An assessment of wetland nature reserves and the protection of China's vertebrate diversity

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Abstract

An assessment of wetland nature reserves and the protection of China's vertebrate diversity.— We assessed 148 wetland nature reserves in China and the distribution of the four taxa of endemic and threatened terrestrial vertebrates, reptiles, amphibians, birds and mammals. Assessment of the wetland nature reserves was combined with the governmental list of the endemic and threatened vertebrates to identify the richness of the species. Species richness was scored as high, medium or low using a factor analysis method, and 31 wetland ecosystems were marked as high protection areas. The relationship between the threatened species and the endemic species in the reserves was also analyzed. We found that both richness patterns were similar. Based on the richness study, a nature reserve classification system with corresponding management is expected to be established in the future to protect species diversity in China.

Key words: Wetland nature reserve, Vertebrate diversity, Threatened species, Endemic species, Factor analysis

Resumen

Evaluación de los humedales declarados reserva natural y protección de la diversidad de vertebrados de China.— Se evaluaron las reservas naturales existentes en China y se estudió la distribución de los cuatro taxones de vertebrados terrestres endémicos y amenazados, que comprenden los reptiles, los anfibios, las aves y los mamíferos. Con vistas a determinar la riqueza de las especies, se combinó la evaluación anterior de los 148 humedales declarados reserva natural con la lista de los vertebrados endémicos y amenazados elaborada por el gobierno. Dicha riqueza de especies se clasificó en tres categorías: alta, media y baja mediante un análisis factorial y se seleccionaron 31 ecosistemas de humedales como zonas de alta protección. Asimismo, se analizó la relación existente entre las especies amenazadas y las endémicas en las reservas, y se observó que ambos modelos de riqueza eran parecidos. Se espera que, sobre la base del estudio de la riqueza, se pueda crear un sistema de clasificación de las reservas naturales, con su gestión correspondiente, con el objetivo de proteger la diversidad de las especies en China.

Palabras clave: Humedal declarado reserva natural, Diversidad de vertebrados, Especies amenazadas, Especies endémicas, Análisis factorial

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Introduction

Wetland ecosystems are considered key habitat environments for mammals, birds, reptiles, amphibians, and aquatic plants (Gibbs, 2000; Gibbons, 2003; Roe et al., 2006). In order to protect biodiversity in wetland ecosystems, in its biotic and abiotic dimensions, the establishment of protected areas, such as nature reserves, has been widely adopted worldwide (Soule, 1991; Margules & Pressey, 2000). Undoubtedly, it is necessary to determine an effective way to protect all types and species of wildlife.

As stated by Margules & Pressey (2000), the main role of reserves is to separate elements of biodiversity from processes that threaten their existence in the wild. However, for social, economic or political reasons, some reserves could be at risk of degradation or revocation of status. Biodiversity loss may occur in wetland systems, for example, due to land use changes, habitat destruction, pollution, exploitation of resources, or invasive species. The human impact is most apparent in wetland systems covering a relatively small area. Establishing protected area networks (PANs) can improve the management of protected areas and reduce human impact. Protected area networks can be defined as collections of at least two individual protected areas or reserves that are managed spatially, economically or socially in a cooperative and synergistic manner. Well–designed, protected area networks can improve species persistence in a certain region, representing the richness of overall species (Bonn et al., 2002). In a protected area, choosing appropriate surrogate species as effective indicators is critical to identify conversation priorities and establish conservation planning and management. Many studies have focused on biodiversity using surrogates of species richness (Wiens et al., 2008; Loyola et al., 2007; Caro & O'Doherty, 1999; Pinto et al., 2008) and the approach has established the relationship between species richness and taxa in some reserves (Plumptre et al., 2007; Lund & Rahbek, 2002; Negi & Gadgil, 2002; Qian, 2007; Wolters et al., 2006). Based on this relationship, the cross–taxon congruence of species diversity in the reserves has been applied to conservation strategies. Furthermore, biodiversity conservation can be planned based on such analysis. Conservation prioritization of all species, especially threatened and endemic vertebrate species, is considered essential for planning (Brooks et al., 2004; Grenyer et al., 2006; Rodrigues et al., 2004).

