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Macrohabitat Characteristics and Distribution Hotspots of Endemic Bird Species in Taiwan

Chia-Ying Ko[1*], Ruey-Shing Lin[2] and Pei-Fen Lee[1]

1. Institute of Ecology and Evolutionary Biology, National Taiwan University, 1, Roosevelt Rd., Sec. 4, Taipei 106, Taiwan; equal contribution.
2. Endemic Species Research Institute, 1, Ming-Shen E. Road, Jiji, Nantou 552, Taiwan.
** Corresponding author. Tel: 866-2-3366246; Fax: 886-2-23623501; Email: f93b44001@ntu.edu.tw*

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ABSTRACT: Understanding species distributions is essential for developing biodiversity conservation strategies. We combined two bird inventories conducted from 1993 to 2004 and identified specific features of 17 endemic bird species in Taiwan. We used eight environmental variables, including elevation, annual total precipitation, annual mean temperature, warmth index, percentage of forest cover, mean Normalized Difference Vegetation Index (NDVI), percentage of building area, and road density, to define macrohabitat characteristics of each species. All the data were in a 1 × 1 km gird system. The 17 species were classified as common (being present in more than 200 grids), uncommon (100–200 grids) or rare (less than 100 grids). The Mikado Pheasant (*Syrmaticus mikado*), as a rare species, had the lowest occurrence records, while the Taiwan Barbet (*Megalaima nuchalis*), as a common species, had the highest. Each species had a specific distribution range and habitat preference. These 17 species occupied heterogeneous elevation and climatic conditions. In general, they favored habitats with high vegetation cover, at almost full forest cover and median to high NDVI. Canonical correspondence analysis (CCA) indicated that elevation had the highest correlations with species distributions, with axis 1 accounting for 57.5% of the variation and axis 2 for 9.8%. The endemic species in Taiwan could be classified into three groups mainly separated by elevation based on the CCA. Potential biodiversity hotspots, in the elevation range of 300 and 1500 m with 45%-100% forest cover, included 33.2% areas of Taiwan. Only 35% of actual hotspots (grid with the number of endemic species ≧7) were located in the potential hotspots. Most of the actual hotspots (65%) occur at higher elevation than the potential hotspots. These data demonstrated the distribution patterns of the endemic bird species in Taiwan, and topography and vegetation are the most important macrohabitat factors associated with these species.

KEY WORDS: biodiversity inventory, macrohabitat, canonical correspondence analysis, endemic bird species, biodiversity hotspot.

INTRODUCTION

Understanding the relationship between a species and its environment provides the foundations for biodiversity conservation. This information provides the basis for early stage conservation programs and can help in the development of possible solutions to specific conservation issues (Goldsmith, 1991; Thomas, 1996; Watson, 2005). Many studies have indicated that qualities of habitats are critical factors affecting the abundance and distribution of species (Harrison and Quinn, 1989; Kindvall, 1996; Franken and Hik, 2004; Armstrong, 2005; Schooley and Branch, 2007). High-quality habitats can not only provide a species with a stable living space in which to maintain its population, but also enable a declining species to recover. In contrast, an unsuitable habitat compromises the survival of a species. By understanding environmental features affecting species distribution, we can determine the preference of a species for a particular habitat, and how it uses that habitat. We could then apply this knowledge to design adequate conservation strategies.

Endemic species are often found in isolated geographical units, such as islands or isolated eco-regions (Gaston, 1994). Because of their limited geographic ranges, endemic species often require specific environments for maintaining healthy populations (Lamoreux et al., 2006; Malcolm et al., 2006). Thus, the identification and conservation of specific habitats are critical issues for conserving endemic species.

Taiwan is located at the junction of the tropical and sub-tropical zones, and thus has diverse ecological environments. Among 560 bird species recorded in Taiwan, 15 are endemic, according to the 6th edition of Clements Checklist of the Birds of the World (Clements et al., 2007). Recent studies by Li et al., (2006) and Feinstein et al. (2008) indicated that two additional species, the Taiwan Barbet (*Megalaima nuchalis*) and Taiwan Hwamei (*Harrulax taewanus*), should be included as endemic. Overall, the number of endemic bird species in Taiwan is one of the highest (*i.e.* a hotspot) in the greater China region (Lei et al., 2003).

This study analyzed distribution patterns of the 17 Taiwanese endemic bird species using data from bird surveys in the recent two decades. We investigated macrohabitat characteristics and evaluated relationship between species distributions and environmental variables by canonical correspondence analysis (CCA). We then mapped the potential biodiversity hotspots of these Taiwanese endemic bird species based on the results of the CCA and compared the map of species' actual occurrence areas. The aims of the study were (1) to point out specific and numeric ranges of the distributions of the endemic bird species, and (2) to range potential biodiversity hotspots of the endemic bird species by macrohabitat factors.

MATERIALS AND METHODS

Species data

We compiled bird distribution data from two bird inventory projects conducted from 1993 to 2004 (Hsu et al., 2004; Koh et al., 2006). The data in Koh et al. (2006) were based on transect sampling, while that of Hsu et al. (2004) used road sampling. The transect sampling technique involved a 1500-m-long transect of avian fauna survey with 10 sampling sites 150 m apart. Each sampling site was observed for a 6-minute period. The road sampling technique was to select a fixed route of investigation covering a distance of 3 km at a walking speed of 1.5 km/hour, without stopping at any specific sites. The sampling sites of the transect sampling technique were selected to best represent habitat characteristics of a particular elevation, forest type and eco-region. Since many breeding birds in Taiwan dwell in forests, whenever possible, the forested areas were chosen to obtain potential occurrence records of all species. Each site was sampled, with sufficient duration (Shiu and Lee, 2003), once a year during the breeding season or seasonally during the survey period. Whether the transect or the road sampling technique, both species sighting and hearing records were taken and geographic coordinates of individual record/sampling site were simultaneously recorded. Each record was regarded as a point of a given species. All points/sampled sites were transformed to a 1 × 1 km grid system (Table 1). We ignored the number of points of a species in a grid and defined a grid with at least one point of a given species as a species-present grid for that species. A grid being sampled and having no points of a given species was regarded as a species-absent grid for that species. All sampled sites and fixed routes with surveys more than twice were included to ensure that absence data of species were credible. In total, 4,082 grids had been sampled and had either the complete presence or absence of bird data (Fig. 1).

