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Application of species distribution modelling in butterfly conservation in Taiwan

物種分布模式應用於臺灣蝴蝶保育之研究

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Abstract

Butterflies provide a wide range of ecosystem services. Considering the threat to global biodiversity posed by climate change and habitat fragmentation, the establishment of a comprehensive nature reserve network to ensure the species richness of butterflies is imperative. This study applied species distribution modelling to simulate the distribution of 233 butterfly species in Taiwan and assessed the effectiveness of a nature reserve network for protecting butterfly species. A species distribution model (SDM) was built for each species, and all the SDMs were stacked together to obtain the species richness and distribution of butterfly species. Furthermore, buffer zones were laid around existing nature reserves to compare their richness in species. The results indicated that the SDMs exhibited reliable performance, but when overlaid with existing nature reserves, the mean species richness in nature reserves was significantly lower than that in buffer zones 5–15 km from nature reserves. Therefore, the importance of buffer zones was established, and this study advises the competent authorities in charge of nature reserve management to take the species richness of butterflies into consideration and to improve the conservation of butterflies in buffer zones.

Key words: ecosystem services, biodiversity, nature reserves, species richness, management

摘要

蝴蝶可供應許多生態系服務，然而，全球生物多樣性正面臨氣候變遷及棲地破碎化等威脅，如何營造健全的自然保護區網絡，確保蝴蝶的豐富度乃至關重要之議題。本研究以建構物種分布模式(species distribution model, SDM)為基礎，模擬臺灣233種蝴蝶物種分布，進而評估自然保護區網絡能否發揮庇護蝴蝶之功效。研究過程中，建構每一蝶種的SDM，並堆疊模擬出來的所有物種分布取得物種豐富度資訊，再根據當前法定的自然保護區範圍，建置多重距離的緩衝區，用以比較不同區域的差異性。研究結果發現，所建構的SDM在整體表現上均達可接受之標準，而與保護區套疊的結果，區域內的平均物種豐富度明顯低於外圍5~15 km處的緩衝範圍，因此，緩衝區對蝴蝶而言更具重要性，建議未來有關各保護區的經營管理策略，也應考慮到蝴蝶的多樣性，並加強外圍緩衝區的保育工作。

關鍵詞：生態系服務、生物多樣性、自然保護區、物種豐富度、經營管理

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Introduction

Insects occupy a dominant position in many ecosystems, providing ecosystem services such as pollination, biological control, nutrient cycling, and the propagation of innumerable species (Losey and Vaughan 2006). Among insect taxa, butterflies have been regarded as effective indicators of the health of land-based ecosystems (Thomas 2005; Bonebrake *et al.* 2010; Bergerot *et al.* 2013) because they are more vulnerable to human interference than other taxa (Koh 2007; Gross 2016). Additionally, butterflies possess aesthetic value and some scholars suggest that butterflies may be an ideal medium for humans to reestablish a harmonious connection with Mother Nature (Soga and Gaston, 2016).

The establishment of nature reserves is one of the main strategies for the preservation of biodiversity. Presently, land-based nature reserves worldwide constitute approximately 12% of the global land surface (Seiferling *et al.* 2012) with the primary function of preserving threatened species. An effective method to evaluate the success of a nature reserve is to determine the species richness within it, i.e., the number of different species belonging to a specific taxon (Jenkins *et al.* 2015; Veach *et al.* 2017).

The emergence of species distribution modelling has enabled the accurate estimation of species distribution. Maximum entropy (MaxEnt) is widely recognised as one of the most effective species distribution models (SDMs) (Elith *et al.* 2006; Phillips *et al.* 2006; Kumar and Stohlgren 2009). By stacking the simulated areas of the distribution of numerous species, researchers are able to determine the species richness of a given area (Dubuis *et al.* 2011; Mateo *et al.* 2012; Cord *et al.* 2014). This SDM-based estimation method has been applied to assess the effectiveness of nature reserves in protecting specific animal or plant species, or species belonging to a specific taxon (Kaky and Gilbert 2016; Hughes 2017; Zhang *et al.* 2017; da Silva *et al.* 2018).

