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Relative contributions of natural and anthropogenic factors to the distribution patterns of nature reserves in mainland China

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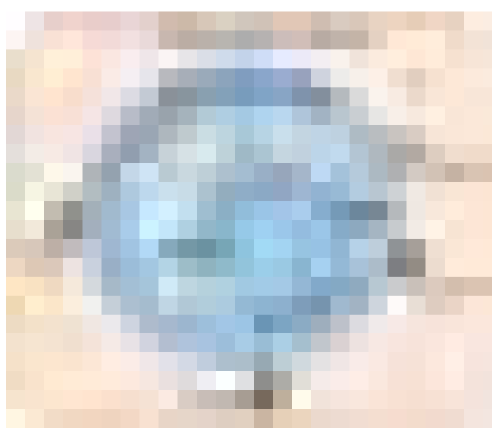
HIGHLIGHTS

- Ecosystem types explained 64.2 % of nature reserve (NR) distribution.
- Anthropogenic factors positively influenced natural factors (0.63).
- Anthropogenic and natural factors had similar impact on NR distributions.

GRAPHICAL ABSTRACT



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ABSTRACT

Nature reserves (NRs) are designated as a result of the ecosystem, species, economy, population, and land use coordination. However, the extent to which these factors influence the geographical pattern of NRs is unclear. Here, 11 indices (seven natural and four anthropogenic) were examined to identify these relationships in over 2600 terrestrial NRs in mainland China at the provincial level. Correlation analysis between natural and anthropogenic factors and NRs showed that desert and grassland had a positive correlation with NR coverage and area, and a negative correlation with NR density. This result was reversed in the correlation analysis between forest wetland coverage, endangered species, wildlife and NR coverage, area, and density. Similar results were found in the correlation analysis of all anthropogenic factors (population density, agricultural land, roads, and per capita GDP) with the coverage, area, and density of NRs. Canonical correspondence analysis (CCA) showed that three significant natural indicators (desert ecosystems, grasslands ecosystems, and forested and wetlands ecosystems) could explain 64.2 % of the pattern of NRs. The largest contributor was desert coverage, explaining 48.3 % ($P = 0.002$) of all indicators, followed by grassland coverage, explaining 8.6 % ($P = 0.012$), and forest and wetland coverage, explaining 7.3 % ($P = 0.008$). Human activities were significantly positively correlated with forest and wetland coverage, flora, and fauna, and negatively correlated with desert and grassland coverage. Compared with sand and grassland in the western region, the forest wetlands and wildlife in the eastern and central provinces were under greater pressure from anthropogenic activities. Therefore, natural

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factors determine the general layout of NRs, while the influence of anthropogenic activities makes the distribution of NRs patchy. When establishing national parks, governments must design strategies to coordinate areas with high biodiversity and high levels of human activity.

1. Introduction

Establishing protected areas (PAs) is a key strategy for conserving biodiversity and natural ecosystems (Jenkins et al., 2015). Approximately 15 % of the Earth's terrestrial surface is covered by PAs (Shrestha et al., 2021), but neither these areas nor the biodiversity they contain is evenly spatially distributed (Rodrigues et al., 2004; Loucks et al., 2008). The distribution of biodiversity is uneven around the world, and many PAs are highly influenced by human activities (Margules and Pressey, 2000; Loucks et al., 2008). The effective conservation of biodiversity in PAs is the result of the integrated coordination of ecosystems, species, the economy, human population, and land use (Loucks et al., 2008; He, 2009; Wu et al., 2018). Therefore, prioritizing only areas with high biodiversity may not be sufficient when designating PAs (Jenkins et al., 2013; Shrestha et al., 2021). In order to better conserve biodiversity, it is important to explore the factors affecting the spatial distribution of PAs.

Studies have found that existing PAs are representative of biodiversity and important ecosystems, but some areas remain under-protected (Naughton-Treves et al., 2005; Yang et al., 2019). There is often significant geographical heterogeneity in the spatial pattern of current PAs, which can be attributed to the influence of different ecosystem distributions (Xu et al., 2008; Sun et al., 2020; Wei et al., 2020). In fact, biodiversity often varies with ecosystems, which directly affects the establishment of PAs. In addition, different ecosystems are affected differently by human activities (Young et al., 2007; Loucks et al., 2008), and PAs tend to be designated in areas that are less affected by human activities (Margules and Pressey, 2000; Liao et al., 2019). Specifically, desert and grassland ecosystems have an arid climates with less human habitation and fewer types of human activities than forest and wetland ecosystems (zhang et al., 2014; Decai and Jianjun, 2003). Due to the wide distribution of flora and fauna, large PAs tends to be established to effectively protect ecosystems and species diversity. In addition, forest and wetland ecosystems have high species richness and a humid climate suitable for human habitation and are highly influenced by anthropogenic activities (Vačkář et al., 2012; Liu et al., 2019). Therefore, to protect hotspots of species richness and biodiversity, the establishment of both large PAs and multiple small PAs may be considered due to human disturbance. At present, the understanding of the influence of ecosystem types on PAs is still quite rudimentary within China, and the influence of different ecosystems on the distribution pattern of PAs has not been fully revealed. Therefore, it is necessary to explore the integrated influence of different ecosystems on the distribution pattern of PAs to improve biodiversity conservation.