Statistical analysis

To identify macrohabitat factors associated with species distributions, we focused on eight environmental macro-variables that were also in 1 × 1 km grid system. These variables were separated into four categories: topography, climate, vegetation, and human disturbance. Elevation is the only topographical variable and was derived from digital elevation model with a 40-m resolution. Annual total precipitation, annual mean temperature and warmth index are the climatic variables. The former two were calculated from meteorological monitoring records taken from 1959 to 1985 by the Central Weather Bureau of Taiwan. The warmth index was calculated from the accumulated mean monthly temperature above 5°C in response to plant growth conditions (Liu and Su, 1992). Vegetation variables, including percentage of forest cover and mean Normalized Difference Vegetation Index (NDVI), were generated from a SPOT mosaic image taken in 2002. NDVI, which has been used as a vegetation index for primary productivity and biomass in terrestrial ecosystems, and is highly correlated with green-leaf area and absorbed photosynthetically active radiation (PAR; Tucker, 1979; Box et al., 1989). The percentage of building area and road density were used to represent the level of human disturbance that were published by the Ministry of the Interior, Taipei, Taiwan, in 2000.

We used the CCA to evaluate the relationship between distribution of a species, *i.e.* presence and absence information, and the eight environmental variables we derived. The CCA is a multivariate method that has been used for comparing the relationships between bird species and their environments (ter Braak and Verdonschot, 1995). The CCA diagram optimally displays how bird assemblage varies with environmental conditions by simultaneously combining species and environmental variables into a two-dimensional illustration. In this study, we used information from the 4,082 grids with species presence and absence data in the CCA analysis. Furthermore, we mapped potential biodiversity hotspots of the endemic bird species in the whole Taiwan using important macrohabitat factors chosen by the CCA. All statistical analyses were conducted using SYSTAT 12, except for the CCA, for which the PC-ORD 5.0 software package was used.

RESULTS

A total of 21,264 points were collected for the 17 endemic bird species in Taiwan (Table 1). The number of the points of individual species ranged from 75 to 5,717. After transferring the points into the 1 × 1 km grid system, the number of species-present grids for a

Table 1. List of 17 endemic bird species in Taiwan. These species are categorized as common (being present in more than 200 grids), uncommon (100–200 grids) or rare (less than 100 grids), based on their sighting and hearing records. Each sighting/hearing record of a species is regarded as a point of which geographic coordinates are taken and transferred to a 1×1 km grid system. A grid with at least one point of a given species is defined as a species-present grid for that species.

English Name[1]	Scientific Name	Category	Number of sighting and hearing points	Number of species-present grids
Corvidae				
Formosan Magpie	*Urocissa caerulea*	Uncommon	374	156
Megalaimidae				
Taiwan Barbet	*Megalaima nuchalis*	Common	5717	1657
Megaluridae				
Taiwan Bush-Warbler	*Bradypterus alishanensis*	Uncommon	259	135
Muscicapidae				
Collared Bush-Robin	*Tarsiger johnstoniae*	Common	517	202
Paridae				
Yellow Tit	*Macholophus holsti*	Uncommon	240	151
Phasianidae				
Taiwan Partridge	*Arborophila crudigularis*	Common	767	408
Mikado Pheasant	*Syrmaticus mikado*	Rare	75	30
Swinhoe's Pheasant	*Lophura swinhoii*	Rare	156	95
Pycnonotidae				
Styan's Bulbul	*Pycnonotus taivanus*	Common	2323	414
Regulidae				
Flamecrest	*Regulus goodfellowi*	Uncommon	305	112
Timaliidae				
Taiwan Hwamei	*Garrulax taewanus*	Common	1088	482
White-whiskered Laughingthrush	*Garrulax morrisonianus*	Common	665	207
White-eared Sibia	*Heterophasia auricularis*	Common	2500	779
Steere's Liocichla	*Liocichla steerii*	Common	2510	673
Taiwan Yuhina	*Yuhina brunneiceps*	Common	2651	772
Taiwan Barwing	*Actinodura morrisoniana*	Uncommon	195	102
Turdidae				
Formosan Whistling-Thrush	*Myophonus insularis*	Common	922	481

[1]Nomenclature follows Clements Checklist of the Birds of the World (Clements et al., 2007).

given species ranged from 30 to 1,657. The 17 species were classified as common, uncommon or rare, based on their sighting and hearing records. Ten species were classified as common with present records of >200 grids. Five species were uncommon with sighting records of 100–200 grids, and two were rare with <100 grids (Table 1). The Mikado Pheasant had the lowest occurrence, consistent with its current conservation status being categorized as rare and endangered in Taiwan, and was listed in IUCN Red List Category in 2009 as a near-threatened species. The Taiwan Barbet had the highest occurrence.

Each endemic species generally exhibited a specific distribution pattern, especially in terms of topographical and climatic variables (Table 2). In comparison of mean values of each species and the whole Taiwan, all species favored habitats with high coverage of vegetation (*i.e.* higher mean values of percentage of forest cover and NDVI than those of the whole Taiwan) and low human disturbance, except for the Styan's Bulbul, who distributed in areas with high road density. The details of distributions for each species were as follows.

Common species

The Taiwan Partridge (*Arborophila crudigularis*) was found in broad-leaved forests of mountains in central Taiwan. These areas were in temperate temperature with moderate annual precipitation (Table 2). Most records were found in areas with high percentage of forest cover and NDVI values as well as with almost no buildings and low road density.