Taiwan is an island situated at the junction of the tropical and subtropical zones to the southeast of China. The mountainous terrain of the island creates sharp rises and falls in its topology, resulting in dramatic changes in the horizontal and vertical climate. Tropical, subtropical, temperate, cold temperate and alpine tundra climates can all be found on the island, resulting in remarkably high biodiversity. Furthermore, the high diversity of the local flora, a quarter of which are endemic species, contributes greatly to the diversity of butterflies. As a result, Taiwan is home to 400 butterfly species, approximately 18% of which are endemic. This level of species richness is rarely found elsewhere in the world (Hsu *et al*. 1997; Chu 2005).

Butterflies, like species worldwide, are threatened by climate change and habitat fragmentation (Forister *et al*. 2010; Oliver *et al*. 2015). In view of butterflies' importance to nature and humans, the establishment of comprehensive conservation strategies is essential. In this study, we investigate the relationship between butterfly species richness and nature reserves in Taiwan. Specifically, butterfly species survey data were used to construct SDMs, revealing the species richness of butterflies in terms of spatial distribution. The information was subsequently overlaid with maps representing established nature reserves to determine how species richness differed inside and outside of those reserves. We hope to promote butterfly conservation in Taiwan through the results obtained from this study.

Materials and methods

Study Area

Taiwan is an island in the northwest Pacific Ocean, to the east of continental Asia. To its west, it is separated from China by the Taiwan Strait, and to its south, it is separated from the Philippines by the Bashi Channel (Fig. 1a). Taiwan is approximately 36,000 km^2 in size, and the island features numerous high mountains and short and fast-flowing rivers. The east side of the island is predominately composed of mountains and hills and most of the plains and level grounds that are suitable for urban development are on the west side. The highest peak, Yu Shan (aka Mount Jade), has an elevation of 3,952 m. Most of the rivers on the island originate from the Central Mountain Range and flow into the western plains. According to Taiwan's Central Weather Bureau, from 1987 to 2008, the island received an average of 2300 mm of rainfall per year and had an average temperature of 23.5°C. The Tropic of Cancer divides the island into two general climate zones, namely the tropical monsoon climate zone to the south, and the subtropical monsoon climate zone to the north (Central Weather Bureau 2009). The dominant type of land cover in Taiwan is forests, which