The main challenges to biodiversity conservation are related to the implementation of conservation plans (Pressey, 1998). Improper management may damage reserves and cause further loss of diversity. To avoid such an outcome, various protection policies have been developed for management of nature reserves (Margules & Pressey, 2000; Margules et al., 2002; Goodman, 2003; Wiersma & Nudds, 2009). National or international reserve systems should be central to biodiversity conservation. In China, endemic and threatened terrestrial vertebrates in the wetland reserves have been considered and protected, and a classification policy was issued by the government in 1994. However, systematic management does not seem to have been effectively implemented, particularly at a national level (Liu et al., 2003; Cui, 2004). There is a pressing need to solve many issues related to wetland conservation and biodiversity protection in China. The first of these is related to a severe decrease in the area of wetlands. In 2005, the area of wetlands was about 660,000 km^2 (Liu & Diamond, 2005) but in 2009 it had decreased to 359,478 km^2 (Niu et al., 2009), causing a sharp decline in habitat for species. Second, numerous threatened and endemic wetland vertebrates might not be registered in the reserves (Li et al., 2002; Wang & Xie, 2004; Yan et al., 2005), so conversation priorities could be incorrect. Third, the existing reserves or PANs are influenced by regional restrictions or distribution of rare species. Some of these reserves were established for maximum return of investment. To optimize reserve resources, it is therefore necessary to develop a new, effective and well–designed network for China's nature reserves, based on others' successful experiences (Reid, 1998; Scott et al., 2001; Cabeza & Moilanen, 2001). Unfortunately, threatened and endemic species in protected wetland areas in China have not been analyzed to date on a large scale to meet such an objective.

In this work, we analyzed the ranking of the protected wetland areas in China based on threatened and endemic vertebrate species richness. The species in those protected areas were identified and their protection value was evaluated. This work could provide useful data and new insights to establish and improve management systems for nature reserves in China.

Methods

Data collection

The data on species richness in wetland nature reserves were provided by the Beijing Forestry University's nature reserve database that includes scientific research reports, management plans, and project reports. The database was originally established as a reference for national and provincial reserve committees. The vertebrates in the database were classified into four taxa: mammals, birds, reptiles, and amphibians.

One hundred and forty–eight wetland nature reserves in China (77 national reserves and 71 local reserves), and 22 international wetlands were involved in this work. The classification was based on the State Bureau of Technical Supervision, 1994. The samples are the most important protected wetland areas administered by the State Forestry Administration of the People's Republic of China. The species data for each of these reserves were collected, as reported in references (Zheng et al., 2012).

Because of differences in information or category, some species that are not in the threatened species list in the IUCN Red List are listed in the China Species Red List. Thus, the threatened species in this work refer to those whose taxonomic level is considered threatened, including critically endangered (CR), endangered (EN), and vulnerable (VU) species, in the IUCN red list, the China Red Data Book of Endangered Animals, or the

China Species Red List. The national key protected species of China are also involved. The endemic species are indexed in the China Species Red List, referring to the species only found on mainland China. The basic information for endemic birds and mammals was collected from the literature (Mackinnon & Phillipps, 2000; Smith & Xie, 2008). The numbers of threatened and endemic species were in accordance with the data in the literature. Therefore, the database was used for all species in each reserve and the sampling covered all provinces in China except Gansu and Chongqing.

Ranking analysis of wetland protected areas

The ranking of the wetland protected areas was analyzed using the method developed by Plumptre et al, 2007. In short, the protected wetland areas were ranked in terms of the number of the endemic and threatened species for four vertebrate taxa. The weight on each taxon was assumed to be the same. The rank scores were standardized for each protected area by dividing by the maximum rank score to account for the fact that some sites do not have data for all taxa, and to account for the varying number of the endemic or threatened species between taxa. A mean rank was then calculated for both the endemic and threatened species for each site across the four taxa by summing ranks from each taxon and dividing this by the number of taxa for which there were survey data. These final standardized scores were then used to rank all the wetland protected areas.

Factor analysis

The following procedure was used to analyze the richness of species, namely factor scores. The richness of four vertebrate taxa was separately analyzed into the following eight classes: threatened amphibians, threatened reptiles, threatened birds, threatened mammals, endemic amphibians, endemic reptiles, endemic birds, and endemic mammals, referred to as indicators of X1, X2, X3, X4, X5, X6, X7 and X8, respectively.