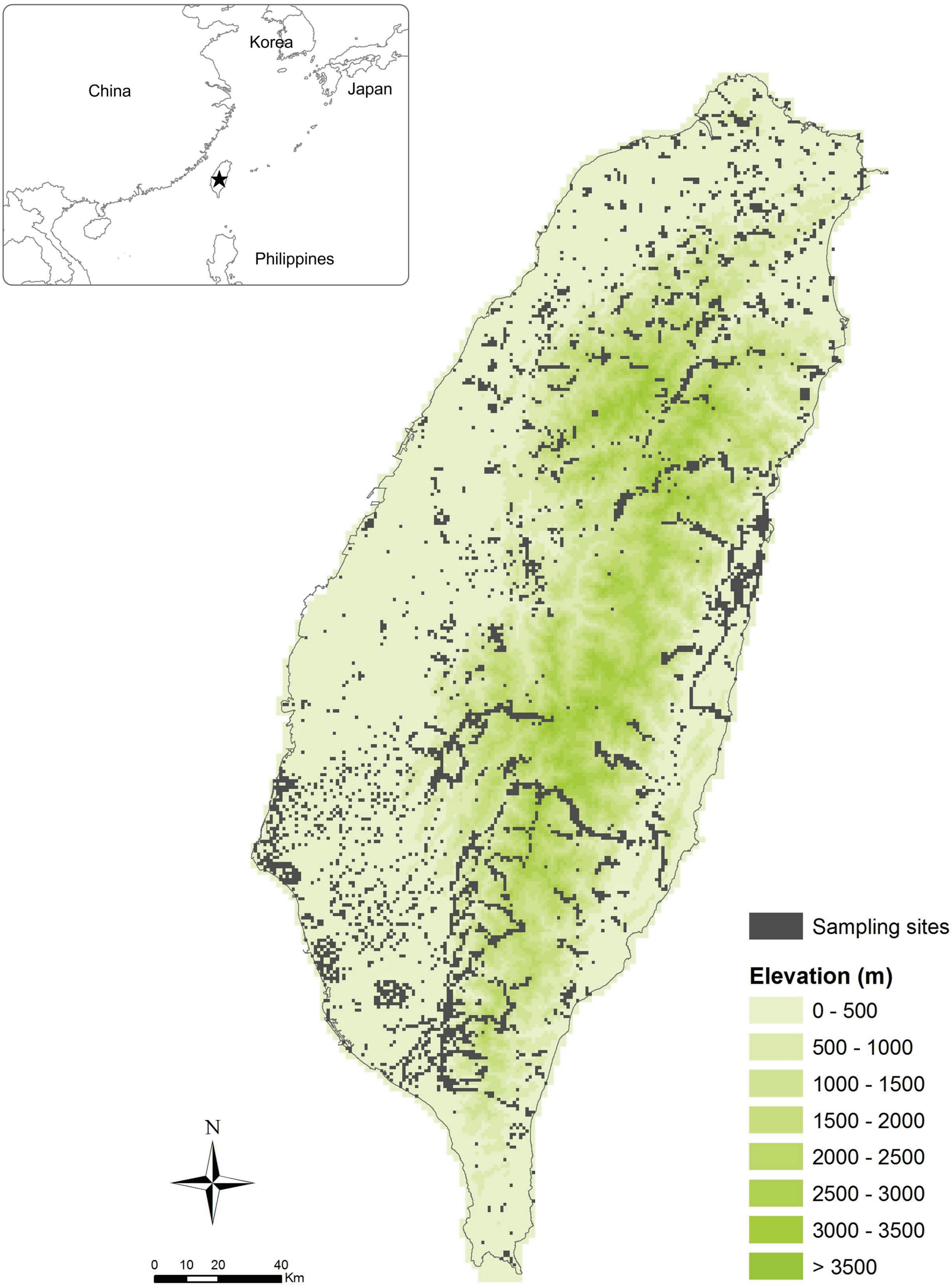

Fig. 1. Location of Taiwan and species occurrence records by grid representation. There are totally 4,082 grids being used in this study.

Table 2. Macrohabitat characteristics of 17 Taiwanese endemic bird species and general habitat characteristics of the whole Taiwan. The warmth index is calculated from the accumulated mean monthly temperature above 5°C.