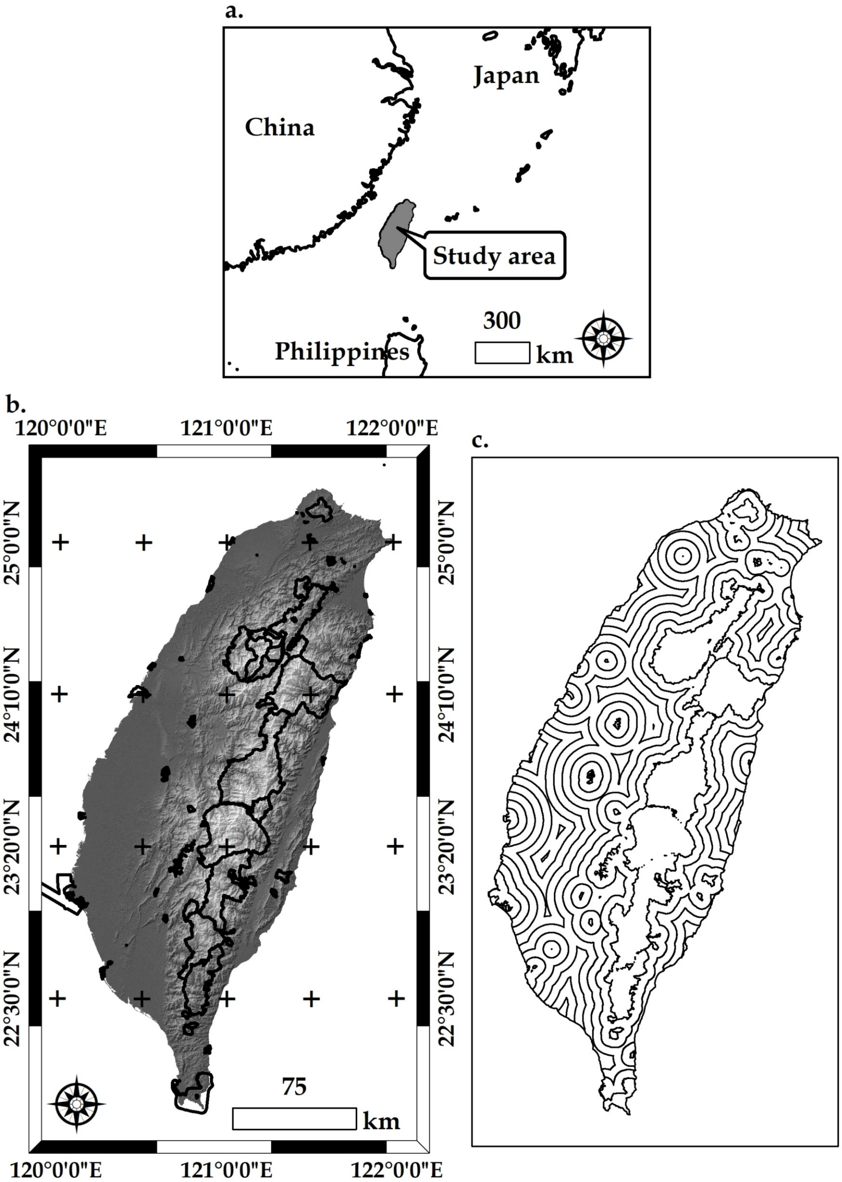

Fig. 1. Maps of Taiwan. (a) Location of the island; (b) Boundaries and altitudes (digital elevation model) of the nature reserves; (c) Buffer zones (5 km intervals from the perimeter of nature reserves).

圖**1**. 研究區，(a) 地理位置；(b) 保護區範圍與數值高程模型(海拔高)；(c) 從保護區邊界逐步向外建置5 km為間距之緩衝範圍。

constitute nearly 61% of the island's land surface (Forestry Bureau 2014). A total of 95 nature reserves have been established following the relevant environmental laws and regulations in place to protect the island's rich biodiversity. These nature reserves occupy 6,945 km^2 of land, accounting for approximately 19% of the island's total land area (Fig. 1b).

Species data

The estimated distribution of butterfly species was calculated using yearly county-based butterfly resource surveys conducted by our research team along with the species habitat data available on the cross-agency species inquiry platform sponsored by the Forestry Bureau. Surveys conducted between 1993 and 2017 were included and the original data they provided were derived from the geographic coordinate system. For the purpose of this study, all numbers were rounded off to the third digit after the decimal point and all data were converted to Taiwan Datum 97 and 2-degree transverse Mercator coordinate system (TWD97/TM2), which was also applied for the environmental data subsequently collected. The unit area of a grid was set to 1 km^2 and multiple recordings of the same species within a grid unit were considered as a single observation. Species that were recorded less than 10 times were deemed unsuitable for species distribution modelling and were excluded from our analysis (Wisz *et al*. 2008). A total of 42,646 sets of data were included in the final analysis, covering 5 families, 120 genera, and 233 species (Table 1).