Species richness in each class in all nature reserves was corrected using the following correction formula:

$$\ln (1 + X) / \ln (area)$$

where x is the number of species and area refers to the area of reserve sites.

The Kaiser–Meryer–Olkin test (KMO) and Bartlett sphericity test were performed, based on the correction results, to check whether the correlation matrix can be presumed to be identified. The corrected richness values were then subjected to the factor analysis in the following procedure. The raw data were first standardized and the principal components were analyzed. The variance of the cumulative contribution rate to eigenvalues was calculated by the varimax orthogonal rotation transform method. A factor score was then calculated by the regression method. Finally, the weighted average of composite scores was calculated based on the contribution rate of the characteristic roots. The following equation was used to calculate the composition scores:

$$CS = \lambda_1 f_1 + \lambda_2 f_2 + + \lambda_n f_n$$

where CS is the composite scores; f_1, f_2 … f_n are the factor values of the first, second, and n^{th} factors, respectively; λ_1, λ_2 ... λ_n are the contribution rates to the eigenvalues for the first, second, and n^{th} factors.

Identification of the conservation priority

SPSS 17.0 software was used to calculate the single variable frequency distribution. Three levels with the composition scores of 1–49, 50–98, and 99–148 were designated as low, medium, or high, respectively, for all reserves. The levels were in accordance with the conservation priorities of the wetland nature reserves.

Correlation analysis

The relationship between the numbers of threatened and endemic species and the ranking of wetland ecosystem was studied. Pearson correlation coefficients were used to interpret the strength of the relationship. The significance of the correlation coefficient for all tests was $P < 0.01$, as shown in table 1. In short, the coefficient of the high correlation was above 0.50. The range of moderate correlation was between 0.30 and 0.10. The coefficient of the low correlation was below 0.10. (Lamoreux et al., 2005).

Results

Correlation analysis and identification of common factors

The value in the KMO test was 0.711, slightly higher than 0.7. The concomitant probability obtained by the Bartlett sphericity test was 0, considerably lower than the significance level of 0.05, fitting the adequacy to enter a factor analysis (Ferguson & Cox, 2007)

Table 1 summarizes the Pearson correlation coefficients for eight diversity indicators. A positive correlation was observed for every pair of indicators, whether cross–taxon or intra–taxon. The correlation coefficient of 11 in 28 cross–taxon comparisons was larger than 0.5, suggesting that they are in moderate correlation. There was a high correlation between the threatened species and endemic species for a certain taxon.

For the threatened species, there was a high correlation between amphibians and reptiles and a moderate correlation between reptiles and birds or mammals. On the other hand, for the endemic species, a strong correlation was found between birds and mammals. However, the richness of threatened birds was lower than that of threatened amphibians and mammals if the indicator values were corrected in the reserve area.

Table 2 shows the correlation matrix between the eigenvalues and eigenvectors. Two eigenvalues, which were larger than 1, were considered as the significant common factors. One of the common factors, referred as to f_1, with an eigenvalue of 4.421, was characterized as the terrestrial species factor for amphibians, reptiles, and mammals. The other common factor, referred to as f_2, with an eigenvalue of 1.198, was characterized as the avian species factor for the birds.

Table 1. Pearson correlation coefficients for eight diversity indicators: * Significant correlation at 0.01 level (2–tailed).

*Tabla 1. Coeficientes de correlación de Pearson para ocho indicadores de la diversidad: * La correlación es significativa al nivel 0,01 (bilateral).*

Taxon	X2	X3	X4	X5	X6	X7	X8
X1	0.647	0.384	0.416	0.714	0.626	0.479	0.465
X2		0.481	0.533	0.698	0.738	0.405	0.344
X3			0.267	0.258	0.418	0.773	0.154
X4				0.412	0.427	0.346	0.722
X5					0.583	0.303	0.412
X6						0.549	0.524
X7							0.449

Reserve ranking and species richness analysis

Results showed 70.77% of the bird species and 59.31% of the mammal species in China were recorded in the 148 protected areas. The percentages for the reptile species and amphibian species were 47.6% and 35.5%, respectively (fig. 1). Except for amphibian species, the proportion of the threatened species taxa was higher than that of the endemic species. Thus, based on the rule of priority, the threatened species was placed on the higher priority than the endemic species in the China wetland protected areas. For the amphibians, only one species, which is *Andrias davidanus*, was in the protection list in a special reserve in China. The endemic amphibians should be considered as the indicator for the protection functions in the protected areas.

