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Endangered and endemic species increase forest conservation values of species diversity based on the Shannon-Wiener index

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Species diversity is the most important component of biodiversity and plays an important role in maintaining forest ecosystem processes and stability. The assessment of the forest conservation value of species diversity is commonly carried out based on the Shannon-Wiener index. However, endangered and endemic species were always ignored in previous studies aimed at assessing the conservation value of forest species diversity. In this study, the conservation value of forest species diversity was assessed in two representative provinces of southern and northern China (Yunnan and Jilin provinces, respectively). The conservation values of species diversity for different forest types was calculated based on the standard Shannon-Wiener index, and on two different indexes derived from it by including: (i) an endangered species index (E_i) based on the China Species Red List; (ii) an endemic species index (B_x) based on the geographic distribution of the species considered. The results showed that the inclusion of the endangered and endemic species indexes dramatically increased the forest conservation values in these two provinces. The total conservation value in the Yunnan province was 268.65 billion yuan yr^{-1} based on the Shannon-Wiener index, 269.78 billion yuan yr^{-1} after including E_i in the assessment, and 324.44 billion yuan yr^{-1} after the inclusion of both E_i and B_x. In Jilin province, the total conservation value was 123.94 billion yuan yr^{-1} based on the standard Shannon-Wiener index, 124.60 billion yuan yr^{-1} after including E_i, and 125.74 billion yuan yr^{-1} after including both E_i and B_x in the assessment. Therefore, the inclusion of endangered and endemic species in the assessment of forest conservation values, as well as other aspects related to biodiversity like the presence of ancient trees, can contribute to the protection of endangered and endemic species in these two provinces of China.

Keywords: Species Diversity, Conservation Value, Endangered Species, Endemic Species

Introduction

Biodiversity is the foundation of human survival and development, and refers to the variety of organisms in terrestrial, marine, and aquatic ecosystems, as well as the ecological complexity of different ecosystems (Purvis & Hector 2000). It is always divided into intraspecific and interspecific diversity, as well as intra-ecosystem and inter-ecosystem diversity (Ma et al. 2007), and comprises three different levels involving gene, species, and ecosystem diversity (United Nations 1993, Mooney 2009). Species diversity, the most important level of biodiversity (Pimentel et al. 1997), is a measure of the number of species in a particular region (Nunes & Van Den Bergh 2001). Species diversity is fundamental as it enhances ecosystem productivity and stability (Odum 1950) and affects ecosystem structure and function (Cardinale et al. 2006).

Forest biodiversity conservation is aimed at promoting the survival of different species in forest ecosystems (Li 2007, Cushman et al. 2008). Bollmann et al. (2009) argued that near-natural sustainable management and the protection of habitats for rare and endangered species in forest ecosystems should be the main targets of forest biodiversity conservation. Furthermore, forest biodiversity is one of the main forest ecosystem services (Naeem et al. 1994, Tilman et al. 1996, Terborgh 1998, Niu et al. 2012). However, our understanding of how to quantify forest biodiversity is still not fully clear (Simberloff 1999, Kuuluvainen 2002).

The assessment of biodiversity includes use and non-use values. The former consists of direct and indirect value, while the latter comprises existence and option values (Kellert 1997, Song 2004). The conservation value of species diversity is a part of non-use value, and is primarily related to the provision of species and genetic resources for ecosystem succession and biological evolution, which play an important role in maintaining ecosystem processes and stability (Schwartz et al. 2000). The ability to assess the conservation value of species diversity is a premise of effective biodiversity protection and sustainable utilization.

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It is widely reported that methods for evaluating the conservation value of species diversity include the actual market price, as well as simulated market, alternative market, contingent valuation (CV), willingness to pay (WTP), expense payment, and cost-benefit methods (OECD 1996, Van Jaarsveld et al. 1998, Jakobsson & Dragun 2001, Christie et al. 2006). However, the common shortcomings of current methods are that they do not reflect the functional value of species in the ecosystems, but are predominantly affected by human-oriented criteria. Thus, these evaluation methods cannot correctly reflect the actual conservation value of species diversity.

