Conservation Biology

Conservation Focus: *Challenges in China*

Combining the Species-Area-Habitat Relationship and Environmental Cluster Analysis to Set Conservation Priorities: a Study in the Zhoushan Archipelago, China

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Abstract: *Identification of priority areas is a fundamental goal in conservation biology. Because of a lack of detailed information about species distributions, conservation targets in the Zhoushan Archipelago (China) were established on the basis of a species–area–habitat relationship (choros model) combined with an environmental cluster analysis (ECA). An environmental-distinctness index was introduced to rank areas in the dendrogram obtained with the ECA. To reduce the effects of spatial autocorrelation, the ECA was performed considering spatial constraints. To test the validity of the proposed index, a principal component analysis–based environmental diversity approach was also performed. The priority set of islands obtained from the spatially constrained cluster analysis coupled with the environmental-distinctness index had high congruence with that from the traditional environmental-diversity approach. Nevertheless, the environmental-distinctness index offered the advantage of giving hotspot rankings that could be readily integrated with those obtained from the choros model. Although the Wilcoxon matched-pairs test showed no significant difference among the rankings from constrained and unconstrained clustering process, as indicated by cophenetic correlation, spatially constrained cluster analysis performed better than the unconstrained cluster analysis, which suggests the importance of incorporating spatial autocorrelation into ECA. Overall, the integration of the choros model and the ECA showed that the islands Liuheng, Mayi, Zhoushan, Fodu, and Huaniao may be good candidates on which to focus future efforts to conserve regional biodiversity. The 4 types of priority areas, generated from the combination of the 2 approaches, were explained in descending order on the basis of their conservation importance: hotspots with distinct environmental conditions, hotspots with general environmental conditions, areas that are not hotspots with distinct environmental conditions, and areas that are not hotspots with general environmental conditions.*

Keywords: area prioritization, conservation planning, environmental cluster analysis, environmental distinctness index, spatially explicit model, species–area–habitat relationship, Zhoushan Archipelago

Combinación de la Relación de Especies-Área-Hábitat y el Análisis Clúster Ambiental para Definir Prioridades de Conservación: un Estudio en el Archipiélago Zhoushan, China

Resumen: *La identificación de áreas prioritarias es una meta fundamental en la biología de la conservación. Debido a la escasez de información detallada sobre la distribución de especies, los objetivos de conservación en el Archipiélago Shoushan (China) fueron establecidos con base en la relación especies-área-hábitat (modelo choros) combinada con un análisis clúster ambiental. Se introdujo un índice de distinción ambiental para clasificar áreas en el dendrograma obtenido con el análisis clúster ambiental. Para reducir los efectos de autocorrelación espacial, en el análisis clúster ambiental se consideraron las limitaciones espaciales. Para probar la validez del índice propuesto, también se aplicó un método de diversidad ambiental basado en un análisis de componentes principales. El conjunto prioritario de islas obtenido del análisis clúster espacialmente*

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constreñido aparejado con el índice de distinción ambiental tuvo gran congruencia con el obtenido con el enfoque tradicional de diversidad ambiental. Sin embargo, el índice de distinción ambiental tuvo la ventaja de proporcionar clasificaciones de áreas de importancia que podían ser integradas fácilmente con las obtenidas del modelo choros. Aunque las pruebas de Wilcoxon no mostraron diferencia significativa entre las clasificaciones del proceso de agrupamiento constreñido y no constreñido, como indica la correlación cofenética, el análisis clúster espacialmente constreñido funcionó mejor que el análisis clúster no constreñido, lo cual sugiere la importancia de la incorporación de la autocorrelación espacial al análisis clúster ambiental. En general, la integración del modelo choros y el análisis clúster ambiental mostró que las islas Liuheng, Mayi, Zhoushan, Fodu y Huaniao pueden ser buenos candidatos para la aplicación de futuros esfuerzos para conservar la biodiversidad regional. Los cuatro tipos de áreas prioritarias, generados de la combinación de los dos métodos, fueron ubicados en orden descendente con base en su importancia de conservación: áreas de importancia con condiciones ambientales distintas, áreas de importancia con condiciones ambientales generales, áreas que no son tan importantes con condiciones ambientales distintas y áreas que no son tan importantes con condiciones ambientales generales.

