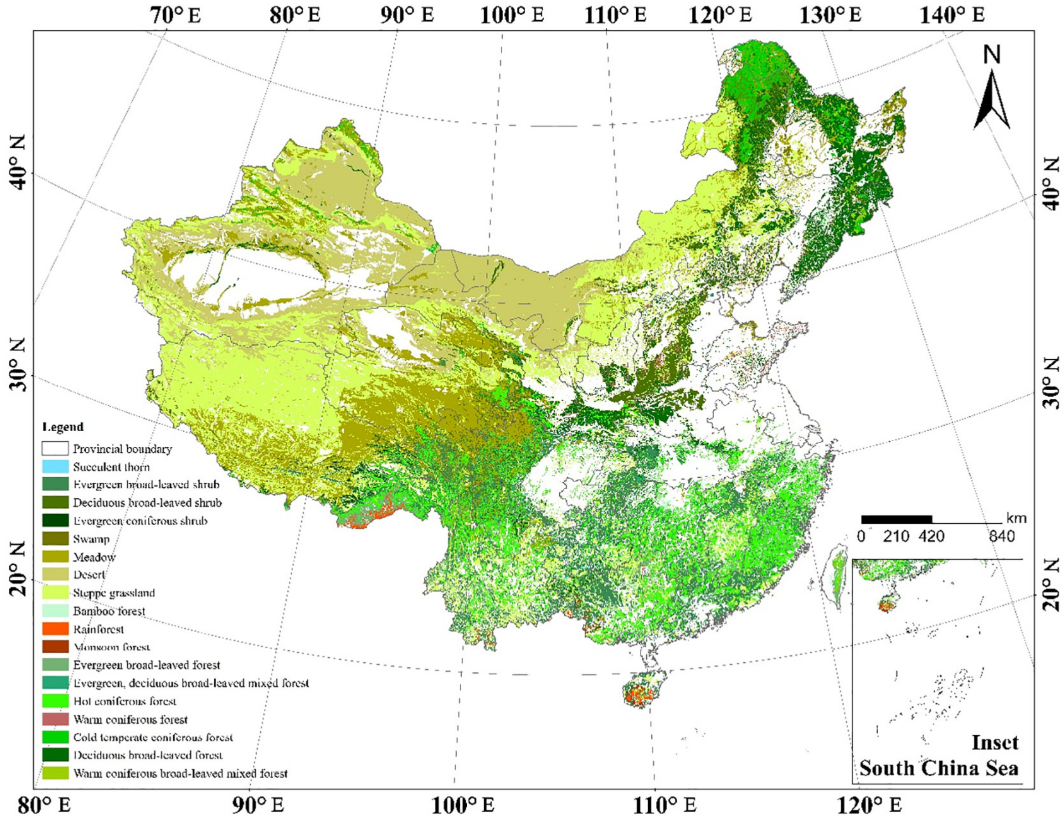

Fig. 1. Map indicating the vegetation types in China.

small proportions of each type are at best protected. Monsoon forests and deserts occurring in this region are both currently not covered by any of the NNRs – but they also both cover very small areas in this region. Warm coniferous forest is the most widely distributed natural vegetation type in this area, covering about 653,585 km^2, but only 6.8% of this area is covered by NNRs. Critically, only 0.09% of the regional rainforest that is characterized by a very high plant diversity (Pennington et al., 2015) is protected in the NNR network. Overall, the proportion of protected area for eight of the 18 vegetation types in this region exceeded 10%, with swamp vegetation showing the highest rate (27.8%) (Tables 3 and 5; Fig. 3).

Table 1
Percentage area of each vegetation type covered by NNRs.