Existing studies have demonstrated that the establishment of PAs is influenced by a variety of both natural and anthropogenic factors (Loucks et al., 2008; He, 2009; Wu et al., 2018), such as population density (Liao et al., 2019), road density (Venter et al., 2016), endangered flora and fauna (Zhang et al., 2020), and wildlife. To minimize human impacts on biodiversity, PAs are often designed to be located in areas with low levels of human activity (Margules and Pressey, 2000; Liao et al., 2019). Rapid economic development and high-intensity anthropogenic activities can encroach on established PAs (Ma et al., 2019; Keles et al., 2020). Economic development projects can also directly affect the establishment of nature conservation areas (McShane et al., 2011; Guo et al., 2015; Zhang, 2015). Specifically, when an area proves to be economically valuable, PAs are not usually established or PAs are downgraded in that area (Huang et al., 2019; Ma et al., 2019). Vijay and Armsworth (2021) and Yang et al. (2019) found that agriculture and roads could encroach on PAs and fragment natural habitats, thus affecting the distribution patterns of nature conservation areas. Increasing population density, arable land expansion, and economic development can also take up significant amounts of natural resources, reducing the number of important natural resources worth protecting (Luck, 2007; Luck et al., 2010; Zheng and Cao, 2015). In addition, scholars have assessed the relationship between important natural resources and the distribution pattern of PAs (Geldmann et al., 2013; Xu et al., 2018; Wei et al., 2020). Wei et al. (2020) studied the spatial consistency of the East African PA network and species richness from the species perspective. Geldmann et al. (2013) analyzed the relationship between PAs and habitat types from the ecosystem perspective. Previous studies have investigated the individual and interaction effects of natural and anthropogenic factors on many ecosystem services, such as phenology (Qiu et al., 2020) and vegetation growth (Yang et al., 2021; Jiang et al., 2021). Scholars have also analyzed the spatial relationship between the distribution of PA systems and the distribution of endangered species and have attempted to reveal the factors influencing species conservation (Jenkins et al., 2015; Zhang et al., 2020). Related studies have found that decisions to conserve species are influenced by a number of key economic sectors, but that natural factors (such as the importance of biodiversity) play an important role in wetland conservation (Getzner, 2002). Wu et al. (2018) have reported that ecological factors play an important role in the delineation of nature reserves (NRs, which represent the main body of China's PA system) in China, but this process is also strongly influenced by economic development. Although the above discussion of factors affecting PA patterns is interesting, most previous studies have assessed the impact of one or several of these factors on PA patterns (Mammides, 2020; Sun et al., 2020). There is still a lack of comprehensive analyses that distinguish the effects of different ecosystems, endangered species, species richness, and different types of anthropogenic activities on PA patterns. Quantifying the relative contributions of different influencing factors can help reveal the driving mechanisms of PA distribution and facilitate the implementation of subsequent biodiversity conservation actions.

China is considered to be one of the countries with the richest species diversity in the world (Liu et al., 2003; López-Pujol et al., 2006). China has >30,000 species of higher plants and 6400 species of vertebrates (Liu et al., 2003; Zhang, 2015). As of 2015, there were 2644 Chinese NRs, with a total area of 1.47 million km^2, accounting for approximately 14.9 % of the country's land area in mainland China (hereafter, “China”) (Huang et al., 2019). However, there is strong heterogeneity in the spatial distribution of these NRs (Huang et al., 2019; Ma et al., 2019), with the area of NRs in the western inland region usually being larger, while many NRs in the eastern coastal region are smaller in size (Wu et al., 2018). Currently, China plans to establish a “national park-based nature reserve system” by integrating and optimizing various NR types (Wu et al., 2020; Xu et al., 2020) to promote the coordination of biodiversity conservation and socio-economic development. In contrast, the integration of biodiversity conservation into socio-economic development requires consideration of multiple factors, such as biodiversity, human pressure, land use and socio-economic development (Tian et al., 2019; Zhang et al., 2020). Therefore, to better understand the variability in the distribution of NRs in China and to facilitate the implementation of future biodiversity conservation actions (Shrestha et al., 2021), it is necessary to systematically assess the relative importance of natural factors (ecosystem and species diversity) and different types of anthropogenic activities to the distribution of NRs. Fortunately, laws and policies on NRs are consistent throughout China's 31 provinces, and the effects of laws and policies on the pattern of NRs among different provinces can be ignored (de Marques et al., 2016; Zhang et al., 2017; Volis, 2018).

The purpose of this study was to investigate the relative contributions of natural and anthropogenic factors to the pattern of terrestrial NRs in China. This study (a) analyzed the influence of different ecosystem types on the distribution patterns of NRs; (b) revealed the influencing factors on the distribution patterns of NRs; (c) quantified the relative contributions of natural and human factors to NRs; and (d) proposed an integrated driving model for the distribution of NRs.

2. Materials and methods

2.1. Data sources

Data on China's NRs were obtained from information officially published by the Ministry of Ecology and Environment of the People's Republic of China (Ministry of Ecology and Environment of the People's Republic of China (MEE), 2015a), which is the central government's authority for NR management authority.

NRs in China are dedicated mainly to nature conservation and are administered by four levels of government (national, provincial, city, and county) (Guo and Cui, 2015). The conservation objectives of NRs include ecosystems (such as forest, wetland, grassland, desert, and marine ecosystems), species (such as wild plant and animal), and natural monuments (i.e., ancient organism remains and geological relics). Because this analysis was focused on 31 provinces in mainland China's terrestrial ecosystems, all marine NRs were excluded. NR sample size, area, coverage, and density were calculated based on the area and the number of NRs, and provincial land area was calculated using simple arithmetic.