Palabras Clave: análisis cluster ambiental, Archipiélago Shoushan, índice de distinción ambiental, modelo espacialmente explícito, planificación de la conservación, priorización de áreas, relación especies-área-hábitat

Introduction

The conservation of biodiversity is one of the main challenges for humankind (Myers et al. 2000; Trakhtenbrot & Kadmon 2005), and a cost-effective means of reducing biodiversity loss is to identify biodiversity hotspots (e.g., Dobson et al. 1997; Myers et al. 2000; Brummitt & Nic Lughadha 2003). The species–area relationship (SAR), in which the number of species found in a given place is explained by the area of that place, is commonly used for identification of biodiversity hotspots. Areas that score well above the resulting regression line exhibit higher biodiversity than expected and are, therefore, classified as hotspots (Veech 2000; Hobohm 2003). Recent research has developed and extended the use of SAR models in biogeographical research. One such advance is the choros model, a species–area–habitat relationship (SAHR) that attempts to unify species "addition mechanisms" determined by area size and habitat diversity (Triantis et al. 2003). Nevertheless, hotspots identified by the series of SAR or SAHR models are not necessarily the most robust means of conserving total species diversity because such areas maximize species numbers, but do not distinguish among species. Thus, the addition of some specific criteria, such as the percentage of total richness included in the selected areas, has been proposed (Fattorini 2006).

An alternative approach that has attracted attention recently is environmental cluster analysis (ECA). In the absence of detailed information on the distribution of species, the ECA selects complementary priority areas (e.g., Leathwick et al. 2003; Trakhtenbrot & Kadmon 2005; Snelder et al. 2007). This approach is tailored for prioritization of areas for conservation in large unexplored landscapes. Nevertheless, in practice it is more valuable to use this method to select representative areas with unique environmental space for conservation (Faith & Walker 1996; Araujo et al. 2001; Faith 2003). Therefore, it is essential to compare quantitatively the areas clustered in the dendrogram and select the best "environmental hotspots" as potential targets for conservation. I developed an environmental-distinctness (ED) index that ranks the clustered areas in a cluster-analysis dendrogram on the basis of their distinctness scores. On the basis of such an index, those areas with the most distinct landscapes can be selected for further scrutiny.

Both approaches have relevant conservation applications. Nonetheless, they have not been unified for use in setting conservation priorities so far. Is it possible to integrate the methods to make decisions in conservation planning when knowledge of species distributions is limited? If so, how can they be combined synergistically and efficiently? I used avian diversity information from the Zhoushan Archipelago to address these questions.

The Zhoushan Archipelago, in the Zhejiang Province of eastern China, is located near the confluence of the Yangtze, Qiantang, and Yong rivers. The archipelago comprises more than 20 islands, located between 29°32′N–31°04′N and 121°30′S–123°25′S; the largest is Zhoushan Island. The Zhoushan Archipelago has a monsoon marine climate with an annual average temperature of 16 °C. I examined 15 islands: Daishan, Fodu, Huanglong, Huaniao, Jintang, Liuheng, Mayi, Putuo, Qushan, Shengshan, Sijiao, Xiushan, Yuanshan, Zhoushan, and Zhujiajian.

The geography of the Zhoushan Archipelago is ideal for an investigation of the utility of combining the SAHR and ECA to establish conservation priorities. First, it contains islands with different avian species richness and islands of different areas and habitat types. Second, because the checklist of avian fauna is incomplete, the species distributions on each island are unclear. Third, because the archipelago is situated at the outlet of the Yangtze River, close to the mainland, future surveys can provide a more detailed description of biodiversity, and therefore the possibility to test the conservation priorities proposed in this analysis.

My objectives were to identify avian conservation hotspots for the Zhoushan Archipelago; demonstrate how to combine SAHR with ECA to set conservation priorities; and provide comparative evidence that shows the essential implications of integrating the ED index and spatial autocorrelation into the ECA.

Methods

The number of avian species on each island in the Zhoushan Archipelago was compiled from a comprehensive literature search, principally from Zhu et al. (1991).