Figure 2 shows the distribution matrix of priority ranking for all wetland nature reserves. The horizontal axis is for threatened species and the vertical axis is for endemic species. The reserves of 31, as marked as dark box, were scored as high level for both threatened species and endemic species. Thus, these reserves should have the highest overall protection value. On the contrary, the reserves of 20 were scored as low level for both threatened species and endemic species. They were considered as the lowest overall protection value. Other reserves were between the highest and the lowest protection values.

Most of the 31 reserves with the highest protection value were located in central and southern China in the middle and lower reaches of the Yangtze River (fig. 3). The major wetland ecosystems in these reserves are lakes, rivers, and marshes. Thus, these 31 reserves may be representative for the diversity of threatened and endemic species.

Figure 4A shows the species richness, expressed in percentages, for the threatened species in the 31 reserves, and figure 4B shows the percentages for the endemic species.

The types of the wetland reserves included offshore (coast) areas, lakes, rivers, and marshes (Tang & Huang, 2003; Scott & Jones, 1995). For the 31 reserves with the highest protection value, the most common type was lake reserves (16 lakes), and the second most common type was river reserves (12 rivers reserves). Lakes can generally provide good habitats for migratory water birds. For instance, the Poyanghu reserve and

Table 2 A summary of factor analysis results: Ts. Terrestrial species; As. Avian species.

Tabla 2. Resumen de los resultados del análisis factorial: Ts Especies terrestres; As. Especies de aves.

Item	Ts (F1)	As (F2)
X1	0.722	0.380
X2	0.715	0.428
X3	0.103	0.940
X4	0.772	0.082
X5	0.779	0.195
X6	0.695	0.461
X7	0.277	0.858
X8	0.778	0.059
Eigen value	4.421	1.198
Variance contribution rate	42.648	27.593
Cumulative variance contribution rate	42.648	70.241

Table 3. Classification of the 31 reserves with the highest conservation value: * Location is shown in parenthesis; LP. Level of protection (N. National; L. Local); ** Wetlands of international importance (Wii).

Tabla 3. Clasificación de las 31 reservas con el valor de conservación más elevado. La ubicación se muestra entre paréntesis; LP. Grado de protección (N. Nacional; L. Local); ** Humedales de importancia internacional (Wii).*

Reserve*	Wetland type	Area (km^2)	LP	Wii**
Poyanghu (Jiangxi)	Lake	224	N	✓
Yancheng (Jiangsu)	Offshore and seacoast	4,530	N	✓
Dongtinghu (Hunan)	Lake	1,900	N	✓
Xinfengjiang (Guangdong)	Lake	1,014	L	
Huidonglianhuashanbaipenzhu (Guangdong)	Lake	140.34	L	
Sanjiangyuan (Qinghai)	Marsh, lake	152,300	N	✓
Zhouzhiheihe (Shananxi)	River	131.25	L	
Anqing (Anhui)	Lake	987	L	
Longganhu (Hubei)	Lake	223.22	N	
Tonglingdanshuitun (Anhui)	Lake	519.50	N	
Nuoshuihe (Sichun)	River	94.80	L	
Longchuanfengshuba (Guangdong)	Lake	156.70	L	
Yangzie (Anhui)	Lake	185.65	N	
Shengjinhu (Anhui)	Lake	333.40	N	
Hanjiang (Shananxi)	River	336.05	L	
Bitahai (Yunnan)	Marsh, lake	330.70	L	✓
Longtan (Guangxi)	River	428.48	L	
Aibihu (Xinjiang)	Lake	267.09	N	
Kashahu (Sichuan)	Lake	317.00	L	
Baheliuyu (Sichuan)	River	492.60	L	
Huangheshidi (Henan)	River	227.80	N	
Weiningcaohai (Guizhou)	Lake	629.63	N	
Haizishan (Sichuan)	Lake	459.16	L	
Yangchengmanghe (Shanxi)	River	55.73	N	
Jiuzhaigou (Sichuan)	Lake	642.97	N	
Heyuanxingang (Guangdong)	Lake	75.13	L	
Yuncheng (Shanxi)	River	868.61	L	
Danjiangshidi (Henan)	River	837.38	N	
Pingnan Mandarin Duck and Macaque (Fujian)	River	14.57	L	
Yinghu (Shananxi)	River	198	L	
Neixiangtuanhe (Henan)	River	45.47	L	