Table 1. Butterfly species in Taiwan included in the species distribution calculations

表**1**．本研究選用之物種科名，以及屬與種之數量

Family	Number of genus	Number of species
Lycaenidae	30	41
Hesperiidae	21	35
Pieridae	12	28
Nymphalidae	49	102
Papilionidae	8	27
Total	120	233

Environmental data

Environmental predictors refer to the critical factors that affect species distribution. We collected data on climate, topology and land-use to include as environmental predictors for the construction of SDMs. Climate data were downloaded from the WorldClim database built by Hijmans *et al*. (2005). WorldClim contains climate data collected from stations around the world between 1950 and 2000 and the data have been converted into climate grids with a spatial resolution of approximately 1 km^2 through interpolation. The bioclimatic data in WorldClim are compiled specifically for the purpose of predicting species distribution.

This study adopted the 19 bioclimatic variables available in WorldClim. The topological data used in this study were also derived from the WorldClim database. A digital elevation (altitude) model was downloaded for the generation of slope maps using the ArcGIS 10.6 software package. We followed methods from Gessler *et al*. (1995) and McCune and Keon (2002) with the Geomorphometry and Gradient Metrics toolbox (version 2.0, Evans *et al*. 2014) to generate compound topographic indices (representing humidity) and heat load indices (representing solar radiation intensity). Land-use data were retrieved from the surveys conducted by the National Land Surveying and Mapping Centre between 2006 and 2008 (National Land Surveying and Mapping Centre 2012). The coverage ratios of the nine land-use types in the land-use classification Level 1 (agriculture, forestry, transportation, water resource, construction, public use, recreation, mining, and other) were calculated using 1 km^2 grids. Overall, 32 predictors were adopted as variables.

To prevent the over-fitting of variables caused by collinearity, a Pearson correlation analysis was performed to eliminate undesirable variables. Specifically, when the correlation coefficient between two variables was > 0.7, the researchers followed the practice of existing studies (Kumar and Stohlgren 2009; Padalia *et al*. 2014) and excluded one of the variables according to considerations regarding research purpose, relevance to target species and ease of explanation. Thus, the correlation coefficient was <0.7 between any two variables of the 17 that were retained.

Species distribution modelling

MaxEnt 3.3.3k software was used to construct SDMs (Phillips *et al*. 2006). First, we established a training set for the model using the data from 75% of the species, which were selected randomly. Each species was computed 10 times, after which the mean value was used to determine the species' logistic distribution. The value range of a prediction is 0–1; the closer it is to 1, the higher the probability of the species appearing in the grid. Subsequently, the MaxEnt threshold calculation method of 10th percentile training presence was applied to determine each species' potential distribution and to convert it into a binary image (Kramer-Schadt *et al*. 2013; Radosavljevic and Anderson 2014). The remaining 25% of the species were used to assess the model validity according to the area under the receiver operating characteristics curve (AUC). The AUC ranged from 0.5–1, with a higher value denoting greater prediction accuracy. An AUC value ≥ 0.7 represents reliable prediction accuracy (Fielding and Bell 1997; Pearce and Ferrier 2000).

To determine the spatial relationship between butterfly distribution and nature reserves in Taiwan, the potential distribution maps of each species were stacked to create a species richness map, which was then laid on a map representing the perimeter of each nature reserve to gain a preliminary understanding of the species' distribution. Next, the island's topology was divided into six elevation ranges by 500 m contour intervals to determine the mean species richness in each elevation range. Introducing this altitude information was conducive for recognising the patterns of butterflies' spatial distribution. Additionally, seven layers of buffer zones were established around the perimeter of each nature reserve (Fig. 1b) at 5 km intervals, reaching 35 km in depth (Fig. 1c). An analysis of variance was performed to assess the difference in species richness between the layers of the buffer zone, and the results were verified with a Scheffé multiple comparison test to determine whether there were significant differences between the layers ($P < 0.05$). Throughout this study, spatial and statistical analyses were performed using the Arc GIS 10.6 and IBM SPSS 20.0 software programs, respectively.