Although they have been debated (Veech 2000), the preferred models (Fattorini 2006, 2007) for SAR are the power function, $S = cA^z$(where A is the size of the area and c and z are estimated parameters), and the linearized form of the power function, $\ln S = \ln c + z \ln A$. In the untransformed power model, the species–area slope is influenced by both c and z (Lomolino 2001). Several researchers used the linearized power function (Ulrich & Buszko 2005), whereas some others used a curvilinear fit (Desmet & Cowling 2004; Duarte et al. 2008). In the choros model (i.e., SAHR), A is replaced by the choros parameter K, and the power function becomes $S = cK^z$. Here, I compared the 2 power functions of the choros model and selected the best one for area prioritization.

I adjusted the choros parameter $K = H{\cdot}A$ as defined by Triantis et al. (2003) to $K = H'{\cdot}A$. Herein, H is the number of habitats, whereas H' is habitat diversity, evaluated as the degree of complexity of vegetation types of the islands. Habitat diversity is a summarized value based on the ranking of all habitats occurring on an island. Specifically, I used the empirically determined natural vegetation characteristics of the archipelago (Zhu 1990) to assess H' in terms of number and extent of habitat types. Generally, islands near the mainland are covered with evergreen broad-leaved trees and forest coverage is very high ($H' = 3$). Islands at intermediate distances from the mainland are covered with forests that are a mixture of evergreen and deciduous broad-leaved trees and forest coverage is intermediate ($H' = 2$). Islands far from the mainland have deciduous broad-leaved trees low forest coverage ($H' = 1$), and some areas undergoing desertification (Zhu et al. 1991). Measures of island areas were from Li and Li (1998).

To compare the curvilinear and linearized functions for the choros model, I used the standard error of estimate in actual units (S_e) (Parresol 1999), which is calculated as $S_e = \sqrt{RSS/(n-p)}$, where p is the number of model parameters (herein $p = 2$); n is the number of sample observations; and RSS is the residual sum of squares in actual units. Lower S_e values denote better fit. The residual values from each function were used to assign a priority ranking for each island (ranking 1, Table 1).

Elevation, minimum temperature, maximum temperature, and precipitation were selected as variables for the ECA. Among them, variables subject to temperature and precipitation were annually averaged. These variables generally represent the dominant factors in patterning species richness (Qian et al. 2007) and are widely used as environmental surrogates (Sarkar et al. 2005). I used the

Table 1. Avian species richness, ecogeographical variables, residuals from the curvilinear species-area-habitat relationship (choros model), and associated conservation priority ranking (ranking 1) for islands in the Zhoushan Archipelago.*

Island	*No. of species*	*Area (km^2)*	*Elevation (m asl)*	*minT*	*maxT*	*P*	H′	R	*Ranking 1*
Mayi	19	2.15	50	3.5	30.6	106.92	3	11.7612	1
Sijiao	23	22.3	217.8	3.3	30.3	83.5	1	11.2326	2
Fodu	22	7	183	3.2	30.8	112.67	3	10.5063	3
Liuheng	40	92.75	299	3.4	30.7	110.08	3	8.3766	4
Zhoushan	64	468.7	503	2.9	30.5	106.67	3	4.3535	5
Huaniao	9	3	236.9	3.4	29.9	84.42	1	3.6364	6
Huanglong	10	5.04	213	3.5	30.2	85.75	1	3.4279	7
Zhujiajian	28	62.8	378.6	3.6	30.4	104.42	3	0.8559	8
Shengshan	4	4.6	213	3.7	30	87.67	1	−2.3411	9
Putuo	12	12.32	291	3.4	30.2	103.33	3	−2.3425	10
Yuanshan	9	7.58	163	3.5	30.5	108.92	3	−2.8578	11
Qushan	13	59.9	250	3.1	30.3	90.67	1	−4.3283	12
Jintang	23	76.4	455.9	2.2	30.5	111.5	3	−6.3103	13
Xiushan	8	23	207	3	30.7	101.33	2	−7.6258	14
Daishan	11	100	175	2.8	30.5	98.08	2	−16.7869	15

Abbreviations: minT, minimum temperature (°C); maxT, maximum temperature (°C); P, average precipitation (mm); H′, *habitat diversity;* R, *residuals from the curvilinear choros model. In ranking 1, the smaller the number is the higher priority the island has.*

UPGMA algorithm, derived from the Gower's coefficient (Trakhtenbrot & Kadmon 2005, 2006), to generate a dendrogram of areas that reflected their similarities in terms of such variables. The cophenetic correlation coefficient, a measure of the correlation between interisland similarities represented on the dendrogram and the actual Gower coefficients, was applied to evaluate the effectiveness of the clustering algorithm (Trakhtenbrot & Kadmon 2006). I used the software NTSYS-pc (Rohlf 2005) to perform the above-mentioned analysis.