Vegetation type	Total area (km^2)	Protected area (km^2)	Percentage (%)
Cold temperate coniferous forest	162,123	21,959	13.54
Warm coniferous forest	43,853	4027	9.18
Warm coniferous broad-leaved mixed forest	23,262	3464	14.89
Hot coniferous forest	709,703	56,339	7.94
Deciduous broad-leaved forest	507,717	46,701	9.20
Evergreen, deciduous broad-leaved mixed forest	25,057	3579	14.28
Evergreen broad-leaved forest	161,481	14,762	9.14
Monsoon forest	6165	204	3.31
Rainforest	19,243	1867	9.70
Bamboo forest	39,137	2575	6.58
Steppe grassland	2,088,161	501,148	23.96
Desert	1,206,271	125,389	10.39
Meadow	1,075,488	217,361	20.21
Swamp	66,160	13,036	19.70
Evergreen coniferous shrub	22,054	4839	21.94
Deciduous broad-leaved shrub	352,195	39,424	11.19
Evergreen broad-leaved shrub	718,944	58,503	8.14
Succulent thorn	1953	153	7.86

3.4. NNRs and floristic diversity patterns

The richness coefficient of the vegetation decreases slightly with an increasing area of the protected area, showing that the phytodiversity contained in small NNRs is regularly higher than that contained in large NNRs. We further differentiated our results by main vegetation types (Fig. 4) The results showed that forest-vegetation type NNRs were mostly limited to small areas, but had a high floristic richness coefficient, while deserts and grasslands commonly dominating in large NNRs had a significantly smaller floristic richness coefficient. Overall, this indicates that the vegetation of highly phytodiverse vegetation types is chiefly protected in small NNRs, while the more species-poor vegetation types of the temperate grassland region, temperate dessert region and the Qinghai-Xizang plateau alpine vegetation region are covered by large reserves.

4. Discussion

In line with our first hypothesis, a strong imbalance in the NNRs coverage of different vegetation types across China was observed, with this pattern partly reflecting the highly uneven regional distribution of NNRs in China (MEE of China, 2018a). It can furthermore be argued, based on our results, that many reserves in the southeast part of China are very small in view of the sustainable provision of ecosystem functions (Liu et al., 2003; Billionnet, 2016). They are unlikely to reach the minimum size required to support sufficiently large populations required by many taxa to sustain themselves over prolonged time periods, and are therefore unlikely to provide their full potential biodiversity conservation effects. From the perspective of island biogeography and the SLOSS debate (Simberloff and Abele, 1976), for an identical area under protection, a single large nature reserve is considered superior

Table 2
The difference in the number and coverage of NNRs among various vegetation regions.

Number	Vegetation region	Number of NNRs	NNR total area (km^2)	NRR coverage (%)
I	Cold temperate coniferous forest region	5	21,164	10.13
II	Temperate needle broad-leaved mixed forest region	30	49,307	12.07
III	Warm temperate deciduous broad-leaved forest region	51	44,936	4.63
IV	Subtropical evergreen broad-leaved forest region	151	172,245	6.43
V	Tropical monsoon forest and rainforest region	25	24,471	8.66
VI	Temperate grassland region	43	122,911	10.56
VII	Temperate desert region	21	173,433	7.95
VII	Qinghai-Xizang plateau alpine vegetation region	13	665,380	41.43
Mean values				12.73

to many separate small nature reserves (Li and Li, 2002). In the east and southeast of China, the NNRs system is dominated by small areas. From the perspective of island biogeography, size and isolation are regarded as key variables determining the size of a species pool an isolated habitat patch can sustain (Laurance, 2008; Burke, 2019). In the increasingly industrialized agricultural landscapes developing across China, NNRs can be regarded as increasingly isolated protected habitat islands, and it can be expected that the species pool of NNRs is indeed determined by their area and degree of isolation, as well as the time since isolation occurred. Therefore, even though the southeastern parts of China are characterized by a very high species richness (Sang et al., 2011), the scattered distribution pattern of the many small NNRs in this region likely fails to maintain the integrity of the composition, structure and function of the ecosystems that they aim to protect.