Since the 1950, twenty-seven different indexes have been used to assess species diversity (Yue et al. 1998a, 1998b). The most widely used is the Shannon-Wiener index, that can reflect species richness and species evenness. According to the forestry industry standard of the People's Republic of China "Specifications for Assessment of Forest Ecosystem Services in China (LY/T 1721-2008)" issued by the State Forestry Administration (PRC Forestry Industry Standard 2008), we previously assessed for the first time the conservation values of Chinese forest ecosystems using the Shannon-Wiener index (Wang et al. 2008, Niu et al. 2013). Subsequently, this index was applied to evaluate the conservation values of different forest ecosystems in China (Wang & Lu 2009, Wang et al. 2011a, 2011b).

For assessing forest ecosystem services, the above forestry industry standard requires the use of specific data sources, the evaluation of several system processes and the application of a given formula that combines all the information in a synthetic index. Three different sources of data are considered: (i) long-term observation data form CFERN; (ii) forest resources inventory data from the State Forestry Administration; and (iii) social/public resource data published by the authority. The eight system processes evaluated are: (i) water conservation; (ii) soil conservation; (iii) carbon fixation; (iv) oxygen release; (v) nutrient accumulation by plants; (vi) biodiversity conservation; (vii) the protective efficiency of forests; and (viii) forest recreation. Finally, the formula accounted for both the quantity and quality of each of the above processes and data sources. Though suitable for assessing forest ecosystem services in China, the standard described above does not include other important aspects, such as the use of forest resources, forest by-products, or intrinsic forest value.

Tab. 1 - Different levels of the Shannon-Wiener index and the corresponding monetary value.

Level	Shannon-Wiener index	Monetary value (yuan hm^{-2} yr^{-1})
1	Index ≥ 6	50 000
2	5 ≤ Index < 6	40 000
3	4 ≤ Index < 5	30 000
4	3 ≤ Index < 4	20 000
5	2 ≤ Index < 3	10 000
6	1 ≤ Index < 2	5 000
7	Index < 1	3 000

Although the Shannon-Wiener index is recognized as a classic indicator of species diversity, the important role of endangered and endemic species is always ignored in the assessment of the conservation value of forest species diversity. Indeed, two forest stands may show the same Shannon-Wiener index values regardless of the presence of endangered or endemic species in one of them. This calls for the inclusion of new criteria related with endangered and endemic species in the calculation of species diversity using the Shannon-Wiener index.

Endangered species are important components of forest ecosystems. Nonetheless, the rapid growth of the human population, the destruction of natural habitats, the over-exploitation of natural resources, environmental pollution, and the introduction of exotic species have threatened a large number of species with extinction (Norris 2012). Generally, endangered species always have a disproportionate conservation value than that of common species, leading to enhanced conservation efforts (Cheng & Zang 2004).

Endangered categories are an important tool used to determine the conservation value of species, as well as the development of conservation strategies and priorities for endangered species. By signing the "Convention on Biological Diversity", some countries and international organizations recognized the assessment of species' endangered statuses as an important step in biodiversity conservation work. In the 1990s, China published the "China Plant Red Data Book" and "China Red Data Book of Endangered Animals" (Fu 1991, Wang 1998).

The heterogeneity of natural habitats, plant genetic variability, as well as interspecific hybridization, may result in endemic species (Sodhi et al. 2004), which in many cases represent unique indicators of some vegetation types (Vilenkin et al. 2009). Being highly dependent upon their specific habitats, endemic species may become endangered as a consequence of habitat destruction or depletion. Therefore, degradation of regions harboring a great number of endemic species would entail a remarkable loss of biodiversity (Brooks et al. 2006).

Bonn et al. (2002) considered that threatened and endemic species are good indicators of patterns of biodiversity on a regional scale. Dobson et al. (1997) used a database of threatened and endangered species in the United States to examine patterns in the geographic distribution of imperiled species. Ceballos et al. (1998) reported that areas of high species richness (*i.e.*, regions with high numbers of endangered and endemic species) should be recognized as conservation priority areas. As the special conservation values of endangered and endemic species have become appreciated, more attention should be paid to such species when assessing forest biodiversity conservation values.