Minimum temperature, maximum temperature, average precipitation, and elevation of each island were extracted from the WorldClim database (http://www.worldclim.org/) with ArcView v3.3 (ESRI: http://www.esri.com/). To identify the most environmentally heterogeneous sites, I ranked all the islands on the basis of degree of rarity of their environmental conditions (i.e., ED index). High scores denoted higher heterogeneity (ranking 2, Table 2).

The ED value for an assumed terminal area a was calculated as follows. At each node i of the dendrogram, 2 area groups were divided. The corresponding environmental distance (1−Gower's coefficient) for the node was D_i. There were n_i terminal areas within the node i and m_i terminal areas within the concerned group where a was located. The partial environmental distinctness, ED_{ai}, of area a at node i was calculated as $\mathrm{ED}_{ai} = D_i \times (1 - {}^{m_i}/_{n_i})$. The overall ED index ED_a for terminal area a was the sum of all the ED_{ai} (i.e., $\mathrm{ED}_a = \sum_{i=1}^{S} \mathrm{ED}_{ai}$), where S is the number of nodes to reach a from the beginning of the dendrogram.

To reduce the influence of spatial isolation among the islands, I introduced a spatially explicit model in the cluster analysis. Such a spatially constrained cluster analysis (Pawitan & Huang 2003) was not derived from the original matrix of environmental distances among the islands; instead, it came from a matrix obtained from the Hadamard (i.e., element by element) product of matrices of environmental distances and connectivity matrices. Thus, islands will tend to cluster if they are spatially connected or adjacent (Legendre & Legendre 1998; SAM help file 2007). To complete this analysis, a connectivity matrix for the islands, on the basis of spatial distance criteria, was constructed in SAM (version 2.0; Rangel et al. 2006). To determine whether the final ordering of islands from spatially constrained and from unconstrained cluster analysis was different, I used a Wilcoxon matched-pairs test (Statistica, version 6.0, http://www.statsoft.com/) to compare the rankings of ED values derived from the 2 methods.

Table 2. Combined conservation-priority ranking of species-area-habitat relationship (ranking 1) and environmental cluster analysis (ranking 2) for islands in the Zhoushan Archipelago.*

Island	*Ranking 1*	*Ranking 2*	*Combined ranking*
Liuheng	4	2	6
Mayi	1	6	7
Zhoushan	5	3	8
Fodu	3	7	10
Huaniao	6	5	11
Sijiao	2	10	12
Yuanshan	11	2	13
Jintang	13	1	14
Shengshan	9	5	14
Huanglong	7	10	17
Zhujiajian	8	9	17
Xiushan	14	4	18
Putuo	10	9	19
Daishan	15	4	19
Qushan	12	8	20

**In combined ranking, the smaller the number is the higher priority the island has.*

To select potential priority areas by integrating the SAHR and ECA, I used a combined ranking procedure (Posadas et al. 2001; Lehman 2006), which was simply summarization of the ranks assigned to each island on the basis of the ordering obtained from choros residuals (ranking 1) and cluster analysis (ranking 2). For simplicity, only the top 5 islands in each ranking were considered of high value as conservation targets.

To test the validity of the ED index in cluster analysis, I also used an environmental diversity approach (Faith & Walker 1996; Araujo et al. 2001). Environmental diversity was measured by maximizing sampling variation within the environmental space. The steps to select priority areas followed Bonn and Gaston (2005). First, variations in environmental variables were summarized in an environmental space matrix with principal component analysis (PCA), after standardization of the data to zero means and unit variances. The first 2 axes (explaining 83.04% of total variation) were retained for further analysis. Then I weighted the axes by their respective eigenvalues so as to consider the different contribution to sampling variation in environmental space. Second, I used a *k*-means cluster analysis to identify homogeneous clusters of cases within the space matrix. To maximize environmental diversity for each cluster, the closest site to each centroid (i.e., the mean of the cluster) was taken as representative of the cluster. The final set of priority areas was the assemblage of the representatives of all the clusters. Similar to the ECA, the *k*-means cluster analysis I used was spatially constrained to consider connectivity among the priority islands and to reduce the effort of spatial autocorrelation. To achieve such a purpose, spatial coordinates were assigned in the environmental space matrix before performing *k*-means cluster analysis. Because a set of 5 clusters was obtained from the ECA, the number of clusters also was set at 5 in the *k*-means analysis. I used the software NCSS/PASS 2000 (http://www.ncss.com/) to perform the analysis.