Species	Elevation (m)	Annual total precipitation (mm)	Annual mean temperature (°C)	Warmth index (°C)	Forest cover (%)	NDVI[1]	Building area (%)	Road density (m/ha)
Common species								
Taiwan Partridge								
Mean	1162	2758	17.2	145	93.1	0.43	0.2	8.8
Median	1125	2765	17.2	146	97.9	0.44	0.0	0.0
Min.-Max.	18-2630	1670-4950	9.5-23.8	54-226	4.9-100.0	0.00-0.64	0.0-20.9	0.0-71.7
IQR[2]	933	696	4.7	56	7.2	0.13	0.0	14.5
Taiwan Barbet								
Mean	564	2546	20.1	182	83.9	0.36	1.1	17.4
Median	415	2536	20.8	190	91.8	0.36	0.0	12.0
Min.-Max.	2-2956	1304-5400	8.8-24.8	50-238	0.0-100.0	0.00-0.64	0.0-82.2	0.0-220.5
IQR	629	826	3.3	40	20.6	0.13	0.4	24.8
Taiwan Hwamei								
Mean	373	2386	21.4	197	77.9	0.31	1.3	18.7
Median	276	2374	21.8	202	88.2	0.31	0.1	12.7
Min.-Max.	2-2735	1204-4425	8.8-24.8	50-238	1.1-100.0	0.00-0.57	0.0-64.1	0.0-241.7
IQR	420	767	2.2	26	29.0	0.13	0.6	27.3
White-whiskered Laughingthrush								
Mean	2363	3113	11.8	82	94.0	0.43	0.1	4.9
Median	2338	3173	11.5	78	98.3	0.44	0.0	0.0
Min.-Max.	100-3707	1674-4261	6.5-22.7	30-212	4.9-100.0	0.15-0.62	0.0-6.3	0.0-67.0
IQR	706	725	2.5	32	6.0	0.10	0.0	7.9
White-eared Sibia								
Mean	1400	2763	16.1	133	92.8	0.43	0.3	8.4
Median	1425	2736	16.0	132	97.7	0.44	0.0	0.0
Min.-Max.	7-3358	1674-4950	6.7-24.2	32-230	4.9-100.0	0.00-0.62	0.0-42.7	0.0-163.8
IQR	969	799	4.5	54	7.9	0.12	0.0	13.9
Steere's Liocichla								
Mean	1624	2816	15.0	120	94.0	0.44	0.1	7.8
Median	1639	2599.00	14.2	110	97.9	0.43	0.0	3.7
Min.-Max.	98-3155	1674-4950	9.0-23.8	52-226	4.9-100.0	0.11-0.62	0.0-20.9	0.0-71.7
IQR	799	758	4.2	50	7.0	0.11	0.0	13.9
Taiwan Yuhina								
Mean	1545	2774	15.4	124	93.5	0.44	0.2	8.2
Median	1587	2735	15.1	122	98.1	0.44	0.0	0.0
Min.-Max.	7-3358	1612-4950	6.7-23.8	32-226	7.0-100.0	0.06-0.62	0.0-42.7	0.0-163.8
IQR	893	804	4.3	52	7.4	0.12	0.0	13.7
Styan's Bulbul								
Mean	282	2168	21.8	201	74.3	0.37	1.6	28.6
Median	169	2135	22.2	206	82.6	0.39	0.1	20.6
Min.-Max.	3-2321	1279-3761	11.0-24.8	74-238	4.5-100.0	0.00-0.64	0.0-42.8	0.0-153.1
IQR	259	338	1.5	18	34.1	0.17	0.7	37.6
Formosan								
Whistling-Thrush	877	2740	18.3	159	89.1	0.40	0.5	10.2
Mean	720	2712	18.8	166	94.8	0.40	0.0	2.0
Median	7-2764	1574-4950	10.0-23.8	60-223	3.5-100.0	0.01-0.62	0.0-42.7	0.0-163.8
Min.-Max.	890	816	4.7	56	13.4	0.12	0.2	16.0
IQR								
Collared								
Bush-Robin	2283	3080	12.3	88	93.5	0.44	0.1	6.0
Mean	2284	3127	12.0	84	97.6	0.44	0.0	0.0
Median	100-3707	1674-3861	6.5-23.8	30-226	4.9-100.0	0.15-0.62	0.0-6.3	0.0-67.0
Min.-Max.	699	637	3.5	40	6.2	0.11	0.0	10.6
IQR								
Uncommon species								
Formosan Magpie								
Mean	486	2960	19.8	178	87.0	0.37	1.1	15.0
Median	406	2992	20.2	182	93.6	0.36	0.1	9.4
Min.-Max.	7-1487	1374-4950	13.7-23.0	104-216	4.9-100.0	0.12-0.64	0.0-42.7	0.0-163.8
IQR	439	938	2.5	30	13.4	0.11	0.3	21.2
Yellow Tit								
Mean	1569	2831	15.1	121	94.5	0.45	0.4	6.9
Median	1622	2785	15.0	120	98.5	0.45	0.0	0.0
Min.-Max.	7-2815	1674-4011	9.8-23.8	60-226	4.9-100.0	0.12-0.60	0.0-42.7	0.0-163.8

Table 2. Continued.

Species	Elevation (m)	Annual total precipitation (mm)	Annual mean temperature (°C)	Warmth index (°C)	Forest cover (%)	NDVI[1]	Building area (%)	Road density (m/ha)
IQR	615	787	2.8	34	6.0	0.12	0.0	8.6
Taiwan Barwing								
Mean	2043	3067	13.6	104	92.6	0.45	0.1	5.3
Median	2102	3107	13.4	101	98.6	0.46	0.0	0.0
Min.-Max.	7-3015	1674-4261	9.0-22.7	52-212	4.9-100.0	0.11-0.62	0.0-6.3	0.0-74.0
IQR	597	800	3.0	36	6.1	0.12	0.0	6.9
Taiwan								
Bush-Warbler	2200	2939	12.5	90	95.3	0.45	0.1	5.4
Mean	2179	2810	12.2	86	98.9	0.45	0.0	0.0
Median	147-3422	2027-4374	6.7-23.8	32-226	43.8-100.0	0.22-0.59	0.0-2.5	0.0-36.0
Min.-Max.	969	848	2.7	32	5.8	0.10	0.0	8.1
IQR								
Flamecrest								
Mean	2551	3079	11.2	76	91.3	0.43	0.1	4.2
Median	2573	3107	11.0	72	96.7	0.43	0.0	0.0
Min.-Max.	378-3707	1990-3861	6.5-21.3	30-196	14.9-100.0	0.21-0.56	0.0-2.5	0.0-36.0
IQR	654	725	2.3	38	10.6	0.08	0.0	3.1
Rare species								
Swinhoe's Pheasant								
Mean	1343	2868	16.8	142	94.7	0.46	0.1	5.8
Median	1389	2898	16.5	138	99.3	0.46	0.0	0.0
Min.-Max.	100-2457	1674-5124	10.5-23.8	68-226	4.9-100.0	0.15-0.62	0.0-6.3	0.0-67.0
IQR	760	697	3.7	44	4.4	0.12	0.0	8.2
Mikado Pheasant								
Mean	1918	2825	13.7	105	94.0	0.42	0.3	9.5
Median	2121	2961	12.8	93	99.8	0.44	0.0	4.6
Min.-Max.	100-2979	1674-3537	9.5-22.7	56-212	4.9-100.0	0.15-0.59	0.0-6.3	0.0-67.0
IQR	623	688	3.5	42	4.4	0.13	0.0	16.9
Taiwan								
Mean	742	2385	19.6	175	70.2	0.32	2.4	22.8
Median	381	2323	21.2	194	90.4	0.34	0.0	9.3
Min.-Max.	0-3707	1004-5700	6.5-25.2	30-242	0.0-100.0	0.00-0.65	0.0-83.6	0.0-288.8
IQR	1194	1057	6.0	72	58.0	0.24	1.2	35.6

[1]NDVI = normalized difference vegetation index. [2]IQR = Interquartile range

The Taiwan Barbet distributed with a wide elevation range (Table 2) and most of the observations were in low-elevation areas. Their preferred habitats were moist and hot. Requirements of vegetation were not as specific as for other species, and they were recorded at all levels of percentage of forest cover and at a wide range of NDVI values. They also could tolerate relatively high human disturbance.