The NNR coverage pattern revealed by our study confirms the worrying trends reported in previous PA network assessments for China. For example, Xu et al. (2017b) significant spatial mismatches between nature reserve locations and the distribution of threatened species and key ecosystems service hotspots. The Qinghai-Tibetan region accounts for 75.3% of the NNR network in terms of area, whereas the region only provides between 11 and 14% of the key ES of water retention, soil retention, sandstorm prevention and carbon sequestration. By contrast, the south region is key for these ecosystem services (58–72%), but NNRs in this region represent only 5.3% of the NNR network. These disparities reflect the fact that nature reserves in the Qinghai-Xizang plateau alpine vegetation region are strongly dominated by vegetation types adapted to relatively harsh environmental conditions like steppe grasslands, deserts and meadows, while the nature reserves in the subtropical evergreen broad-leaved forest region are mainly composed of evergreen broad-leaved forests and scrubs, tropical coniferous forests and swamp vegetation. These habitats are of great importance for the retention of water and soils as well as for carbon sequestration. The exceptionally high phytodiversity of Southern China's forests further supports the importance of ecosystem services generated in this area. The uneven distribution of the NNRs coverage across the different vegetation regions and types therefore also has severe implications for a highly uneven coverage of ecosystem services. More generally speaking, central, but especially the southeastern and southern parts of China are characterized by highly complex habitats and habitat mosaics with diverse vegetation types dominated by forest and wetlands ecosystems with their rich biodiversity, resulting in a high ecosystem service value per unit area (Shi et al., 2012; Zheng et al., 2012; Zhang et al., 2017).

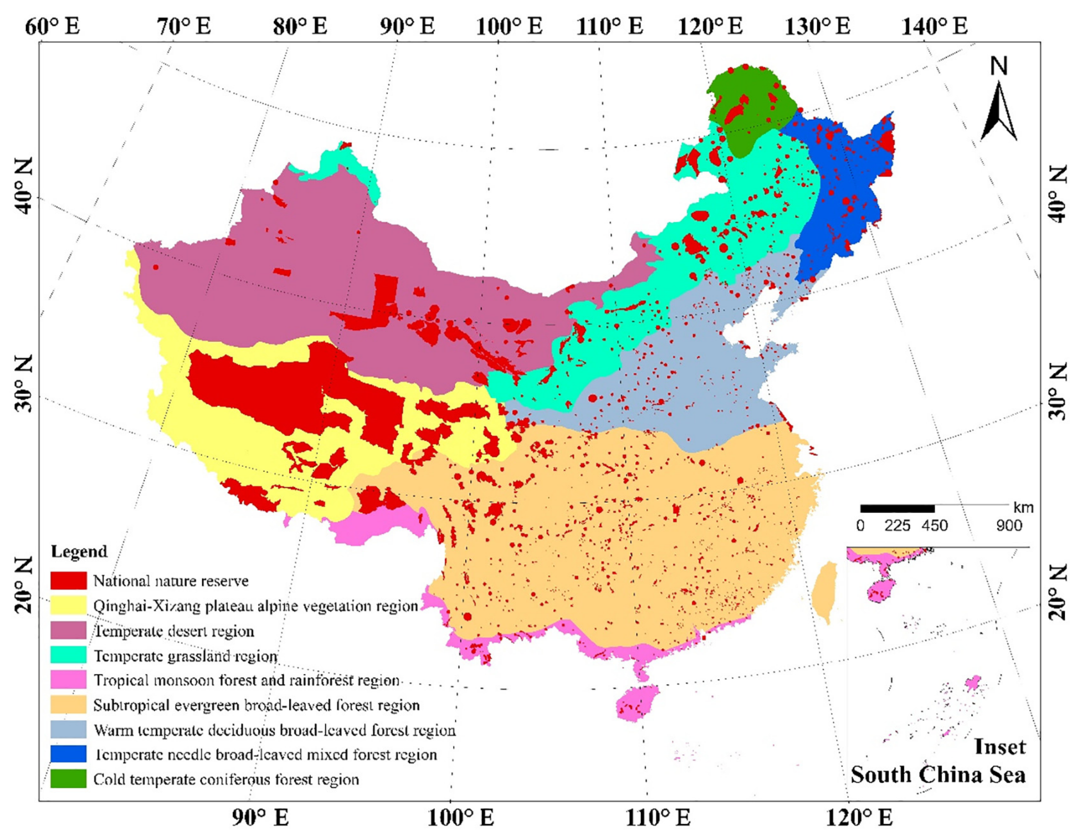

Fig. 2. Map showing the national nature reserve network and the different vegetation regions in China.