The forest coverage data were obtained from the Ninth National Forest Resources Inventory (2014–2018) of the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/2019/indexch.htm). Wetland coverage data were obtained from the second China wetland survey (2009–2013) by the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/2015/indexch.htm). The grassland and desert area data were obtained from the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/2017/indexch.htm) and the Ministry of Natural Resources official website (http://www.mnr.gov.cn/).

The number of vertebrates and higher plant species in 31 provinces was derived from 2015 and 2013 biodiversity assessment reports. The IUCN red-list data of higher plants and vertebrates were obtained from assessment reports on China's biodiversity by the Ministry of Ecology and Environment of the People's Republic of China (Ministry of Ecology and Environment of the People's Republic of China (MEE), 2013 and Ministry of Ecology and Environment of the People's Republic of China (MEE), 2015b). The IUCN Red List Categories and Criteria (Version 3.1) and Application of the IUCN Red List Criteria at regional levels (Version 3.0) for higher plants, along with the IUCN Red List Categories and Criteria (Version 3.1), Guidelines for Using the IUCN Red List Categories and Criteria (Version 8.1), and Guidelines for Application of IUCN Red List Criteria at Regional and National Levels (Version 4.0) for vertebrates, were used to assess IUCN red-list species by scientists from the Chinese Academy of Sciences, universities, and other agencies. Both higher plants and vertebrates were classified into nine groups: extinct, extinct in the wild, regionally extinct, critically endangered, endangered, vulnerable, near threatened, least concern, and data deficient. Higher plants, including bryophytes, pteridophytes, gymnosperms, and angiosperms, and vertebrates, including mammals, birds, reptiles, and amphibians were assessed in all of the 31 provinces. Fish assessments were based on river basins, rather than the 31 provinces. Thus, the data for IUCN red − list vertebrates did not include fishes in the present study.

Based on previous studies, this study selected population, agricultural land and roads as anthropogenic factors. Population data and terrestrial land area, including inland waters, were obtained from the official website of China's Ministry of Civil Affairs (http://xzqh.mca.gov.cn/map). Data on agricultural land, including farmland, gardens, and vegetable plots for the 31 provinces, were obtained from the official website of the Ministry of Natural Resources of China (http://www.mnr.gov.cn/). Data on provincial road mileage of highways, railways, and inland waterways were obtained from the official website of China's National Bureau of Statistics (http://www.stats.gov.cn/). Economic development factors were represented by the per capita GDP for the 31 provinces, which was obtained from the official data of the National Bureau of Statistics. Economic development was also the result of man-made activities, which were classified as man − made activities in the subsequent analysis.

2.2. Statistical analysis

The coverage and density of NRs were calculated based on the area and number of NRs, and on the land area of 31 province units, respectively, using the simple arithmetic method. Grassland and desert coverage were calculated by dividing the areas of grassland and sand by the total area of each province. The IUCN red-listed higher plant and vertebrate density were calculated by the number of the IUCN red-list higher plants and vertebrates, excluding fishes, and the land area in each of the 31 provinces. Higher plant and vertebrate density (excluding fish) were calculated in the same way. Population density, agricultural, land and road density were calculated according to the population number, agricultural land area, road mileage and land area for the 31 provinces.

A three-step approach was used to examine the effects of anthropogenic and natural factors on NR area, coverage, and density and to identify the pattern determinants, as well as to evaluate the spatial consistency between human activities and natural resources in China.

First, to reduce the heteroscedasticity, data on the NR area and density, population density, per capita GDP, vertebrate and higher plant species and density, and the density of IUCN red-list species were normalized using log transformation (base e). Autocorrelation analysis was performed between each variable among the human population, per capita GDP, agricultural land, road density, NR area coverage and density, forest and wetland coverage, grassland coverage, desert coverage, the density of vertebrates and higher plant species, and the density of IUCN red-list species (Wu et al., 2011a; Wu et al., 2011b; Harcourt et al., 2001; Parks and Harcourt, 2002; Luck, 2007). Determining all indicators allows for subsequent correlation analysis. Correlation analysis can be used to determine the extent of a relationship between two individual variables (Wu et al., 2011a; Wu et al., 2011b; Luck, 2007). This study examined the effects of anthropogenic and natural factors on the area, coverage, and density of NRs separately using Pearson correlation analysis.

Next, the relationships between anthropogenic factors, natural factors, and NR area, coverage and density were analyzed using canonical correspondence analysis (CCA) (Bai et al., 2021). Typical CCA was selected for the analysis because all NRs area, coverage and density indicators could be directly integrated with the impact factor indicators, and the relative contribution of each impact factor could be ranked (Bai et al., 2021). The relative contribution of each influencing factor was ranked to obtain the explanation rate of each factor in the distribution pattern of NRs. CCA can also reduce the impact of spatial autocorrelation and covariance between anthropogenic and natural factors on the pattern of NRs (Ter Braak and Verdonschot, 1995; Wagner, 2004). CCA was performed using Canoco for Windows 5.0.