Results

Species-Area-Habitat Relationship

For each island, avian species richness, the size of the area, the values of environmental variables, and the assigned score of habitat diversity H' were determined (Table 1).

For conventional SAR models, the curvilinear power function ($\log[S] = 0.287\log[A] + 0.811$, $S_e = 11.190$) outperformed the linearized power function: ($S = 4.017A^{0.435}$, $S_e = 9.334$). Comparatively, the curvilinear choros model ($S = 3.488K^{0.392}$, $S_e = 8.355$) gave a better fit than the linearized one ($\log[S] = 0.280\log[K] + 0.738$, $S_e = 9.955$).

For the total avian diversity in the Zhoushan Archipelago, as expressed by the residual values from the curvilinear choros model (Table 1), Mayi had the highest residual value (11.761), followed by Sijiao (11.233), Fodu (10.506), and Liuheng (8.377), whereas Daishan had the lowest value (−16.787). Therefore, Mayi, Sijiao, Fodu, Liuheng, and Zhoushan were considered to possess distinctly higher diversity and were thus regarded as richness hotspots (Fig. 1). Daishan, Xiushan, and Jintang were considered of distinctly low diversity.

ECA

The cophenetic correlation for the dendrogram was 0.858 and indicated that UPGMA was effective in representing interisland similarities (Fig. 2). On the basis of ED scores, the top-ranked areas were Jintang (ED = 0.919), followed by Liuheng (ED = 0.899), Yuanshan (ED = 0.899), and Zhoushan (ED = 0.897). In contrast, the least unique areas were Sijiao and Huanglong, and they had the lowest ED score of 0.845. The top 5 islands ranked according to the ED values were Jintang, Liuheng, Yuanshan, Zhoushan, and Xiushan (or Daishan). Xiushan and Daishan had the same ED score, and therefore their selection was optional. Wilcoxon matched-pairs test indicated no significant difference between the rankings obtained from unconstrained and constrained ECA ($Z = 0.596$, $p = 0.55$). Nevertheless, the cophenetic correlation indicated the clustering algorithm implemented in spatially constrained cluster analysis performed better than that in unconstrained analysis (for unconstrained cluster analysis, the cophenetic correlation was 0.726).

By comparison, a PCA-based environmental diversity approach selected complementary priority islands, including Liuheng, Zhujiajian, Huanglong, Yuanshan (or Mayi), and Zhoushan (or Jintang). The 2 pairs of islands, Yuanshan and Mayi and Zhoushan and Jintang, individually constituted one cluster in terms of k means and had the same distance to the centroid of the respective cluster; therefore, their selection was optional, which would offer some flexibility in decision making. In contrast, the other 3 islands were irreplaceable. Consequently, the combination of these islands could generate 4 equal priority sets in which one set that included Liuheng, Zhujiajian, Huanglong, Yuanshan, and Zhoushan islands shared 60% of the islands selected in the ECA. This supported the rationality and validity of the ED index in area prioritization.

Combined Ranking of Priority Areas

The combined ranking on the basis of the SAHR and ECA highlighted 5 areas for conservation planning (Table 2): Liuheng, Mayi, Zhoushan, Fodu, and Huaniao.