In this study, we assessed the conservation values of forest species diversity in Yunnan and Jilin provinces, which are representative provinces of southern and northern China, respectively. The conservation values were calculated based on the Shannon-Wiener index, and a specific endangered species index and an endemic species index were added to amend the calculation in a stepwise manner. These three assessment methods were tested and verified to select the best one.

Materials and methods

Assessing conservation value based on the Shannon-Wiener index

The conservation values of different types of forest stands in Yunnan and Jilin provinces were calculated based on the Shannon-Wiener index, defined as follows (eqn. 1):

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where p_i is the proportion of individuals belonging to the *i*-th species in the total population. Index values calculated for each stand type were then divided into seven levels (see Tab. 1), and for each level the conservation value of species diversity per unit area was assigned based on the Forestry Industry Standard of the People's Republic of China "Specifications for Assessment of Forest Ecosystem Services in China (LY/T 1721-2008)" (Tab. 1 - PRC Forestry Industry Standard 2008).

The total conservation value of species diversity was calculated for all stands by multiplying the stand area and the conservation value of species diversity per unit area (eqn. 2):

$$U_B = S_B A$$

where U_B (yuan yr^{-1}) is the total conservation value of species diversity for all the stands, S_B (yuan hm^{-2} yr^{-1}) is the conservation value of species diversity per unit area, and A (hm^{-2}) is the stand area.

Inclusion of the endangered species index in the Shannon-Wiener index

In this study, endangered species were divided into four categories, according to the "China Species Red List" (Wang & Xie 2004)": (i) critically endangered; (ii) endangered; (iii) vulnerable; and (iv) near threatened (Tab. 2). An endangered species index was used to modify eqn. 2 as follows (eqn. 3):

$$U_B = \left(1 + \sum_{i=1}^{n} E_i \cdot 0.1\right) S_B A$$

where E_i is the endangered index of the i-th endangered species in a specific assessed stand (E_i = 1, 2, 3, 4 – see Tab. 2), and n is the number of endangered species.

Inclusion of the endemic species index in the Shannon-Wiener index

Since endemic species are not considered in the estimation of the biodiversity conservation value (see eqn. 3), an endemic species index was defined and included into eqn. 3. The final formula was as follows (eqn. 4):

$$U_B = \left(1 + \sum_{i=1}^{n} E_i \cdot 0.1 + \sum_{x=1}^{m} B_x \cdot 0.1\right) S_B A$$

where B_x is the endemic index of the x-th endemic species in a specific assessed stand (B_x = 0, 1, 2, 3, 4 – see Tab. 3), m is the total number of endemic species, and n is the total number of endangered species.

Tab. 2 - The endangered species index and endangered species categories.

Endangered species index	Endangered categories	Endangered species
4	critically endangered	See the "China Species Red List" (2004)
3	endangered	
2	vulnerable	
1	near threatened	

Tab. 3 - The endemic species index according to their geographic distribution.

Endemic species index	Species distribution
4	Species exhibits a small-scale distribution in the mountains or in a special natural and geographical environment
3	Species is distributed in a larger natural and geographical environment, *e.g.*, larger islands, plateaus, and numerous mountains
2	Species is distributed in a specific continent
1	Species is distributed in at least two continents
0	Species is widely distributed throughout the world

Data resources

Floristic and inventory data of the two provinces were taken from the 7th Chinese forest resource inventory. All the stand types considered in both Yunnan and Jilin provinces are shown in Tab. 4.

Results

Conservation values by the standard Shannon-Wiener index

The total conservation values of different stand types in Yunnan and Jilin provinces were 268.65 and 123.94 billion yuan yr^{-1}, respectively (Fig. 1a, Fig. 2a). The top 10 conservation values in the Yunnan province were as follows: other soft broadleaved forest, broadleaved mixed forest, shrubbery forest, broadleaved and coniferous mixed forest, other hardwood, *Quercus* forest, *Pinus yunnanensis* forest, coniferous mixed forest, economic forest, and *Codonopsis lanceolata* forest. In the Jilin province, the top ten were: broadleaved mixed forest, *Quercus* forest, *Larix* forest, broadleaved and coniferous mixed forest, coniferous mixed forest, *Pinus sylvestris* forest, *Populus* forest, shrubbery forest, miscellaneous tree forest, and *Pinus koraiensis* forest.