Table 3
Percentage protection of 18 vegetation types in different vegetation regions.

Number	Vegetation region	Total number of vegetation types	Number of unprotected vegetation types	Number of vegetation types protected at 0–10%	Number of vegetation types protected at >10%
I	Cold temperate coniferous forest region	7	2	3	2
II	Temperate needle broad-leaved mixed forest region	8	0	2	6
III	Warm temperate deciduous broad-leaved forest region	14	4	5	5
IV	Subtropical evergreen broad-leaved forest region	18	2	8	8
V	Tropical monsoon forest and rainforest region	15	0	8	7
VI	Temperate grassland region	14	2	2	10
VII	Temperate desert region	11	2	2	7
VII	Qinghai-Xizang plateau alpine vegetation region	12	0	0	12

For example, mangroves on the coastline of southeastern China provide crucial ecosystem services in the form of coastal protection, carbon sequestration and the retention of nutrients and heavy metals (Wang et al., 2018). Nonetheless, while the nature reserve network preforms reasonably well with regards to threatened mammals and birds, with their habitat coverage exceeding the 15.1% coverage of NRs for China's total land area, for plants and other organisms the corresponding level of protection is significantly smaller (Xu et al., 2017a).

The generally low levels of protection for vegetation regions and ecological areas in nature reserves in eastern and southern China that are strongly emphasized in this research are in line with observations made by Guo et al. (2015) and Wu et al. (2011). Similar to their research, we confirm that the subtropical evergreen broad-leaved forest region and the tropical monsoon forest and rainforest region have the highest proportion of vegetation types with a protection ratio <10%. We therefore add a strong voice to the clearly emerging picture that the distribution of nature reserves in China, here exemplified by the spatial distribution of the NNR network, is only poorly aligned with the distribution of vegetation types across the country, with the NNRs particularly in the southeast likely being highly inadequate to meet the requirements for an effective protection of the local plant diversity.

The causes behind the mismatch between the spatial NNR distribution and the distribution of plant diversity in China can to an extent be traced back to a historic lack of systematic planning and an inadequate conceptual base for NNR designations (Wu et al., 2018). Financial factors linked strongly to the opportunity cost of land conservation in this context have a significant influence. The designation of NNRs therefore reflects a balancing act between economic and ecological factors, with economic considerations triggering a reduction in the opportunity costs associated with the current nature reserve system, while at the same time leading to insufficient safeguards for some areas that from an ecological perspective are highly protection-worthy (Ma et al., 2019). With the rapid development of the economy and modernization of agricultural practices, the protection of large amounts of land with high ecological value in nature reserves under strict protection has often been riddled with hurdles, and in the case particularly of areas of high human population density along the southeastern coastline of China, nature reserves are currently further threatened by the rapid expansion of China's cities and mega-cities, not least due to the high growth in economic wealth and associated demands on environments in the vicinity of these growing settlement areas and a relatively weak protection (Yang et al., 2019). These factors appear to already impede the rapid expansion of China's nature reserves particularly in Eastern China.

Table 4
Percentage area of each vegetation type covered by NNRs in the Qinghai-Xizang plateau alpine vegetation region.

Vegetation type	Total area (km^2)	Protected area	
		(km^2)	(%)
Cold temperate coniferous forest	1370	967	70.59
Warm coniferous forest	57	57	100
Hot coniferous forest	11,981	3256	27.18
Deciduous broad-leaved forest	151	103	68.33
Evergreen broad-leaved forest	179	40	22.47
Steppe grassland	861,231	385,219	44.73
Desert	109,323	39,050	35.72
Meadow	482,386	141,381	29.31
Swamp	3382	839	24.81
Evergreen coniferous shrub	7427	986	13.28
Deciduous broad-leaved shrub	38,995	9290	23.82
Evergreen broad-leaved shrub	14,899	4887	32.80

In general, we should expand existing important protected areas particularly in cases where this carries relatively low opportunity costs, and strategically deprioritize areas with relatively low protection value but high opportunity costs. Furthermore, the future development of the NNR network should not only meet requirements with regards to the protection and maintenance of biodiversity, but ideally also enhance plant ecosystem services (Xiao et al., 2016).