Results

The 32 initial variables were reduced to 17 after applying the standard of Pearson's correlation coefficient < 0.7; resulting in six climate-related predictors, three topology-related predictors and eight land-use-related predictors. SDMs were established accordingly using MaxEnt, and the training results revealed that the AUCs of the butterfly species in the validation set were 0.72–0.98, with a mean of 0.83 and standard deviation of < 0.18, indicating reliable simulation results. Furthermore, calculations based on the number of records revealed that the mean AUC of species with a low number of records was approximately 0.84, and this value decreased with higher record numbers. Even so, the AUCs of species with a high number of records were all ≥0.79, indicating no significant differences (Fig. 2).

The binary potential distributions of

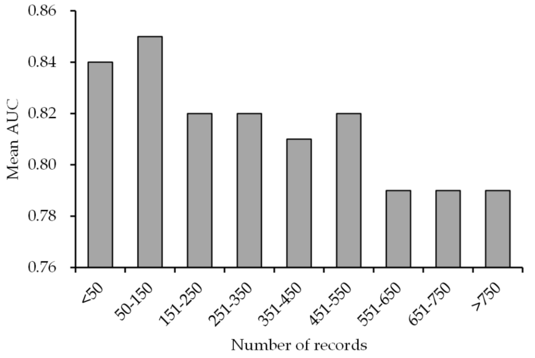

Fig. 2. Relationship between the number of species records and mean AUC in the SDMs of butterfly species in Taiwan.

圖**2**. 蝴蝶分布模擬下，物種樣點數與平均AUC值之關聯性。

butterfly species were stacked to generate a species richness map. The values were subsequently divided into high, medium and low species richness levels. Calculation of the respective areas of each level on the map revealed that the areas with a high level of species richness covered 5,200 km^2 (approximately 14%) of the island's total land area. These areas were distributed primarily on the eastern and western sides of the island, forming conspicuous belts. On the western side of the island, they congregated in the central region, with extensions stretching north and south. On the eastern side of the island, they congregated along the Coastal Mountain Range (the Hai'an Range) spanning the Hualien and Taitung Counties. When the areas exhibiting a medium level of species richness were also included, the total area reached 14,000 km^2 or 39% of the island's total land area, and the distribution expanded to low altitude regions. By contrast, most of the areas with a low level of species richness were either in high altitude regions in the centre of the island, or in the plains along the western coast (Fig. 3).

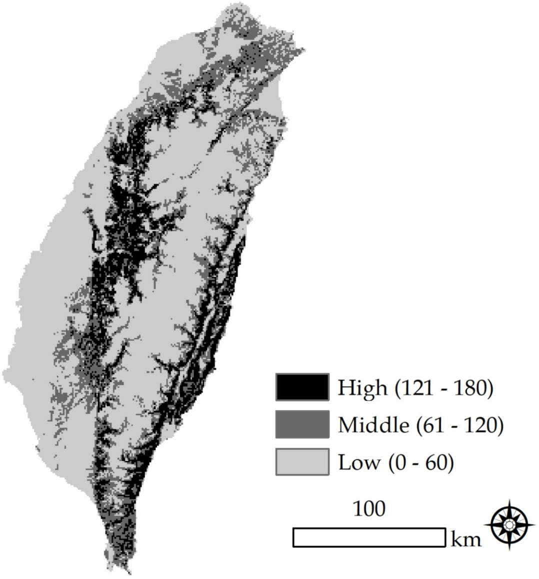

Fig. 3. Species richness of butterflies in Taiwan.

圖**3**. 臺灣蝴蝶的物種豐富度分布圖。

In terms of altitude, the highest species richness levels (mean value = 96) occurred at 501–1000 m, which was considered mid to low altitude. The second and third highest richness levels were identified at 1,001–1,500 m and < 500 m, which were 62 and 58, respectively; these two ranges did not exhibit a significant difference. None of the three ranges above 1,500 m had a value exceeding 32, suggesting that they had relatively simple species compositions (Fig. 4).