Most records of the Taiwan Hwamei were at low elevations, with moderate climatic situation (Table 2). Like the Taiwan Barbet, they distributed at all levels of percentage of forest cover and had a wide range of NDVI values. Meanwhile, they lived in areas of higher human disturbance.

The White-whiskered Laughingthrush (*Garrulax morrisonianus*) had the highest-elevation distribution of the endemic species in the Timaliidae family (Table 2). They occupied areas with very high variations in annual precipitation, and low mean temperature and warmth index. They favored habitats covered with more forests and had high NDVI values. Additionally, the areas that White-whiskered Laughingthrush inhabited had the lowest percentage of building area and road density among the ten common species.

The White-eared Sibia (*Heterophasia auricularis*) was a fairly common species in Taiwan. They usually inhabited broad-leaved forests or broad-leaved forests mixed with grass and shrubs. Most of their occurrences were recorded in a temperate climatic state (Table 2). They were more common in areas of high percentage of forest cover and NDVI values where the impact of human disturbance was low.

The Steere's Liocichla (*Liocichla steerii*) had a wider distribution range and frequently in broad-leaved forest bottom or thick bushes. They also inhabited various climatic areas (Table 2). They were active in areas with high vegetation cover and low human disturbance.

The Taiwan Yuhina (*Yuhina brunneiceps*) was found in temperate forest, mostly at middle elevations. They were closely related to the White-eared Sibia and both occupied similar habitats (Table 2). The climatic state was moderate when compared to that of the whole Taiwan. They could be easily found in dense forests and high NDVI areas. Most of their distributions were with almost no buildings and low road density resembled those on the Taiwan Partridge.

The Styan's Bulbul (*Pycnonotus taivanus*) was mainly found in eastern Taiwan on the coastal plains. They occurred in low-elevation forests and in a wide variety of habitats including secondary forests, scrubs, agricultural areas, and gardens. The distributions of the Styan's Bulbul peaked in areas of 2000–2400 mm annual precipitation. Among all endemic bird species, they lived in the hottest areas with the highest mean temperature and warmth index (Table 2). The Styan's Bulbul differed from other species in occupying all percentages of forest cover, where the NDVI range was huge as well. Human disturbance they could tolerate was relatively high and the average road density of distributions of the Styan's Bulbul was higher than that of the whole Taiwan.

The Formosan Whistling-Thrush (*Myiophonus insularis*) was distributed in the mid- and low-elevation mountains, often alone beside streams, near rocks, or in wet woodlands. Their occurrences decreased with increases of elevation from 100 to 2764 m. Their climatic preferences were in line with the overall environment in Taiwan, although they were more numerous in areas with more annual precipitation and higher temperature and warmth index (Table 2). Vegetation cover and human disturbance showed few effects on the distribution of the species.

The Collared Bush-Robin (*Tarsiger johnstoniae*) lived at an average elevation of 2283 m, in the mid- and high-mountains (Table 2). Its habitats were often characterized by high annual precipitation, cold temperature, and low warmth index. They favored areas with high percentage of forest cover and NDVI values. Their distributions were limited by human disturbance and they were found in areas with few buildings and low road density.

Uncommon species

The Formosan Magpie (*Urocissa caerulea*) had a restricted range, below 1500 m in elevation, where was the lowest distribution among the five uncommon species (Table 2). They lived in stable and warm climatic conditions. Although they favored areas of high percentage of forest cover, the NDVI values were relatively low. In addition, they could tolerate higher human disturbance than other uncommon species.

The Yellow Tit (*Macholophus holsti*) occurred in primary broad-leaved forests and occasionally in secondary growth at low- and mid-elevation forests. Its habitats were usually marked by moderate annual precipitation, low temperature, and low warmth index (Table 2). They preferred areas with high percentage of forest cover and NDVI values. The two indices of human disturbance were low.

The Taiwan Barwing (*Actinodura morrisoniana*) was found in areas of high elevation. Its habitats had relatively low mean temperature and warmth index, however, with high annual total precipitation (Table 2). Most records were from areas of high percentage of forest cover and moderate NDVI values. This species endured the least human disturbance of all 17 species, occurring only in areas with <6.3% building areas and an average 5.3 m/ha road density.

The Taiwan Bush-Warbler (*Bradypterus alishanensis*) occurred more widely than the other uncommon species (Table 2). They appeared in vicinity of bamboo grasslands or dense bushes within low- and mid-elevation areas. These areas were in temperate temperature with moderate annual precipitation. They occurred mostly in areas of 80%–100% forest cover and 0.4–0.5 NDVI values. They had a relatively low tolerance of human disturbance, choosing areas with almost no buildings and low road density.

The Flamecrest (*Regulus goodfellowi*) was found in mid- and high-elevation coniferous forests and in broad-leaved mixed forests at high elevations, mainly at 2000–3600 m. Its average elevation (2551 m) was the highest of all endemic bird species (Table 2). Its habitats had the coldest mean temperature and lowest warmth index among all 17 species as well as the highest annual total precipitation for the five uncommon species. However, its distributions with regard to vegetation and human disturbance were similar to those of other species.

Rare species

The Swinhoe's Pheasant (*Lophura swinhoii*) was recorded at mid-elevations in dense primitive forests. They appeared in areas with a temperate climatic state (Table 2). They were mostly found in areas of high percentage of forest cover and NDVI values, principally at 80%–100% forest cover and 0.4–0.5 NDVI values. More records were obtained in less-disturbed areas with almost no buildings and low road density.