Over the past three decades, the Chinese Government has established a substantial nature reserve network. However, this establishment has not yet been followed by the necessary massive financial investments required to secure the conservation efficiency of the existing network. This lack of funding is reflected in a lack of investments into reserve research and monitoring (Li et al., 2013). Thus, reserve management decisions regularly have to be made based on a scarcity of scientific foundations, and with extremely limited insights into the efficiency for example of individual management actions. Many nature reserves in China have not even completed basic inventories of their vertebrate or plant communities, and lack an adequate understanding of successful reserve management. Any ecological or environmental problems affecting such reserves are therefore commonly only detected once conditions have already strongly deteriorated, making counteractions extremely costly, where such actions are still possible.

In conclusion, we argue that the highly uneven regional distribution of NNRs and the fragmentation and underrepresentation of key vegetation types with view of their biodiversity and ecosystem service provisions lead to a surprisingly low effectiveness of the existing NNR network with regards to phytodiversity conservation and the protection of associated ecosystem services. A consolidation of the small isolated protected areas typically found in southeastern China with its high levels of species richness can be best achieved by increasing the connectivity between NNRs, potentially including by areas under less strict protection regimes than the NNRs themselves, and a strengthening of the general structural planning and management of the site, linked also to a stronger financial foundation for their protection. Generally, key protection targets and ecological protection objectives need to be clearly determined and formulated prior to the establishment of new protected areas, as well as for all existing NNRs.

4.1. Lessons for the future

For the future conservation of China's highly diverse vegetation, the country's conservation governance frameworks need to be closely aligned to the key objects outlined in the Convention on Biological