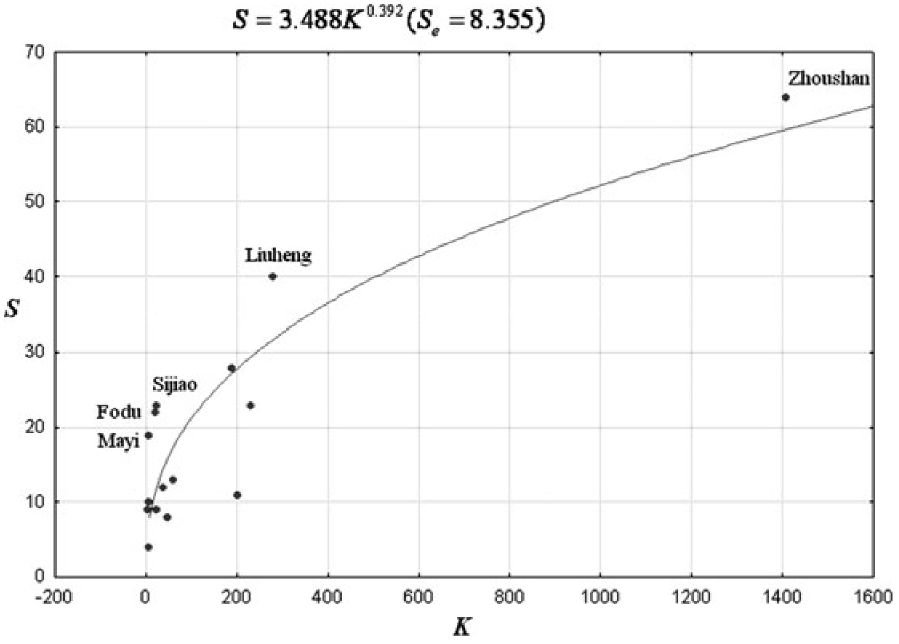

*Figure 1. The curvilinear fit for the species-area-habitat relationship with top hotspot islands indicated (*S*, number of bird species;* K*, choros parameter;* S_e*, standard error of estimate).*

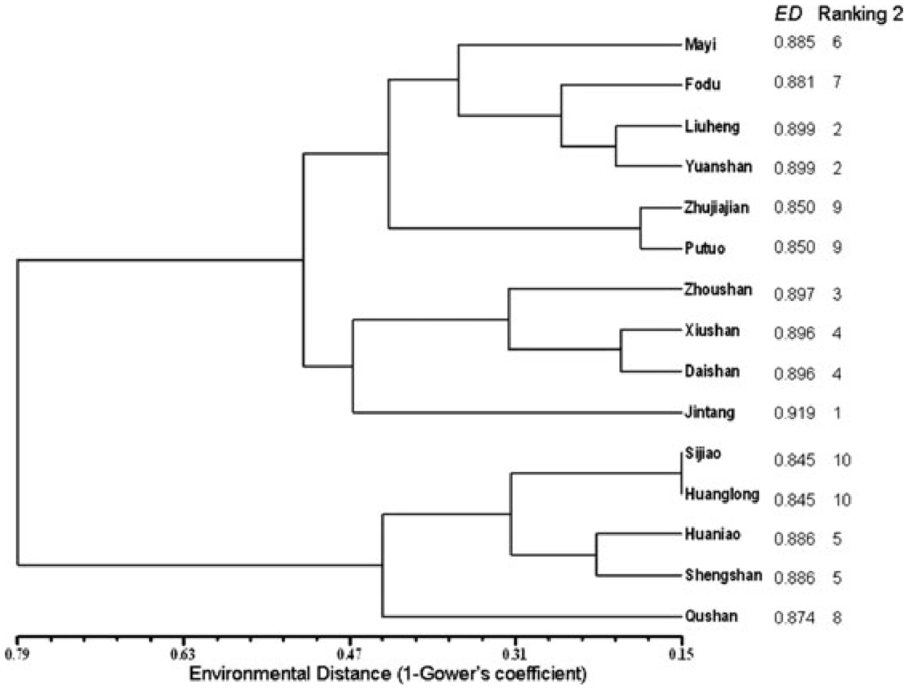

Figure 2. Spatially constrained environmental cluster analysis for the Zhoushan Archipelago. For each island, the environmental-distinctness (ED) index and the associate rank (ranking 2) are also shown. The smaller the ranking number is the higher the ED value and conservation priority the island has.

This combined priority set had 4 islands (Mayi, Fodu, Liuheng, and Zhoushan) in common with that of the SAHR and 3 islands (Liuheng, Zhoushan, and Huaniao) in common with the ECA.

Discussion

Species-Area-Habitat Relationship

My comparative results agreed with Fattorini (2006) on the use of different functions to model the SAR to set conservation strategies. First, the curvilinear power function, not the linearized power function, of both the SAHR and SAR models was the best-fit model to explain species richness and to select hotspots (Roos et al. 2004; Ulrich & Buszko 2005). Second, my results showed that the choros model was likely to have a better fit than the SAR, a result that has also been found in other studies (e.g., Panitsa et al. 2006; Duarte et al. 2008).