In the third step, in order to determine whether there was spatial overlap between the distribution of anthropogenic activities and the distribution of natural resources, Pearson correlations were used to examine the relationships among GDP per capita, population density, the proportion of arable land, road density, forest and wetland cover, grassland cover, desert cover, the density of higher plants and vertebrates, and the density of IUCN Red List higher plants and vertebrates in 31 provinces. The 31 provinces of China were divided into three regions, namely, the east, central, and west regions, and the distribution of natural and anthropogenic factors in different regions was analyzed.

A conceptual framework was further used to evaluate the direct and indirect relationships between NR area, coverage and density, and anthropogenic and natural factors. Given that the anthropogenic and natural variables were strongly correlated, principal component analysis (PCA) was conducted to create a multivariate functional index before conceptual

Fig. 1. Relationships between nature reserve (NR) coverage, area, and density and natural factors.

framework construction. The first component (PC1) explained 57.32 %–73.1 % of the total variance for these two groups and was introduced as a new variable into the subsequent analysis (Chen et al., 2016). Linear regression modeling was used to analyze the effects of anthropogenic and natural factors on NR area, coverage, and density.

3. Results

3.1. Effects of natural factors on NR coverage, area, and density

NR coverage, area, and density were strongly correlated with several natural variables (Fig. 1). The NR coverage in 31 provinces was positively correlated with desert ($R = 0.43$, $P < 0.05$) and grassland coverage ($R = 0.64$, $P \le 0.0001$), while it was negatively related with forest and wetland coverage ($R = -0.45$, $P = 0.01$), IUCN red-list vertebrate ($R = -0.56$, $P < 0.05$) and higher plant density ($R = -0.52$, $P < 0.01$), and vertebrate density ($R = -0.52$, $P < 0.01$). There was no significant correlation between NR coverage and higher plant density (Fig. 1). Consistent with these findings, the NR area per province was positively correlated with desert ($R = 0.72$, $P < 0.0001$) and grassland coverage ($R = 0.65$, $P < 0.0001$), and negatively correlated with forest and wetland coverage ($R = -0.62$, $P < 0.001$), IUCN red-list vertebrate ($R = -0.65$, $P < 0.001$) and higher plant density ($R = -0.54$, $P = 0.001$), and vertebrate ($R = -0.60$, $P < 0.001$) and higher plant density ($R = -0.55$, $P = 0.001$). The NR density in each province was negatively correlated with desert ($R = -0.76$, $P < 0.0001$) and grassland coverage ($R = -0.61$, $P < 0.001$), while it was positively correlated with forest and wetland coverage ($R = 0.68$, $P < 0.0001$), IUCN red-list vertebrate ($R = 0.70$, $P < 0.001$) and higher plant density ($R = 0.44$, $P = 0.01$), and vertebrate ($R = 0.65$, $P < 0.001$) and higher plant density ($R = 0.44$, $P = 0.01$). These findings showed that NRs in desert and grassland areas were small in number and large in area, while NRs in forested and wetland areas and NRs that contained IUCN red-list species and wildlife were small in area, low in coverage, and large in number.

3.2. Effects of anthropogenic factors on NR coverage, area, and density

There were significant pairwise correlations between the NR coverage, area, and density and the population density, percentage of agricultural land, road density, and per capita GDP (Table 1). NR coverage was negatively correlated with the population density ($R = -0.80$, $P < 0.01$), percentage of agricultural land ($R = -0.56$, $P < 0.01$), road density ($R = -0.63$, $P < 0.01$), and per capita GDP ($R = -0.59$, $P < 0.01$). Consistent with these findings, there were negative correlations between the NR area and population density ($R = -0.83$, $P < 0.01$), percentage of agricultural land ($R = -0.60$, $P < 0.01$), road density ($R = -0.61$, $P < 0.01$), and per capita GDP ($R = -0.58$, $P < 0.01$). Instead, significant positive correlations were observed between the NR density and population density ($R = 0.78$, $P < 0.01$), percentage of agricultural land ($R = 0.55$, $P < 0.01$), road density ($R = 0.58$, $P < 0.01$), and per capita GDP ($R = 0.56$, $P < 0.01$). Therefore, regions with high population density, proportion of agricultural land, road.

density and per capita GDP hosted high density, low coverage, small area NRs.

3.3. Critical factors in determining NR patterns

CCA diagrams were constructed to illustrate the combined effects of 11 indicators of anthropogenic and natural factors on NR area, cover and density (Fig. 2). The first two axes of the CCA together explained 81.1 % of the total variability. The first axis accounted for 74.06 % of the total data variance. The first axis was correlated with desert coverage, grassland coverage, forest and wetland coverage, higher plant density, and the percentage of agricultural land. The second axis (5.05 % of data variance) was correlated with population density and road density (Fig. 2). After ranking their relative influence, it was found that natural factors play had a significant influence on the pattern of NRs, explaining a total of 64.2 %

Table 1
Correlation between nature reserve (NR) coverage, area and density, and various indexes.