Dongtinghu reserve are the most important protected areas in China for birds. Besides, they have served as habitats for many threatened mammals. For instance, the Yangzie reserve and Tonglingdanshuitun reserve play a primary role in the protection of Chinese alligator, such as *alligator sinensis*, and freshwater dolphin, such as *Lipotes vexillifer*.

The reserves which are not located around the Yangtze River are the Huidonglianhuashanbaipenzhu reserve, Xinfengjiang reserve, Longchuanfengshuba

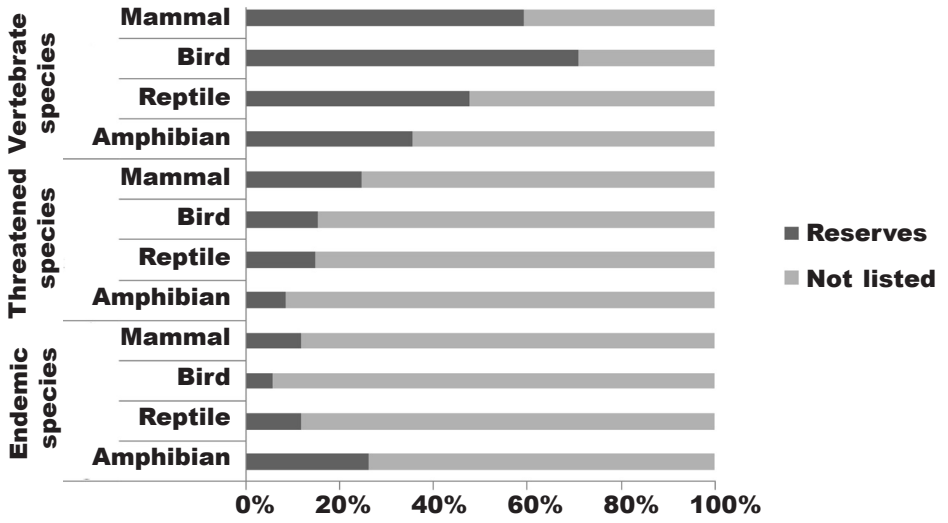

Fig. 1. The percentage of vertebrate species in reserves in China.

Fig. 1. Porcentaje de especies de vertebrados en reservas en China.

reserve, and Heyuanxingang reserve. These reserves are distributed mainly in Guangdong Province in southeast China. This type of reserve includes lakes, artificial reservoirs, and forests, providing ideal habitats for amphibians and reptiles.

The typical river reserves in the 31 reserves include Danjiangshidi reserve, Hanjiang reserve, and Huangheshidi reserve. All of them are highly important migrating sites for migratory birds, especially for waterbirds such as ciconia nigra, cygnus cygnus, grus grus, geese, and ducks. The regions of these reserves generally cover the forest ecosystems by rivers. The abundance of threatened amphibians, reptiles, and mammals living in these reserves is greater than those in other wetland reserves.

The Yancheng reserve is the only offshore type reserve, providing the largest winter habitat for *grus japonensis*. It also provides a comfortable habitat for migratory waterbirds. The Sanjangyuan reserve and the Bitahai reserve are typical plateau marsh type reserves in a plateau environment with high richness of endemic species.

The primary lake and river reserves have high richness and they are home to both threatened and endemic species. Nevertheless, some of the reserves have not received sufficient attention at the national level. For example, the Pingnan Mandarin Duck and Macaque reserve and the Nuoshuihe reserve are not well–protected because of their small size.

Discussion

The fundamental aim of nature reserves is to protect wildlife. Many reserves, however, are in areas of scenic interest, such as near like lakes and rivers, and it is foreseeable that local government develops scenic spots for the public. In doing so, reserves would lose their basic conservation function and biodiversity in these areas will decrease. Wildlife habitats are declining in many areas in China due to the expansive development and urban sprawl. High priority reserves therefore urgently require an adaptive management approach to protect the habitats of the species.