The Mikado Pheasant was confined to mountains of central Taiwan, especially at 1800–2500 m elevation in virgin, broad-leaved mixed forests or coniferous forests. Most records were in areas with mean annual precipitation of 2825 mm, temperature of 13.7 °C, and warmth index of 105 °C (Table 2). Suitable habitats for the Mikado Pheasant were in areas with high percentage of forest cover and NDVI values, and low human disturbance.

Distribution patterns

The CCA diagram showed that elevation had the highest correlations with species distributions, with the most contribution at axis 1 as percentage of forest cover

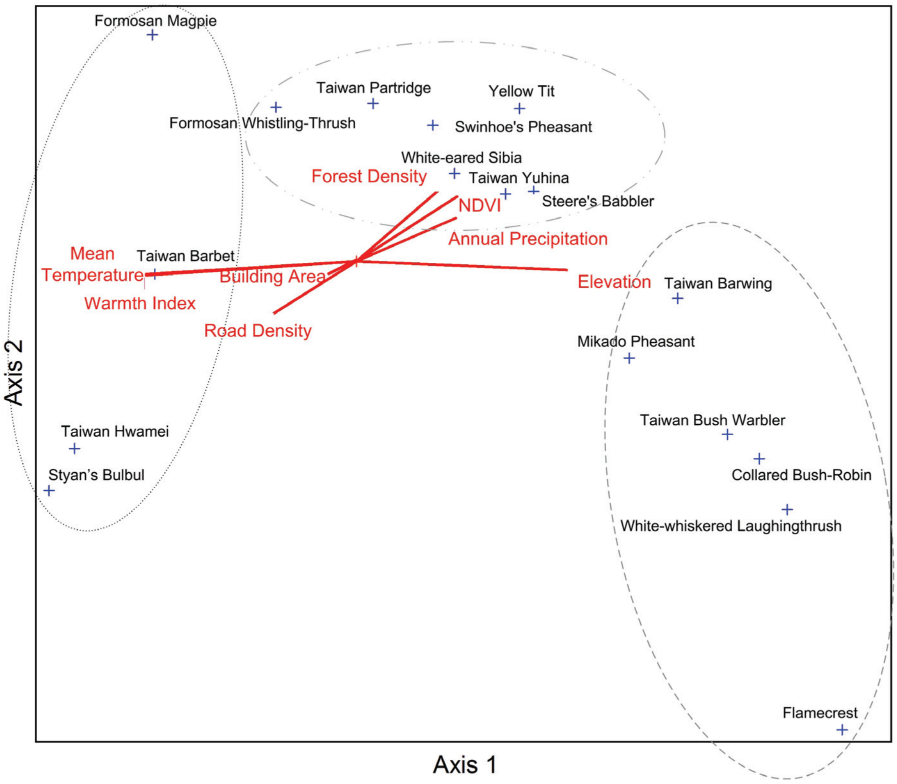

Fig. 2. Canonical correspondence analysis (CCA) of 17 endemic bird species in Taiwan by eight macro-environmental variables. These 17 species are classified into three groups based on the CCA.

at axis 2 (Fig. 2). The axis 1 accounted for 57.5% of the distributions, and the axis 2 for 9.8%. The first axis corresponded to a well-marked and monotonic gradient from low-elevation species (*e.g.* the Styan's Bulbul, the Taiwan Hwamei, and the Taiwan Barbet) to high-elevation species (*e.g.* the Collared Bush-Robin, the Taiwan Barwing, the Taiwan Bush-Warbler, and the Flamecrest). The second axis showed an arch effect, indicating a characteristic of a strong environmental gradient on the first axis. The six species scattered in the lower right corner (the Mikado Pheasant, the Taiwan Barwing, the Taiwan Bush-Warbler, the Collared Bush-Robin, the White-whiskered Laughingthrush and the Flamecrest) were those affected mostly by elevation. The four species, scattered on the left side (the Styan's Bulbul, the Taiwan Hwamei, the Taiwan Barbet and the Formosan Magpie) were those affected negatively by elevation. Overall, these results indicated a strong gradient of topographical and vegetation influences.

The endemic species in Taiwan could be classified into three groups based on the CCA diagram (Fig. 2). The first group included the Formosan Magpie, the Taiwan Barbet, the Taiwan Hwamei and the Styan's Bulbul, and mostly distributed in areas of low elevation. The second group was the mid-elevation species including the Taiwan Partridge, the White-eared Sibia, the Steere's Liocichla, the Taiwan Yuhina, the Whistling-Thrush, the Yellow Tit, and the Swinhoe's Pheasant. Finally, the species in the third group were typically distributed above 2000 m in elevation and included the White-whiskered Laughthrush, the Collared Bush-Robin, the Taiwan Barwing, the Taiwan Bush-Warbler, the Flamecrest, and the Mikado Pheasant.

Potential biodiversity hotspots of all 17 species were defined using the environmental characteristics of each species identified by the CCA (Table 2). The results indicated that the potential biodiversity hotspots distributed at elevation of 300-1500 m with 45%-100% forest cover (Fig. 3). In these areas, about 33.2% areas of Taiwan, we expected to see as many as 17 species occurred simultaneously. However, within these areas, most of the grids only had less than seven species. As figure 3 shown, not all the potential hotspots included actual biodiversity hotspots (grid with the number of endemic species ≧7). Only 35% of the actual hotspots were located in the potential hotspots. Most of the actual hotspots (65%) occurred at higher elevation than where the potential hotspots were.