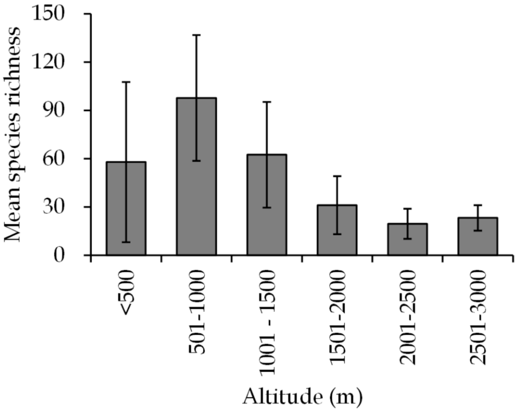

Fig. 4. Mean species richness of butterflies in different altitude ranges in Taiwan.

圖**4**. 不同海拔範圍之平均物種豐富度。

We compared the spatial distribution of butterflies in the areas designated as nature reserves and buffer zones. The mean species richness within nature reserves was 37, and this value progressively increased by zone, starting from the first 5 km outside the perimeter of nature reserves and culminating at the 5–15 km distance zone (mean species richness = 64–72). The species richness started to decrease at the 20 km zone, and continued decreasing to the 35 km limit (Fig. 5). The analysis of variance results indicated that species richness was highest at 5 km, 10 km and 15 km from the nature reserve boundaries, with comparable mean values (i.e., a non-significant difference). Conversely, those zones had significantly higher species richness compared to the reserve area (0 km) and the zones 20 km or further from the reserve. These results indicate that the areas with the highest species richness were not included within the existing nature reserves (Table 2).

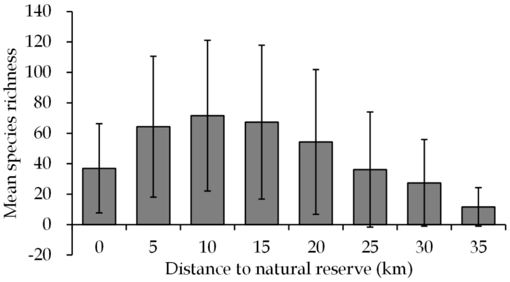

Fig. 5. Mean species richness of butterflies in nature reserves and buffer zones in Taiwan.

圖**5**. 保護區與不同緩衝範圍之平均物種豐富度。

Table 2. Analysis of variance results in butterfly species richness between nature reserves and buffer zones in Taiwan

表**2**. 物種豐富度在不同緩衝範圍之變異數分析結果

	0 (A)	5 (B)	10 (C)	15 (D)	20 (E)	25 (F)	30 (G)	35 (H)
0 (A)	-	B > A*	C > A*	D > A*	E > A*	A > F	A > G*	A > H*
5 (B)		-	C > B	D > B	B > E*	B > F*	B > G*	B > H*
10 (C)			-	C > D	C > E*	C > F*	C > G*	C > H*
15 (D)				-	D > E*	D > F*	D > G*	D > H*
20 (E)					-	E > F*	E > G*	E > H*
25 (F)						-	F > G*	F > H*
30 (G)							-	G > H*
35 (H)								-

*=significant according to Scheffé's test at $P < 0.05$.

Numbers are the distance (km) from the boundary of natural reserve.

Discussion

AUC often serves as an indicator for the accuracy of MaxEnt-based SDMs. However, some researchers have voiced doubts regarding the validity of AUC as an indicator (Jiménez-Valverde *et al*. 2008; Lobo *et al*. 2008). According to these studies, AUC can easily be affected by a species' number of records; more specifically, a species with a low number of records tends to yield a large AUC, whereas a species with a high number of records tends to result in a relatively small AUC. In our study, 233 butterfly species were investigated and the model performed acceptably in terms of mean AUCs. Although the situation addressed by the aforementioned studies did occur, the mean AUCs of species with a high number of records were all close to 0.8 and there was no significant difference when compared to the AUCs of species with a low number of records (Fig. 2). Therefore, the MaxEnt-based SDMs in this study were not strongly affected by the number of records. This is consistent with similar studies that suggest that a large sample size can be used to build reliable SDMs (Kadmon *et al*. 2003;

Hernandez *et al*. 2006; Kaky and Gilbert 2016).