Factor	ln (NR coverage)	ln (NR area)	ln (NR density)
ln (population density)	−0.80**	−0.83**	0.78**
percentage of agricultural land	−0.56**	−0.60**	0.55**
road density	−0.63**	−0.61**	0.58**
ln (per capita GDP)	−0.59**	−0.58**	0.56**

** $P < 0.01$.
* $P < 0.05$.

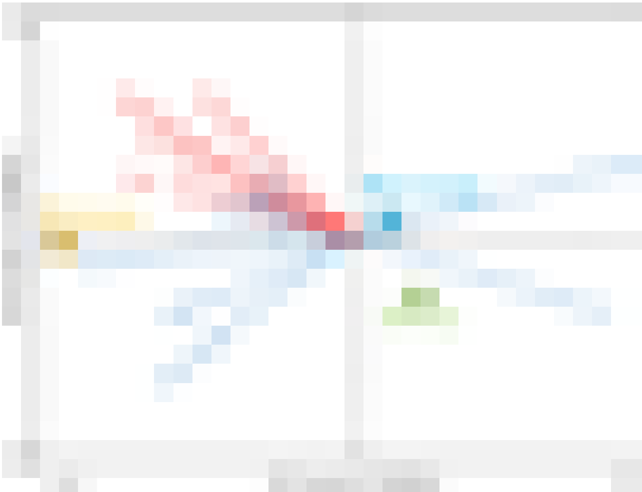

Fig. 2. Comprehensive effects of natural factors and human factors on nature reserve (NR) coverage, area and density. Note: CCA, canonical correspondence analysis; DC, desert coverage; GC, grassland coverage; FWC, forest and wetland coverage; IIUCN VD, IUCN red-list vertebrate density; IUCN HPD, IUCN red-list higher plant density; VD, vertebrate density; HPD, high plant species density; PD, population density; PC GDP, per capita GDP; PAL, percentage of agricultural land; RD, road density.

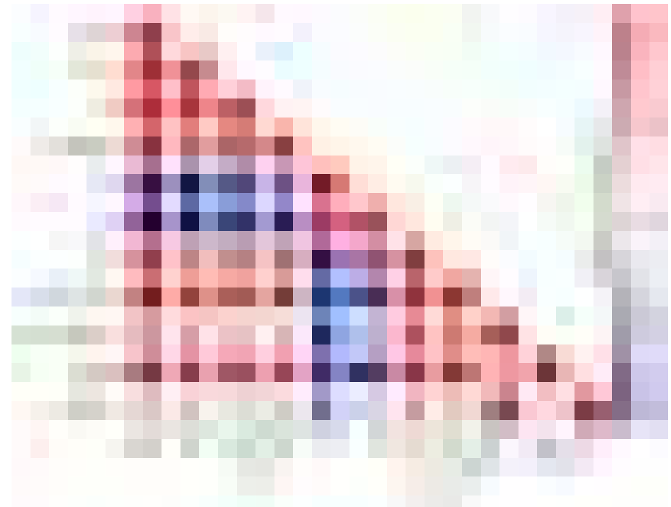

Fig. 3. Correlation coefficients of natural and anthropogenic factors. The circle size and label indicate the Pearson's correlation coefficients from a two-tailed test significance. Note: DC, desert coverage; GC, grassland coverage; FWC, forest and wetland coverage; IIUCN VD, IUCN red-list vertebrate density; IUCN HPD, IUCN red-list higher plant density; VD, vertebrate density; HPD, high plant species density; PD, population density; PC GDP, per capita GDP; PAL, percentage of agricultural land; RD, road density.

of all significant variables. All anthropogenic factors contributions were not significant (Fig. 2; Table 2). Desert coverage explained the proportion of the largest proportion of the pattern of NRs at 48.2 % ($F = 27.1$, $P = 0.002$), grassland coverage explained 8.6 % ($F = 10.8$, $P = 0.012$), and followed by forest and wetland coverage explained 7.3 % ($F = 5.5$, $P = 0.008$) (Table 2). Therefore, a comprehensive analysis of all the influencing factors that may affect the distribution pattern of NRs shows that natural ecosystems are the most influential, while the relative contribution of anthropogenic activities is smaller.

3.4. Effects of anthropogenic activities on natural resources

There was a significant positive correlation between human activities and the forest and wetland coverage rate as well as animal and plant indexes and a significant negative correlation between human activities and desert and grassland (Fig. 3). Therefore, there is spatial consistency in the distribution of anthropogenic activities with forested wetland ecosystems, except for desert and grassland ecosystems. This also indicated that desert and grassland ecosystems in China face less anthropogenic activity pressure compared to forest and wetland ecosystems, as mentioned in the introduction. Areas rich in natural resources also showed high levels of human activity. It was found that forests, wetlands, vertebrates, and higher plants in the eastern and central provinces ere under greater pressure from anthropogenic activities compared to deserts and grasslands in the western provinces (Fig. 4). The conceptual model showed that anthropogenic factors influenced NR distribution in two ways (Fig. 5). Anthropogenic factors directly affected the NR area (standardized coefficient −0.77), coverage (standardized coefficient −0.76), and density (standardized coefficient 0.73). Additionally, anthropogenic factors exerted strong indirect effects on the NR area (standardized coefficient −0.81), coverage (standardized coefficient −0.71), and density (standardized coefficient 0.84) through their positive correlations with natural factors ($R = 0.63$, $P < 0.001$). These findings suggested that the interactions among the 11 variables

Table 2
Proportion of nature reserve (NR) distribution patterns explained by each variable.