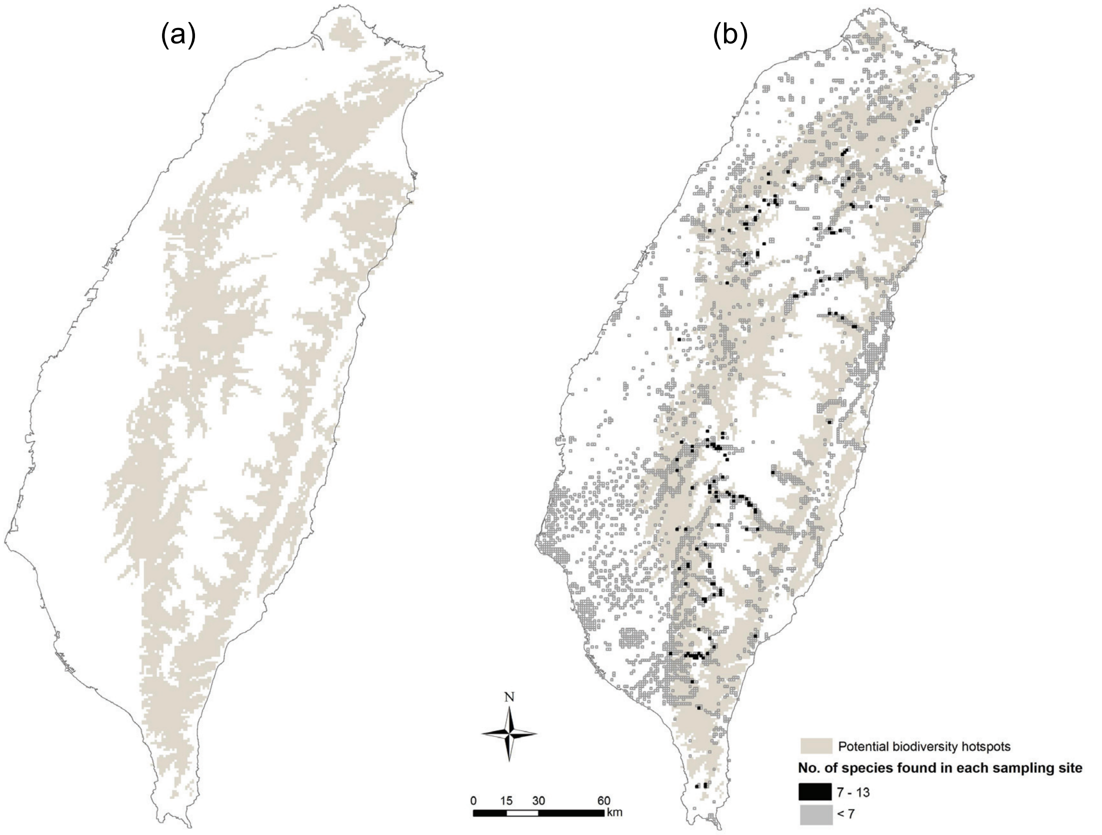

Fig. 3. Potential and actual biodiversity hotspots of 17 endemic bird species in Taiwan. (a) The potential biodiversity hotspots (light gray areas) are ranged by elevation and percentage of forest cover which have the highest correlations with species distributions in the canonical correspondence analysis (CCA). (b) Sampled grids are added on areas of the whole Taiwan. The actual biodiversity hotspots (black grids) are defined as more than seven species occurrence records in each grid while dark gray grids have less than seven species occurrence records.

DISCUSSION

The understanding of species distributions based on their actual occurrences and general macrohabitat factors is fundamental to species conservation. Mapping the potential biodiversity hotspots, through those data, is especially valuable for knowing differences between ideal and actual occurrence conditions for the focal species. In the study, we analyzed the presence or absence of the Taiwanese endemic bird species and the macrohabitat factors associated with their unique distributions. Topographical and vegetation factors separated the 17 endemic bird species into the three groups. However, our results showed that discrepancy existed between locations of the potential and actual biodiversity hotspots.

Most of the actual biodiversity hotspots located at higher elevation than the predicted potential hotspots (Fig. 3). In Taiwan, forested areas within low-elevation (<1000 m) were mostly converted to urban and agricultural usages, while in mid-elevation (1000–2200 m), many broad-leafed forest areas were cut and replanted with conifers such as *Cryptomeria japonica*. Human activities and disturbances have been important factors that affect species' distributions (Lee et al., 2004). Most of the species' distributions showed interrupted patterns due to these influences. The fact that only 35% of the actual biodiversity hotspots were within the potential hotspots, less than 1% occurred at low elevation, and most were found at high elevation (Fig. 3) also suggested high human influences. Meanwhile, among all macrohabitat characteristics of the 17 species, values of human disturbance (*i.e.* percentage of building area and road density) were always low in predicting species occurrences. Using a modeling approach that combined species distributions and current environmental variables, Ko et al., (2009) also found that the hotspots were located at high elevation. Their results showed that the hotspots for the endemic bird species had peaks at around 1844–2308 m in elevation, and had moderate mean temperature (11–14°C), high mean NDVI (0.4–0.6), little human disturbance, and high forest cover.

The spatial distributions of the species also affected the observed hotspot discrepancy. Despite the fact that most of the species distributed along an elevation gradient and showed some preferences for particular ranges, some bird species had spatially restricted distributions. For example, the Styan's Bulbul distributed only in eastern areas of Taiwan according to the data in this study. Even in some introduced areas in the eastern Taiwan, the Light-vented Bulbul (*P. sinensis*), being a strong competitor with the Styan's Bulbul, could exert some limitations on the distributions of the Styan's Bulbul. As the other example, the Formosan Whistling-Thrush could only be found in the river regions that also showed some limitations in their representative ranges.

The environmental variables, *i.e.* topography, climate, vegetation, and human disturbance, used to define species' general distribution patterns in this study were based on suggestions addressed by Chapin et al. (2002). Obviously, species distributions and habitat characteristics have strong relationships. Choosing appropriate and specific environmental indicators to describe species distribution patterns is of fundamental and critical importance. Chapin et al. (2002) suggested using five independent control factors, including climate, parent material, topography, potential biota, and time, to set the bounds for the characteristics of an ecosystem. We believed that these eight environmental variables being used in this study can structure a broad framework for species distributions and represent terrestrial ecosystems in Taiwan.