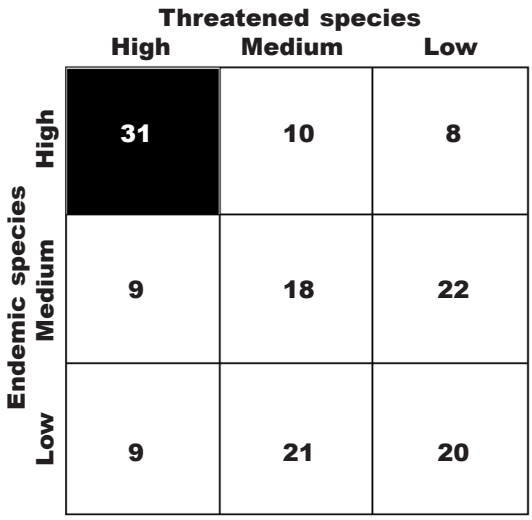

Fig. 2. Matrix of priority levels in 148 wetland nature reserves in China.

Fig. 2. Matriz de grados de prioridad de los 148 humedales declarados reserva natural en China.

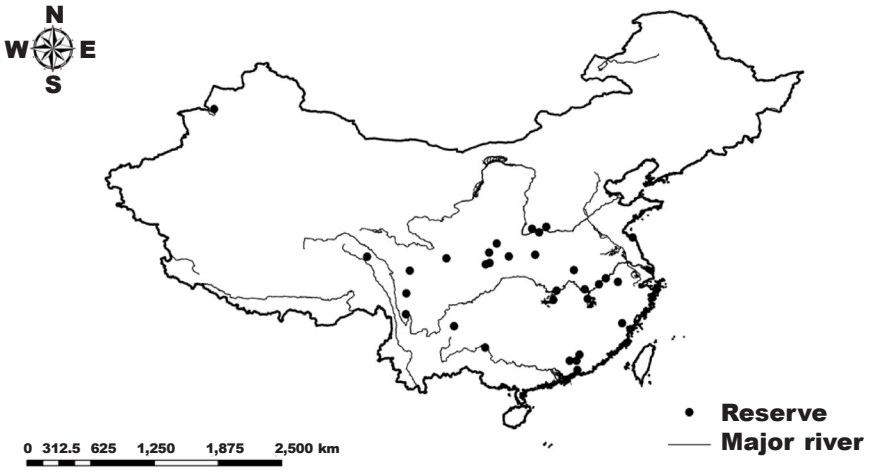

Fig. 3. The distribution of the 31 wetland nature reserves with high species protection value in Mainland China.

Fig. 3. Distribución de los 31 humedales declarados reserva natural que albergan especies con un alto valor de protección en la China continental.

The national protected areas are generally well–protected under Chinese law. However, many reserves are in a relatively low protection condition because of the lack of clear protection objectives and purposes. For example, the Pingnan Mandarin Duck and Macaque reserve is only 14.57 km^2, but its level of species richness is relatively high. According to the island theory of biogeography, habitat size has a