Previous researchers have studied birds as an indicator for environmental monitoring (Gregory and van Strien 2010; Herrando *et al*. 2012). However, contemporary researchers have maintained that butterflies have equal potential to reflect the biodiversity and health of an environment. Butterflies are relatively easy for humans to spot compared to other insect species, so they can serve as a representative taxon in insect surveys (Thomas 2005). Moreover, because of the close coevolution between butterflies and plants (Edger *et al*. 2015), a reduction in the population or diversity of butterflies can result in, or be indicative of, the decline of undomesticated plants (Gillespie and Wratten 2012). Numerous member states of the European Union have initiated studies on the feasibility of using butterflies as indicators in urban environment surveillance (Roy *et al*. 2015; Dennis *et al*. 2017; Mills *et al*. 2017; Ramírez-Restrepo and MacGregor-Fors 2017).

The results of our study indicate that, in Taiwan, both the eastern and western sides of the island harbour hot spots with high butterfly species richness (Fig. 3), most of which are distributed in mid to low altitudes (Fig. 4). Accordingly, the habitats of most butterfly species overlap with cities or other human activity, making butterflies a suitable biodiversity indicator for environmental surveillance. If social resources in communities with high butterfly species richness areas can be mobilised for the systematic establishment of long-term observation stations, a solid understanding of the real-time status of ecosystems in these areas and their peripheries can be obtained.

The spatial analysis results of this study revealed that the areas with the highest butterfly species richness in Taiwan have not been included in the existing nature reserves (Fig. 5, Table 2). This implies that most butterfly species have not received adequate protection. The same problem has been reported in the rest of Asia and in Europe (Klorvuttimontara *et al*. 2011; Zografou *et al*. 2014; Cheng and Bonebrake 2017), suggesting that countries worldwide may have to reevaluate their butterfly conservation strategies.

We advise the competent authorities in charge of nature reserve management to take the diversity of butterfly species into consideration, particularly in the addition or amendment of regulations. Notably, this study demonstrated that buffer zones surrounding nature reserves were hot spots of high butterfly species richness. Similar observations have been reported in other countries. For example, Zografou *et al.* (2014) investigated butterfly species in the Dadia National Park in Greece and found that the buffer zone is of greater conservation importance for butterflies than the core areas. In the case of Taiwan, the high population density exerts a considerable human interference on the buffer zones around nature reserves. As numerous studies have reported, interference on the boundary of a nature reserve can adversely affect the ecological function and biodiversity of the nature reserve's core area (Hansen and DeFries 2007; Balme *et al*. 2010; Laurance *et al*. 2012). Therefore, buffer zones should not be regarded as mere transition areas. Instead, they should be regarded as an integral part of a nature reserve and conservation practices should take the management of buffer zones into account. These practices will aid in maintaining the biodiversity within the nature reserve, allowing the ecosystems within to continue to function normally.

Conclusions

This study used butterfly survey data to establish SDMs, which were overlaid with maps of nature reserves to assess the current status of butterfly conservation. The results led to the following conclusions: (1) the SDMs that we constructed were effective in predicting the spatial distribution of butterfly species, which was useful in providing the species richness of various butterfly species; (2) the habitats of most butterfly species fall in mid to low altitudes, indicating that the species richness of butterflies is an ideal biodiversity indicator for the surveillance of urban environments; and (3) buffer zones 5–15 km from the perimeter of nature reserves are hot spots for high butterfly species richness. Accordingly, this study advises those in charge of nature reserve management to take the diversity of butterfly species into consideration and to improve the conservation of such species in buffer zones.

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