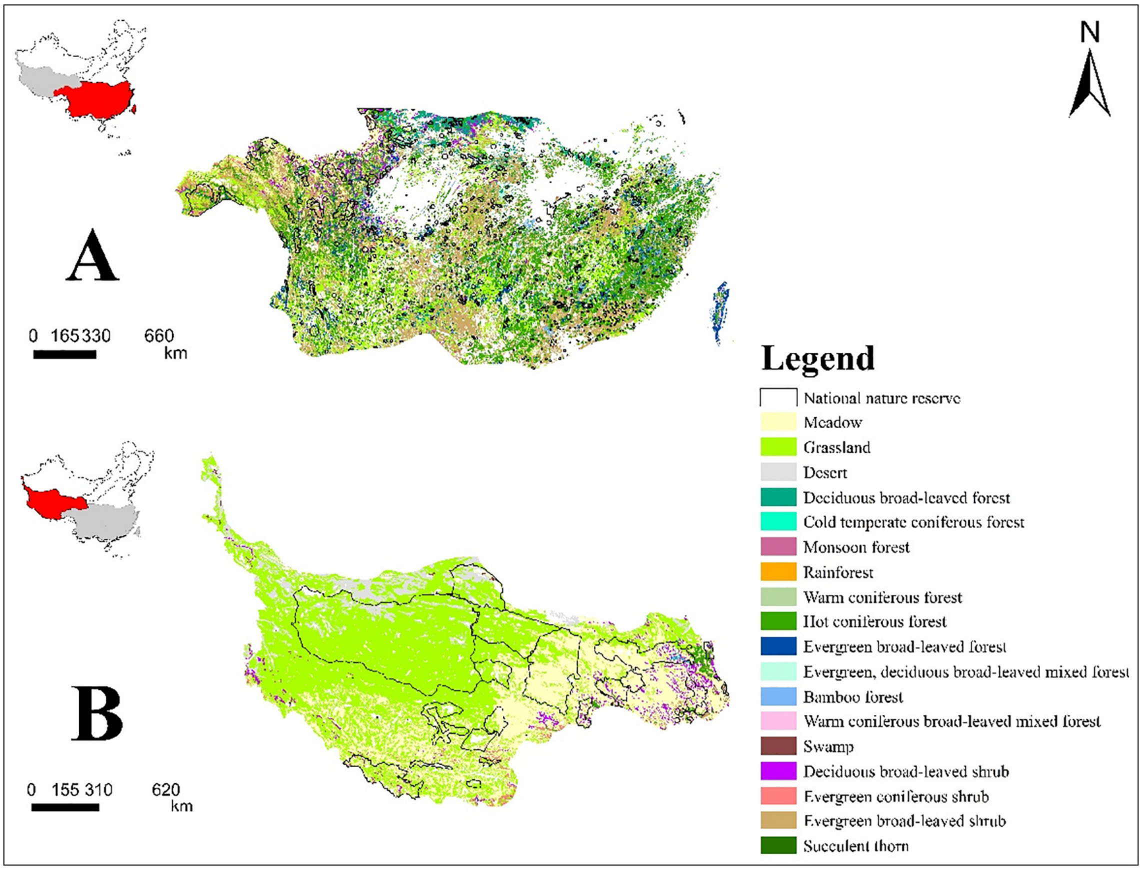

Fig. 3. Detailed maps showing the NNR distributions and vegetation types at A) The subtropical evergreen broad-leaved forest region and B) the Qinghai-Xizang plateau alpine vegetation region.

Diversity (CBD); managing the vegetation as a public good while integrating the conservation of both, fauna and flora, into public and private decision-making, and creating conditions strongly enabling policy implementations. The increasing urbanization provides us with a time window to expand the existing NNR network in many parts of the country, with abandoned, marginal former agricultural land potentially being available to an expanding NNR estate. The effective future protection of China's outstanding phytodiversity and the ecosystems China's vegetation provides will impact not only on the country itself, but have much more far-reaching implications for the entire world.

Table 5
Percentage area of each vegetation type covered by NNRs in the subtropical evergreen broad-leaved forest region.

Vegetation type	Total area	Protected area	
	(km^2)	(km^2)	(%)
Cold temperate coniferous forest	3172	755	23.80
Warm coniferous forest	9684	1222	12.62
Warm coniferous broad-leaved mixed forest	5582	1000	17.91
Hot coniferous forest	653,585	44,462	6.80
Deciduous broad-leaved forest	95,250	9354	9.82
Evergreen, deciduous broad-leaved mixed forest	24,556	3217	13.10
Evergreen broad-leaved forest	120,943	10,061	8.32
Monsoon forest	1613	–	–
Rainforest	425	0.38	0.09
Bamboo forest	38,570	2320	6.01
Steppe grassland	316,770	19,944	6.30
Desert	245	–	–
Meadow	136,287	20,725	15.21
Swamp	3677	1021	27.79
Evergreen coniferous shrub	11,899	3138	26.37
Deciduous broad-leaved shrub	65,280	7490	11.47
Evergreen broad-leaved shrub	632,000	45,525	7.20
Succulent thorn	1498	149	9.95

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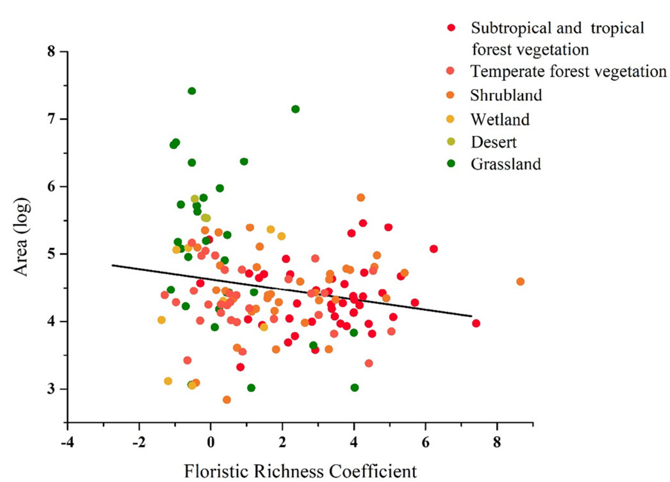

Fig. 4. Relationship between the area of a NNR and its floristic richness coefficient.

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