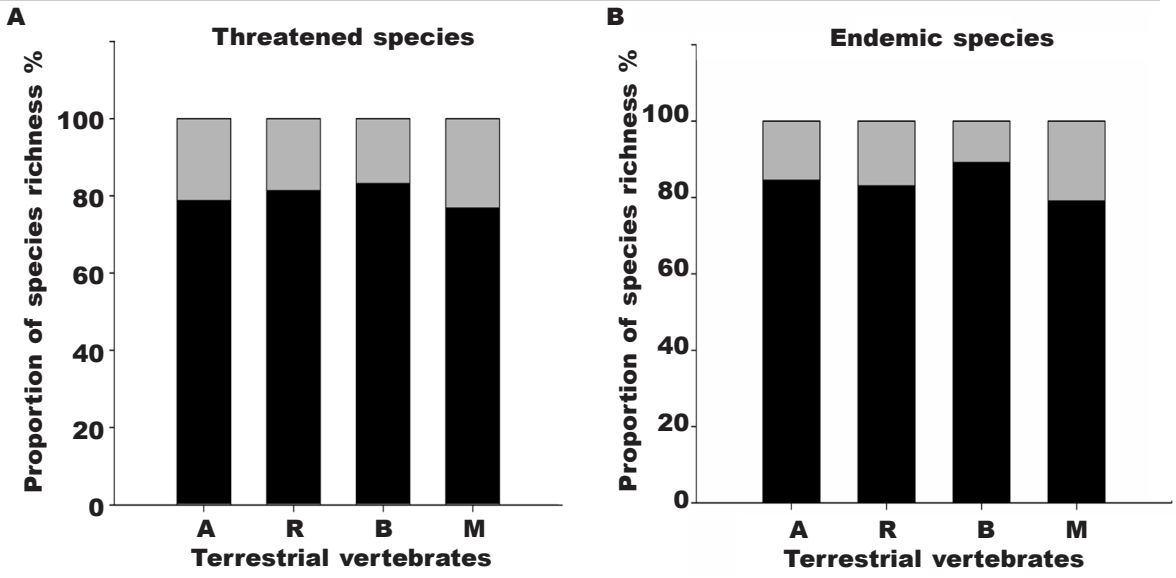

Fig. 4. Proportion of threatened species richness (A) and endemic species richness (B) of four vertebrate taxa in wetland nature reserves: A. Amphibians; R. Reptiles; B. Birds; M. Mammals; ■ Percentage of the 31 reserves with the highest conservation value; ■ Percentage of the other 117 reserves.

Fig. 4. Proporción de la riqueza de especies amenazadas (A) y endémicas (B) de los cuatro taxones de vertebrados en los humedales declarados reserva natural: A. Anfibios; R. Reptiles; B. Aves: M. Mamíferos; ■ Porcentaje de las 31 reservas con el valor de conservación más elevado; ■ Porcentaje de las otras 117 reservas.

significant, direct influence on species. A larger area should contain a larger diversity of species, and vice versa. Each single reserve is like an isolated island and is limited by local species size and management. If reserves are too small, the diversity of species will disappear. The current management mode in China is to rely on local capacity for protection and resources. If reserves have a highly scattered distribution, therefore, the island effect can be formed in the protection of diversity. To be a viable ecosystem for biodiversity, a protected reserve must be a certain size. Small reserves with a high richness, such as the Pingnan Mandarin Duck and Macaque Reserve, should thus be brought within the protected area network to avoid the disappearance of the species and conserve the regional biodiversity.

Regarding the 31 reserves which are mostly located near lakes and rivers, although their composite scores are high, human activity, such as that related to water supply, aquaculture, reclamation planting, and shipping, significantly influence the reserves. Excessive activity has a strong impact on vertebrate species and could lead to the serious depopulation of a species, such as the functional extinction of *Lipotes vexillifer* en Yangtze River in 2007.

Comprehensive management seems to be a need for all reserves. The key point is to make the ranking of reserves clear. All reserves can be ranked by conversation priority and an establishment policy can be made to protect wildlife and obtain funding. A protected area network should be developed rather than individual reserve protection based on the 31 high–score reserves. The results in this work indicate that the degree of concern of threatened terrestrial vertebrates in the wetland protected areas is obviously higher than that of endemic terrestrial vertebrates. The endemic species do not seem to have priority protection in a protected area as do threatened species, especially in a small–sized protected area. In the protected area network, the concern for the endemic terrestrial vertebrates should be increased. Biodiversity conservation planning should have solid roots in protection values of species and establishing a protected area network.

The classification and ranking results provide useful insight for the development of protection policies for vertebrate species for the government in China. The 31 national reserves should be included in a national reserve network. Furthermore, 15 provincial or municipal reserves which are also highly scored should be upgraded to a national level.

Conclusions

This work discusses the protection status of wildlife in wetland nature reserves in China. The composite score of the reserves was analyzed for both threatened and endemic species. The richness of species was correlated with the ranking of reserves and may help to address protection priorities. The characteristics of the highest scores in 31 reserves were analyzed. The results indicate that the management of reserve should be reinforced and a national reserve network should be established to protect the biodiversity in China. A nature reserve classification system with corresponding management will help to protect species diversity in China.

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