A number of recent studies have focused on the utility of SARs for setting biodiversity targets (e.g., Kinzig & Harte 2000; Ulrich 2005; Wilsey et al. 2005). In contrast, I used a SAHR (modeled with the choros model) to set conservation priorities within the Zhoushan Archipelago in China. This method has the advantage that it is able to integrate the influences of habitat diversity and thus may be more effective in identifying priority hotspots for conservation strategies. The use of the choros model was supported by its better fit compared with traditional SARs. In particular, the curvilinear power function of the choros model provided the best fit to empirical data compared with the linearized choros model applied by Triantis et al. (2003, 2005).

The habitat diversity parameter, H', in the choros model represented the vegetation complexity of each island. Thus, H' reflected the biotic characteristics of the islands, whereas the environmental variables used in the ECA reflected the abiotic characteristics of the islands. Because forest coverage is an important factor in avian species richness (Boulinier et al. 1998; Herbers et al. 2004), I used it, in addition to the vegetation types, to evaluate the extent of habitat types on each island and to assign a discrete value to each island in the choros model. One possible problem with this is that the inclusion of H' (or H) might strongly influence SARs. Nevertheless, ranking of the islands on the basis of the choros model was almost the same as ranking on the basis of the traditional SARs (not showed here; Wilcoxon matched-pairs test: $Z = 0.0, p = 1.0$), but the presence of H' (or H) in the choros model offers the possibility of a better conceptual integration with the ECA than the simple SAR does.

ECA

In the ECA I considered spatial autocorrelation so that the priority set of areas would reflect the influence of geographic isolation. Integration of the ED index and the spatially constrained ECA method selected the most environmentally heterogeneous areas for conservation.

Species do not occupy a landscape at random but rather on the basis of the presence of their preferred ecological requirements (Waltari et al. 2007). Areas with idiosyncratic environmental conditions generally contain rare or endemic taxa (Trakhtenbrot & Kadmon 2005). Use of the ED index means the resulting priority set can serve, to some extent, as a surrogate for hotspots of rare or endemic species. Here, I embedded a spatial analysis into the ECA, which has not been done previously (Trakhtenbrot & Kadmon 2005, 2006). The advantage of a spatially constrained ECA is that it diminishes the effect of spatial autocorrelation and takes regional contiguity into account (SAM help file 2007).

The formula of the ED index, for the purpose of selecting areas with the most "rare" landscapes in the ECA, is grounded in the following principles. Areas in which the environmental variables are considerably dissimilar to others are first separated in the dendrogram. These areas are weighted higher than other subsequently divided areas. Therefore, the environmental distance (i.e., 1-Gower's similarity coefficient) is allocated in the formula of the index. Because one would optimally like to select only a few distinct areas, however, the dissimilar coefficient is not enough to distinguish all the areas. Although some groups are separated first in the dendrogram, they contain a large number of areas, not all of which are worthy of conservation. It is more effective to select as conservation targets those areas with unique environmental spaces (Faith & Walker 1996; Faith 2003). Hence, groups with fewer areas at each node are weighted higher than other groups with many areas at a node. Assigning the groups with fewer areas higher weight is actually regarding these groups as "more rare" compared with other groups.

The calculation of the ED index is partially analogous to the phylogenetic diversity indices applied to a species cladogram (e.g., Vane-Wright et al. 1991; Faith 1992; Posadas et al. 2001; Lehman 2006). It differs from traditional environmental diversity approaches (Faith & Walker 1996) in that the latter uses PCA to identify representative areas for maximizing environmental spaces (Faith 2003; Bonn & Gaston 2005) and follows a complementary principle to select priority areas. By contrast, the ED index is designed to use a hierarchical cluster analysis to identify environmental hotspots, which parallel biological hotspots. This point distinguishes the ED-index-based ECA from the PCA-based environmental diversity approach and makes the ECA I used different from that of Trakhtenbrot and Kadmon (2005, 2006), although the basal analytical procedure is almost the same.

One advantage of the PCA-based environmental diversity approach is that it can deal with large amounts of data quickly because the implementation of *k*-means cluster analysis and PCA is very rapid. Nevertheless, compared with PCA-based environmental diversity, the ECA allows a quantitative ranking of areas by the ED index. Ranks assigned to the selected environmental hotspots can be coupled easily with those of the richness hotspots obtained from the SAHR to form a final combined priority set (Posadas et al. 2001; Lehman 2006).