Inclusion of the endangered species index

The endangered species index (E_i) described above was used to amend the Shannon-Wiener index. Using the modified index (eqn. 3), the total conservation values

Tab. 4 - The stand types considered in this analysis for the Yunnan and Jilin provinces (China).

Yunnan province			Jilin province		
Num	Stand type	Area (10^4 ha)	Num	Stand type	Area (10^4 ha)
1	Other soft broadleaved forest	162.20	1	Miscellaneous tree forest	407.71
2	Broadleaved mixed forest	239.46	2	Broadleaved mixed forest	109.92
3	Shrubbery forest	102.01	3	Shrubbery forest	79.37
4	Broadleaved and coniferous mixed forest	145.39	4	Broadleaved and coniferous mixed forest	86.48
5	Other hardwood forest	79.64	5	Coniferous mixed forest	29.53
6	Coniferous mixed forest	222.19	6	*Pinus sylvestris* forest	12.92
7	Economic forest	310.47	7	*Quercus* spp. forest	65.72
8	Bamboo forest	50.39	8	*Larix* spp. forest	18.98
9	Other *Taxodium* forest	19.24	9	*Populus* spp. forest	8.18
10	*Cunninghamia lanceolata* forest	35.50	10	*Pinus koraiensis* forest	8.07
11	*Abies alba* forest	34.06	11	*Picea asperata* forest	3.98
12	*Pinus armandii* forest	32.14	12	*Betula platyphylla* forest	5.67
13	*Pinus kesiya* forest	59.03	13	*Ulmus pumila* forest	4.79
14	*Pinus densata* forest	22.07	14	*Pinus thunbergii* forest	1.76
15	*Eucalyptus robusta* forest	24.00	15	*Juglans mandshurica* forest	1.90
16	*Keteleeria fortunei* forest	23.52	16	*Fraxinus mandshurica* forest	0.75
17	*Tsuga chinensis* forest	3.36	17	*Salix babylonica* forest	0.41
18	*Schima superb* forest	6.72	18	*Betula costata* forest	0.53
19	*Picea asperata* forest	6.24	19	*Abies nephrolepis* forest	0.16
20	*Quercus* spp. forest	12.51	20	*Tilia amurensis* forest	0.15
21	*Betula* spp. forest	3.84	21	*Phellodendron amurense* forest	0.03
22	*Pinus yunnanensis* forest	3.36	22	*Acer mono* forest	0.05
23	*Populus* spp. forest	3.36	23	Other pine forest	0.01
24	*Cupressus funebris* forest	2.88	24	-	-
25	*Larix* spp. forest	1.44	25	-	-
26	*Cinnamomum* forest	0.48	26	-	-
27	*Paulownia fortunei* forest	0.48	27	-	-
28	*Cryptomeria fortunei* forest	0.48	28	-	-