Factor	Explains % (81.1 %)	Contribution %	pseudo-F	P
Desert coverage	48.3	61.1	27.1	0.002
Grassland coverage	8.6	10.8	5.6	0.012
Forest and wetland coverage	7.3	9.3	5.5	0.008
Higher plant density	3.4	4.3	2.7	0.09
IUCN red-list higher plant density	3.0	3.7	2.5	0.106
Road density	2.3	2.9	2.1	0.15
Per capita GDP	1.3	1.7	1.2	0.306
Population density	1.3	1.7	1.2	0.31
Percentage of agricultural land	1.3	1.6	1.2	0.308
Vertebrate density	0.5	0.6	0.4	0.64
IUCN red-list vertebrate density	1.8	2.3	1.6	0.178

Fig. 4. Distribution of natural and human factors in eastern, central, and western provinces of mainland China. Note: DC, desert coverage; GC, grassland coverage; FWC, forest and wetland coverage; IIUCN VD, IUCN red-list vertebrate density; IUCN HPD, IUCN red-list higher plant density; VD, vertebrate density; HPD, high plant species density; PD, population density; PC GDP, per capita GDP; PAL, percentage of agricultural land; RD, road density.

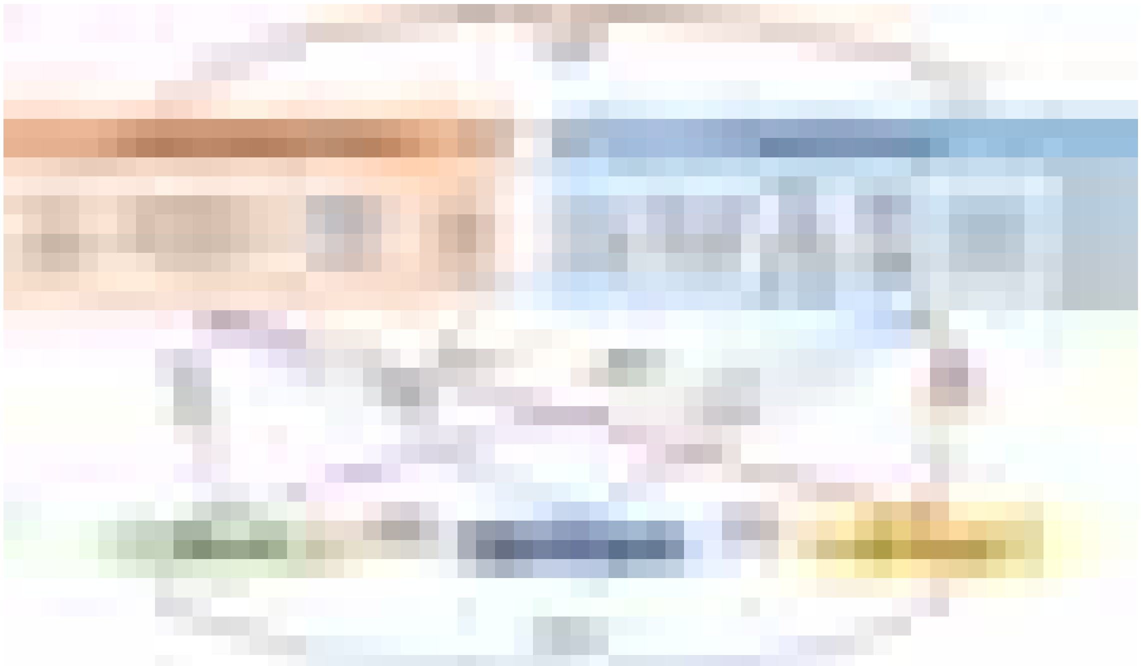

Fig. 5. Direct and indirect effects of anthropogenic factors on nature reserve (NR) coverage, area and density.

(including four anthropogenic factors and seven natural factors) influencing terrestrial NRs together determined the distribution patterns. NRs also face severe threats due to anthropogenic activities.

4. Discussion

4.1. Impact of different ecosystems on the pattern of NRs

There is great variability in the impact of different ecosystems on the pattern of NRs. Due to differences in resource endowments, the ecological pattern of the 31 provinces in mainland China is uneven (Zhao et al., 2016; Sun et al., 2020; Zhang et al., 2020), resulting in an uneven distribution of NRs. This study found that desert and grassland coverage was positively correlated with the area and coverage of NRs and negatively correlated with the density of NRs, indicating that deserts and grasslands tended to be covered by large NRs, which were relatively few in number. It was also found that forest and wetland coverage in 31 provinces was strongly negatively correlated with NR area and coverage and positively correlated with density (Fig. 1), suggesting that forests and wetlands tended to be protected by high densities of small NRs.

Ecological patterns were found to be the keys to determining the NR distribution in mainland China. The most important natural factor was desert coverage, which explained 48.3 % of all indicators. The most important influencing factor was also desert cover, which accounted for 48.3 % of all indicators, followed by grassland and forested wetland cover at 8.6 % and 7.3 %, respectively (Table 2). Natural grasslands and deserts account for more than half of the country's total land area, and large areas of grasslands and deserts are mainly located in the western provinces (Zhang et al., 2014; Decai and Jianjun, 2003). Nearly half of all NRs in China are located in the grasslands and deserts of the western provinces. Deserts and grasslands are often protected by large, low-density NRs in the western provinces. The small number and large area of grassland and desert NRs in the western provinces play an important role in the pattern of NRs.