My results demonstrated that spatially constrained ECA can be recommended for use in selecting priority areas because the final priority set is not significantly different from that of unconstrained cluster analysis (as shown by the Wilcoxon matched-pairs test), but the spatially constrained clustering procedure is more realistic (as indicated by the cophenetic correlation).

Owing to limited information on avian species' occurrence in the Zhoushan Archipelago, I could not test the effectiveness of the 2 methodologies applied here in comparison with other data. Thus, it is unclear whether the PCA-based environmental diversity approach or the ED-index-based ECA is a better surrogate to capture biodiversity. Nevertheless, the concordance between results obtained from the ED-index-based ECA and the well-established PCA-based environmental diversity approach (maximally 60% of priority islands were shared by both) stresses the validity of the new approach.

Conservation Framework for the Combination of Two Approaches

I propose an integration of the SAHR with ECA to set conservation priorities. The underlying basis for this procedure is that species diversity is assumed to be driven by surrounding environmental conditions and that species diversity can in turn characterize the surrounding environments (e.g., Brocque & Buckney 2003; Qian et al. 2007; Baselga 2008).

Generally, areas identified as biological hotspots and with high habitat distinctness have high conservation values. These areas presumably have multiple ecogeographical resources that promote a rich biodiversity, which might not be found in areas with more homogenous landscapes (Table 3). Areas not selected as hotspots but that have idiosyncratic habitats may also warrant attention because they may have high levels of endemic or rare species (Trakhtenbrot & Kadmon 2005, 2006) because spatial heterogeneity is the most important predictor of restricted-range species (Jetz & Rahbek 2002; Ceballos

Table 3. Possible interpretations of 4 kinds of areas identified by the combination of species-area-habitat relationship (SAHR) and environmental cluster analysis.*

SAHR *ECA*	*Hotspots*	*Nonhotspots*
Distinct	important: areas might have multiple resources for the survival of various species	less important: areas might contain endemic or rare species
Common	less important: areas might be influenced by widespread species	not important: areas might be heavily influenced by humans

**For SAHR areas are distinguished as hotspots (high species richness) or nonhotspots (low species richness), and for ECA areas are distinguished as distinct or common landscapes.*

& Ehrlich 2006). Areas selected as richness hotspots but with common environmental characteristics are likely to harbor large numbers of common or widespread species (Ceballos & Ehrlich 2006), and this kind of site can be redundant in optimal-area prioritization. Finally, areas that are not hotspots and that have common physical or climatic characteristics (Table 3) are the least important for conservation practice compared with other area types. Commonly, these areas have been fragmented and disturbed by human activities, which can lead to floral and faunal homogenization (Rahel 2000, 2002; Olden et al. 2006) and reduction in taxonomic diversity (Naeem 1998; Warwick & Clarke 1998; Maranon et al. 1999).

The results of my analyses identified 5 islands in the Zhoushan Archipelago as priority candidates for conservation (Table 2). Liuheng and Zhoushan were identified as conservation priorities in both approaches. Mayi and Fodu islands are worthy of being considered because they were identified as richness hotspots. Huaniao Island was characterized as having a distinct environment (lowest maximum temperature and second-lowest precipitation compared with other islands; Table 1) and should be further assessed because it may support rare or endemic species.

Some may think my framework involves too many speculative elements that do not have an empirical basis. Nevertheless, the framework is based on a long-standing assumption: there is a close correlation between species and environmental diversity (e.g., Brocque & Buckney 2003; Qian et al. 2007; Baselga 2008). Previous researchers have tested the richness–environment relationship and used environmental information as a surrogate to select conservation targets (e.g., Levin et al. 2007), and my results represent further development in this field.

Another possible criticism of my study lies in the low effectiveness of hotspot-based approaches in setting conservation targets. Recently, complementarity analysis has been recommended for selection of complementary areas for conservation (e.g., Margules & Pressey 2000; Chen 2007; Chen & Bi 2007). Nevertheless, in the absence of detailed information on species distributions, complementarity analysis is impossible to perform. Hotspots approaches, including the species-richness hotspots and environmental hotspots used here, can facilitate rapid assessment of the status of biodiversity in areas that have not been thoroughly surveyed and help identify relevant conservation activities.

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