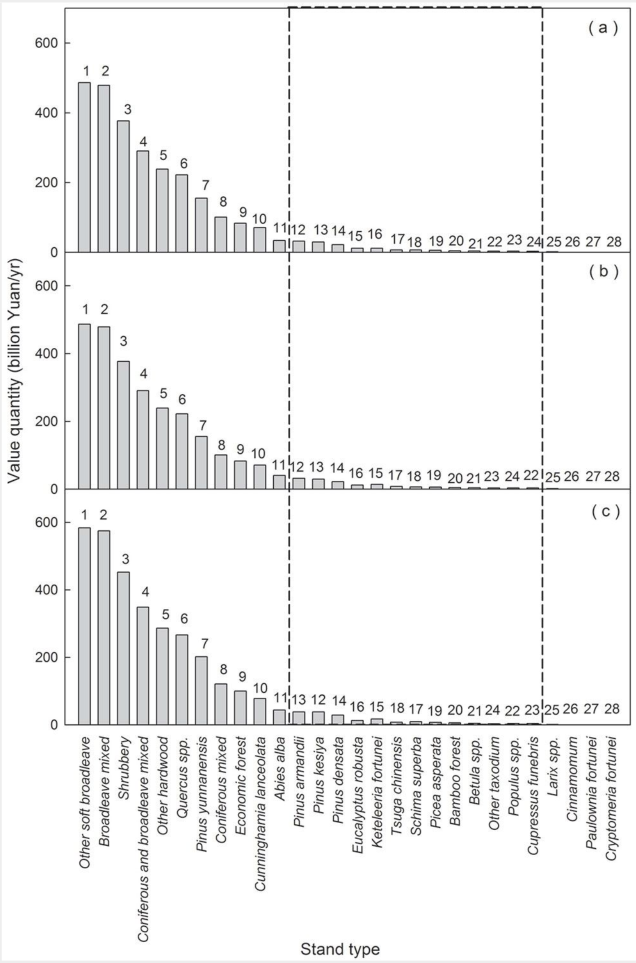

Fig. 1 - Conservation values of different forest stand types in the Yunnan province based on: (a) the standard Shannon-Wiener index (eqn. 2); (b) the inclusion of the endangered species index (eqn. 3); and (c) the inclusion of both the endangered species index and the endemic species index (eqn. 4). The numbers on the top of each bar are the ranking of each stand type based on the calculated conservation value. The rectangle within the dotted lines represents the stands whose conservation value ranking changed using the different indexes.

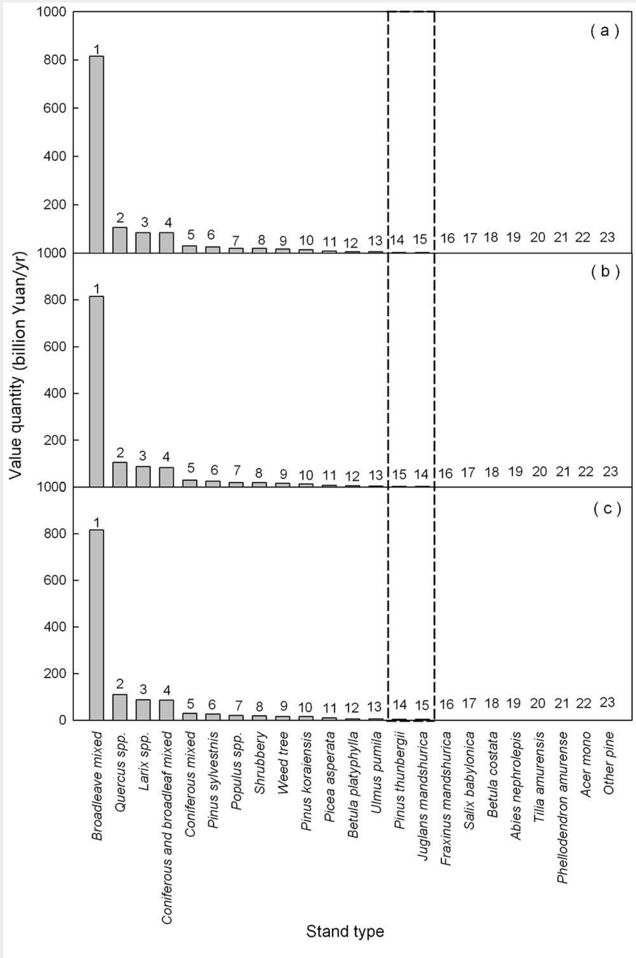

Fig. 2 - Conservation values of different forest stand types in the Jilin province based on: (a) the standard Shannon-Wiener index (eqn. 2); (b) the inclusion of the endangered species index (eqn. 3); and (c) the inclusion of both the endangered species index and the endemic species index (eqn. 4). The numbers on the top of each bar are the ranking of each stand type based on the calculated conservation value. The rectangle within the dotted line represents the stands whose conservation value ranking changed using the different indexes.

of the different stand types in the Yunnan and Jilin provinces were 269.77 and 124.60 billion yuan yr^{-1}, respectively (Fig. 1b, Fig. 2b). The top 10 conservation values in the Yunnan and Jilin provinces did not change. In the Yunnan province, the conservation value of the *Keteleeria fortunei* forest moved up one place, replacing the originally 15^{th} ranked *Eucalyptus robusta* forest. The conservation value of the *Cupressus funebris* forest moved up two places and ranked 22^{th}. In the Jilin province, the conservation value of the *Juglans mandshurica* forest moved up one place and ranked 14^{th}.