Forests and wetlands are important habitats for higher plants and vertebrates (Huang et al., 2019) and provide valuable ecosystem services (Lü et al., 2017; Xu et al., 2017; Sun et al., 2020). Many forests and wetlands are preserved in numerous small, isolated fragments due to human use of the land (Ewers and Didham, 2006; Kupfer, 2006; Abdullah and Nakagoshi, 2007). Forests are unevenly distributed in China, and fragmentation is more of a problem in the densely populated eastern part of the country (Liu et al., 2019). In addition, the number of NRs shows that forest and wetland ecosystem reserves occupy more than half of the NRs in China, but most of these reserves are small in size (Ministry of Ecology and Environment of the People's Republic of China, 2015 https://www.mee.gov.cn/hjzl/hjzlqt/sthj/201606/t20160602_353281.shtml). Although China's total forest area is 2.08 million km^2, most of these forests are highly fragmented, and only 3.4 % are intact (Li et al., 2017), while many wetlands are at risk of being converted to farmland (He et al., 2018). Therefore, many small, high-density NRs were found in forested and wetland areas in the central and eastern provinces (Wenhua, 2004; Sun et al., 2020).

In China, public relations have been established based on administrative geography (Guo and Cui, 2015). China has a vast territory, with obvious differences in area and biodiversity among provinces, particularly the natural differences between the north and south (Guo and Cui, 2015). Key global biodiversity conservation projects and biodiversity hotspots are mainly distributed in the southern and eastern provinces (Zhao et al., 2016; Ma et al., 2019). The climate and topography of the eastern regions of China are more suitable for human habitation than those of the western regions (Zhang et al., 2017). Eastern provinces have a high population density and a long history of socio-economic development. Many natural habitats have been converted into farmland, roads, and residential areas due to long-term human settlement and development (Dobson et al., 1997; Zheng and Cao, 2015; Yang et al., 2019). Areas with high conservation value are usually scattered across highly transformed landscapes. In addition, the southern and eastern provinces are much smaller than the western provinces. The opportunity cost of land conservation is greater in the above highly developed and densely populated provinces (Wu et al., 2018; Ma et al., 2019). This inevitably limits the scale of NR establishment, which has led to the creation of thousands of small NRs in the southern and eastern coastal provinces. Large-scale NRs are mostly distributed in western provinces with small populations and low levels of economic development. Therefore, although the NR distribution identified in this study generally followed the ecological distribution pattern, there were also many cases of small NRs in southern and eastern forests, wetlands, and provinces with rich species resources.

When NRs are created, the county and provincial governments measure the abundance of local biodiversity and the socioeconomic development of the entire region when designating the NR area. The contradiction between development and the protection of biodiversity in the eastern and southern provinces, which are suitable for human habitation and rich in natural resources, will be more prominent than in the western provinces. In this situation, a large number of small-scale NRs will be established in the eastern and southern provinces, and it is inevitable that some provinces in the west will establish relatively large-scale NRs (Sun et al., 2020). This is essentially a trade-off between biodiversity conservation and the opportunity cost of land resources in various provinces.

4.2. Comprehensive analysis of the influence of natural and anthropogenic activities on the pattern of NRs

Based on previous studies, the present study analyzed various anthropogenic and natural indicators. Understanding the relative contribution of each factor provides a more complete picture of the driving mechanisms influencing the pattern of NRs. It was found that the indicators of IUCN red-list vertebrate density, IUCN red-list higher plant density, vertebrate density, and higher plant density were all significantly negatively correlated with the area and coverage of NRs, and all were significantly positively correlated with the density of NRs (Fig. 1), indicating that plants and animals tended to be protected by small NRs with high density. Furthermore, it was found that the population density, percentage of agricultural land, road density, and per capita GDP had significant negative correlations with area and coverage and positive correlations with density, which was supported by previous studies (Luck et al., 2010; Wu et al., 2011b; Liao et al., 2019).

Many endangered higher plants and vertebrates depend on natural ecosystems for survival. In forest wetland ecosystems, the species richness of higher plants and vertebrates is high but is accompanied by a high intensity of human activities (Carter et al., 2012; Pautasso, 2007). The fragmentation of these ecosystems leads to the fragmentation of species habitats, so there are many small, high-density NRs in areas of high species richness. In addition, the distributions of higher plant and vertebrate species as well as biodiversity centers of threatened higher plants and vertebrates overlap with the number of NRs (Volis, 2018; Sun et al., 2020; Zhang et al., 2020; Shrestha et al., 2021). Although there is a high degree of overlap between ecosystem species and PAs, many species are under-protected (Xu et al., 2017; Jenkins et al., 2015). This suggests that where species richness is high, many species are not effectively protected by PAs or are protected by many high-density small PAs.

The area and coverage of NRs in areas with high anthropogenic activity are generally smaller but more numerous. Increased population density and the conversion of land to agricultural land and roads accelerate the depletion and destruction of natural resources. The impact of economic development on NRs is bi-directional. Land conversion serves economic development projects, and some natural habitats will be converted to industrial land, even if the biodiversity of these areas is high (Ma et al., 2019; Wei et al., 2020). However, economic development will allow for increased investment in ecological protection and increase public awareness of environmental protection, thereby promoting the establishment of more NRs (Zhang et al., 2017). The overexploitation of land resources and the disordered expansion of agriculture have led to the direct conversion of a large number of natural habitats to other uses and the intensification of species extinction (Zheng and Cao, 2015; Ma et al., 2019; Shrestha et al., 2021). With China's rapid economic development, many road networks have been constructed to improve transportation. However, road expansion disrupts the connectivity of natural habitats, causing the extinction of native species and altering the structure and function of ecosystems (Wang et al., 2014; Venter et al., 2016), and leads to the miniaturization of NR areas. Many endangered higher plants and vertebrates depend on these ecosystems for survival. In China, 60 % of terrestrial NRs have an area <100 km^2. These small NRs are very important for biodiversity (Wu et al., 2011a) and could make an important contribution to reducing habitat loss and preventing the degradation of fragile ecosystems (Liao et al., 2019).