Although vegetation types are often mentioned in macrohabitat use by bird species, we used percentage of forest cover and NDVI in this study. There was, unfortunately, no complete vegetation type database, nor definite vegetation types available in Taiwan, especially in a grid system. We, therefore, used percentage of forest cover and NDVI as two general vegetation factors to represent the macrohabitat use of the 17 endemic species across the whole Taiwan. In the results, in order to describe the macrohibitat use of a given species as exhaustive as possible, several vegetation types were described according to observations from field work.

Identifying macrohabitat use leads to the establishment of criteria for assessing the suitability of the landscape for a species and to the development of conservative procedures at a large scale. With deforestation, fragmentation, habitat loss, and accelerating climate change, natural systems have faced increasingly anthropogenic-induced impacts in recent decades (Walther et al., 2002; Hampe and Petit, 2003; Parmesan and Yohe, 2003), which have called for more discussions of effective and feasible conservation strategies. Protecting endemism is especially an important part of conservation and management to maintain global biodiversity and regional biological specificity. Protection statuses of the 17 Taiwanese endemic bird species, unfortunately, are not clear. Human activities pose an additional threat to distributions and populations for these endemic species in Taiwan, for example, by accelerating the hybridization between the Styan's Bulbul and the Light-vented Bulbul (Lei et al., 2007). The hybridization between the Taiwan Hwamei and the exotic Chinese Hwamei (*G. canorus*), and the Formosan Magpie and the exotic Red-billed Blue Magpie (*U. erythrorhyncha*) are serious problems. Most of the 'exotic' birds were originated by the human activities and have created some problems for conservation. So far as we know, for the conservation of the Styan's Bulbul, Kenting National Park has started to conduct ecological studies on these two species (*i.e.* the Styan's Bulbul and the Light-vented Bulbul) and proposed to setup some protected areas for the Styan's Bulbul (Severinghaus, 2005, 2006). For the preservation of the Formosan Magpie in Central Taiwan, the introduced exotic Red-billed Blue Magpie had been eradicated successfully (Yao et al., 2007). However, there has no actions been taken yet to control the feral Chinese Hwamei. The current dataset can be used as a baseline data to compare their dispersal abilities and further conservation strategies can be proposed.

Moreover, monitoring long-term population changes are integral parts of effective conservation- oriented research and management, and are critical to the debate on the current statuses of bird species. Ways to enhance the value of bird surveys have aroused discussions in many groups (Sauer et al., 2005; Francis et al., 2005). Although no consensus has yet been reached, most researchers believe that the analysis of bird survey data should provide a vitally important tool for monitoring bird populations. Three possible sources of bias, including roadside effects, observer effects, and analytical methods, have been proposed and should not be ignored (Sauer et al., 2005; Francis et al., 2005). For effective conservation, we suggest continuous monitoring of our sampling sites. We also recommend that the bird survey protocols used in this study can be improved by (1) increasing survey coverage areas, (2) setting additional goals, and (3) estimating effects of distance from roadsides on detection rates. Measures should be implemented to reduce the biases and eventually enhance the usefulness of the survey data.

In conclusion, species inventory across its distribution ranges remains an important task for assessing ecological statuses, identifying conservation priorities, and placing regional population changes into context. Endemic species have unique values and are representative indicators of a geographical region, and thus the statuses of these species should be further monitored to ensure their survival.

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臺灣特有鳥種巨棲地特徵與熱點分布

柯佳吟[1*]、林瑞興[2]、李培芬[1]

1. 國立臺灣大學生態學與演化生物學研究所，106 台北市羅斯福路 4 段 1 號，臺灣。
2. 行政院農業委員會特有生物研究保育中心，552 南投縣集集鎮民生東路 1 號，臺灣。
* 通信作者。*Tel: 866-2-33662469; Fax: 886-2-23623501; Email: f93b44001@ntu.edu.tw*

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摘要：了解物種分布是用以發展生物多樣性保育經營管理策略的基本要素。本研究結合 1993 至 2004 年鳥類調查觀察記錄，識別出 17 種特有鳥種在臺灣個別與獨特的分布形態。在一平方公里的解析度下，利用八個環境因子，包含海拔、年雨量、年均溫、溫量指數、森林密度、植被指數、建物與道路密度等定義物種的巨棲地特徵。依據物種出現記錄的網格數，可將此 17 種特有鳥種分為普遍種 (具有多於 200 個網格的出現記錄)、不普遍種 (100 至 200 個網格) 與稀有種 (少於 100 個網格) 共三大類型，其中稀有種之一的帝雉 (*Syrmaticus mikado*) 含有最少的出現記錄，而普遍種之一的五色鳥 (*Megalaima nuchalis*) 則有最多的發現記錄。研究結果顯示，各特有種具有其特定的分布範圍以及棲地類型喜好，整體而言，17 種特有鳥種棲息地乃於相異的海拔與氣候條件下。植被覆蓋度高、森林密度大以及植被指數中至高的棲地類型普遍為 17 種特有鳥種所偏好。於典型對應分析中可發現，海拔與物種分布相關性最高，其中第一軸的解釋可達 57.7%，第二軸解釋力為 9.8%，同時特有鳥種可在此分析下被區分為三個海拔分布族群。植基於典型對應分析的結果，生物多樣性可能熱點乃坐落在海拔 300 至 500 公尺與森林密度 45%至 100%之間，占臺灣總面積約 33.2%。比較生物多樣性實際熱點，即該網格內實際觀察到之物種數高於 7 種者，僅 35%位於可能熱點區域內，多數的實際熱點 (65%) 發生於更高海拔處。透過這些資料證實了特有鳥種在臺灣的分布情形，而地形與植被是為了解物種於巨棲地下分布特徵的重要且高度相關因子。

關鍵詞：生物多樣性調查、巨棲地、典型對應分析、特有鳥種、生物多樣性熱點。