Inclusion of the endemic species index

The endemic species index (B_x) was used to modify the Shannon-Wiener index. Using eqn. 4, the total conservation values of different stand types in the Yunnan and Jilin provinces were 324.44 and 125.74 billion yuan yr^{-1}, respectively (Fig. 1c, Fig. 2c). The top 10 conservation values in the Yunnan and Jilin provinces did not change. In the Yunnan province, the conservation value of the *Pinus kesiya* forest moved up one place and replaced the originally 12^{th} ranked *Pinus armandii* forest. The *Shorea superba* forest also moved up one place. The conservation value of the *Populus* forest moved up two places and ranked 22^{th}. In Jilin province, the conservation value of the *J. mandshurica* forest moved down one place and ranked 15^{th}.

Discussion

In this study, the total conservation values of different forest ecosystems increased in both Yunnan and Jilin provinces when endangered and endemic species were included by suitable indexes into the Shannon-Wiener index. The Yunnan province is located in a tropical belt of China and is renowned for its species richness, especially for endangered and endemic species (Ge et al. 1997). Contrastingly, the Jilin province is in the northern of China, thus the overall number of species is lower than that found in the Yunnan province. In both cases, the conservation values increased dramatically when the endangered and endemic species indexes were included in the assessment.

In the Yunnan province, as the endangered species index of *K. fortunei* is 2 and *E. robusta* is not included in the "Chinese Species Red List", the conservation value of *K. fortune* surpassed that of *E. robusta* when considering the endangered species index in the assessment. The rank of the *C. funebris* conservation value increased from 24 to 22 as its endangered index is 2; thus, the conservation value of *C. funebris* surpassed those of the *Populus* and other *Taxodium* forests when including the endangered species index.

When the endemic species index was included the Shannon-Wiener index (eqn. 4), the total conservation value increased dramatically. The conservation value of the *P. kesiya* forest increased from 2.21 to 2.87 billion yuan yr^{-1}, and replaced the originally 12th ranked *P. armandii* forest. This is because the endemic index of *P. kesiya* is 3, and it is only distributed in the Yunnan province. As an indigenous species, the conservation value of *S. superba* also increased from 0.67 to 0.94 billion yuan yr^{-1}, replacing the *Tsuga chinensis* forest in the ranking. The conservation value of the *Populus* forest increased from 0.34 to 0.40 billion yuan yr^{-1}, and moved up two places in the ranking, as an indigenous species, *Populus yunnanensis*, grows only in the Yunnan province.

In the Jilin province, when the endangered species index was included in the assessment, the *F. mandshurica* forest replaced the *Pinus thunbergii* forest type by moving from 16th to 15th place in the ranking, because it is classified as a vulnerable species. However, when the endemic species index was included in the assessment, the conservation value of *F. mandshurica* moved down one place, ranking 16th again. Although the endemic indexes of both *F. mandshurica* and *P. thunbergii* were 2, the areas covered by these two species are very different, changing the ranking based on conservation values.

In this study, the economic value of biodiversity was described by the species diversity conservation value, and the assessments carried out using two different modified forms of the Shannon-Wiener index. Compared with the conservation values based on the standard Shannon-Wiener index, increased values were obtained when endangered and endemic species indexes were incorporated in the assessment. The conservation values of endangered and endemic species can therefore contribute to the protection of endangered and endemic species in these two provinces of China.

Ancient trees are worthy of great conservation efforts because they are a record of a region's climate, hydrology, geology, geography, vegetation, ecology, and other natural conditions, and have been witness to human activity and the historical process of social development. Additionally, ancient trees have special significance for the study of tree physiology because they allow researchers to analyze how a tree's physiological processes change as it ages. Additionally, ancient trees are also the foundation of forest ecosystems, and an ancient tree index should also be considered when calculating biodiversity conservation values. Since data on ancient trees were not available, the conservation values of ancient trees were not evaluated in this assessment. However, this will be the future direction of our research.

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