Anthropogenic activities can reduce the protectable area through the use of natural resources. On this basis, this study constructed an integrated model of the effects of anthropogenic and natural factors on the pattern of PAs (Fig. 5). The model showed that increased anthropogenic pressures directly affected the stability of local species populations and ecosystems (Kerr and Currie, 1995; McDonald et al., 2008; Shrestha et al., 2021), leading to habitat loss and threatening the survival of species (Kerr and Currie, 1995; Shrestha et al., 2021). Due to the increase in human activities, some natural habitats with high ecological value have been converted. These converted habitats limit the amount of land that can be designated as NRs, even if there is a high demand for protection in some areas (Pressey et al., 1993; Margules and Pressey, 2000).

The distribution of natural and anthropogenic factors in eastern, central, and western China shows that the natural resources in the eastern and central regions are under greater pressure from anthropogenic activities than those in the western region (Fig. 4). Most of the eastern provinces with high population density are located in areas with high levels of economic development. These areas are highly urbanized and natural habitats are heavily converted, creating a large number of habitat patches. Therefore, these provinces can only establish a relatively large number of small NRs. Thus, the pattern of biodiversity determines the distribution pattern of NRs, and the long-term impact of human activities makes NRs patchy.

4.3. Implications

Based on this study, it can be suggested that when the state adjusts and integrates NR scope and functional areas, it should fully consider the characteristics and needs of what is to be protected and improve environmental impact assessments. As cities and rural areas develop, and agricultural land and roads expand, NR areas will become more constricted and more habitat fragmentation will occur (Venter et al., 2016; Ma et al., 2019). Because the natural resources in various regions are basically stable, the area that can be used to establish NRs is stable. China's urban and rural economic level will continue to develop, and its economic activities and population will continue to increase. Therefore, the tension between human land use and the need to protect biodiversity through land conservation will become more serious (Liu et al., 2003; Long, 2014; Montesino Pouzols et al., 2014). Furthermore, we propose reducing the fragmentation of adjacent and connected NRs within the same geographic unit due to administrative division and resource classification. The integrity of natural ecosystems and the connectivity of species habitats should be considered in unified conservation management (Saura et al., 2018; Wu et al., 2020). Merging and reorganization will help to optimize the boundaries and functional zoning of the merged NRs, solve the problems of protection management zoning, fragmentation and islanding of reserves, and realize the overall protection of natural ecosystems (Etienne and Heesterbeek, 2000; McCarthy et al., 2011). Finally, NRs need to be evaluated scientifically to understand the most fundamental anthropogenic threats to NRs and to develop strategies for the optimal coordination of whole landscapes, including areas allocated to both production and protection (Margules and Pressey, 2000; Shrestha et al., 2021). For areas with low conservation value, dense populations, and rapid agricultural expansion, the plan adjusts the scope of NRs. Dynamic monitoring of each NR should be carried out to fully describe ecosystem composition, distribution and dynamic changes, and to assess ecological risks with timely early warning. Comprehensive monitoring of human activities should be implemented, such as the expansion of agricultural land and the development of mineral resources in NRs.

5. Conclusions

The results showed that desert and grassland ecosystems were positively correlated with the area and coverage of NRs, while they were negatively correlated with reserve density. The influence of forests and wetlands on the distribution pattern of NRs was opposite to that of desert and grassland ecosystems. Plant and animal densities and anthropogenic factors were negatively correlated with the area and coverage of NRs, while they were positively correlated with NR density. Desert coverage (48.3 %) was the most important determinant of the NR model, followed by grassland coverage (8.6 %) and forest and wetland coverage (7.3 %). The positive correlation between natural resources and anthropogenic factors, except in desert and grassland ecosystems, suggests that human pressure may influence the delineation of NRs by appropriating natural resources. Thus, natural factors determine the distribution pattern of NRs, while human factors make the distribution of NRs patchy. The protection of important ecosystems such as forests and wetlands should be strengthened, and more attention to should be paid to the impacts of and population density growth and agricultural and road expansion on the establishment and effective management of NRs in order to balance the trade-offs between biodiversity and the intensity of human activities.

CRediT authorship contribution statement

Ting Zhao: Conceptualization, Methodology, Investigation, Visualization, Formal analysis, Writing-original draft. **Congke Miao:** Investigation, Formal analysis. **Jing Wang:** Methodology, Investigation. **Pinjie Su:** Investigation, Writing-review & editing. **Yifu Luo:** Investigation, Formal analysis. **Kuo Chu:** Investigation, Formal analysis. **Qiqi Sun:** Methodology, Formal analysis. **Yanzhong Yao:** Investigation, Formal analysis. **Guohui Zhang:** Conceptualization, Investigation. Naishun Bu: Conceptualization, Investigation, Supervision, Writing-review & editing, Funding acquisition. **Youtao Song:** Conceptualization, Resources, Date curation, Writing-review & editing, Funding acquisition.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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