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RESEARCH ARTICLE

# A Rule-Based Species Predictive Model for the Vulnerable Fairy Pitta (*Pitta nympha*) in Taiwan

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ABSTRACT: A fundamental step in biodiversity conservation is to identify potential distribution and quality habitat for a desired species, especially when the target is rare and difficult to detect. We demonstrated a GIS application in developing a quick predictive model to study the globally vulnerable Fairy Pitta *(Pitta nympha*) in Taiwan. We compiled sighting data between 1982 and 2000, established a rule-based model to predict its distribution, and applied the predictive map to design a sampling protocol, conduced field surveys to evaluate the accuracy of the model and to obtain hotspots. The results showed that most known distribution of the Fairy Pitta occurred in low elevation, hilly and forested areas. The map predicted 21.6% areas of Taiwan suitable for the Fairy Pitta and 78% of them occurred in western Taiwan. A total of 511 pittas were detected during the 2001 survey that covered 4% areas of Taiwan or 14.3% of predictive areas, with a mean of 30.2% detection probability per grid cell (2 × 2 km in resolution). The adjusted data indicated that the overall accuracy of our model was increased to 40.3% with 290 qualified cells. Most of the new sightings of the Fairy Pitta arising from the 2001 field survey fell in our predictive areas with most of them occurring in western Taiwan. The probability of detecting pitta was highest in the active selection cells within predictive areas. Based on mean number of pitta detected per cell, the hotspots of the Fairy Pitta in Taiwan included three regions: the watershed of Shimen Reservoir within Hsinchu and Taoyuan County, Linnei of Yulin County and the watershed of Wusanto Reservoir in Tainan County. We concluded that the model provides quick and effective predictions for planning conservation strategies and is particularly useful for rare species.

KEY WORDS: Niche, rule-based model, spatial sampling, vulnerable species, macrohabitat.

## INTRODUCTION

The Fairy Pitta (*Pitta nympha*) is currently listed as a vulnerable species by the Birdlife International Red Data Book (BirdLife International, 2001) and IUCN Red List of Threatened Species (IUCN, 2007), and its trading is also restricted by CITES (Erritzoe and Erritzoe, 1993; Inskipp and Gillett, 2005; CITES Species Database, 2008). Distributed in East Asia, the bird is migratory, and its worldwide population size may be less than 10,000 individuals (BirdLife International, 2001). However, information of Fairy Pitta worldwide is scattering and limited. Due to its distribution in the low-elevation regions that are highly susceptible to human activities, conservation efforts of the Fairy Pitta is urgent (Lambert and Woodcock, 1996; BirdLife International, 2001). In Taiwan, the Fairy Pitta is a summer visitor and previous studies (e.g., Severinghaus et al., 1991) have shown limited sighting records.

Geographic Information System (GIS) has become a widely-used tool to investigate species distribution (Smith-Ramirez et al., 2007; Isaac et al., 2008) and macrohabitat characteristics (Murgante and Las Casas, 2004; Uy and Nakagoshi, 2008). Digital environmental information layers relating to a target species can be analyzed to identify potentially suitable habitats (Vogiatzakis, 2003). Conservation applications using GIS, for example species predictive models, have emerged in the last decade to help in guiding future survey efforts for rare and endangered species (Guisan and Zimmermann, 2000; Walther et al., 2007).

Designing a field sampling scheme, particularly for a rare species faces great challenges due to limited information. Spatial distribution modeling provides relatively accurate information when preparing for field survey. With this help, researchers can design better and efficient sampling plan to gather field information in a short time period (Powell et al., 2005; Walther et al., 2007) that would save time and money.

We hypothesized that the distribution of the vulnerable Fairy Pitta can be formulated using existing know distribution. In this study, we demonstrated the development of a predictive distribution model using GIS to study the Fairy Pitta in Taiwan. In particular, we compiled known sighting data between 1982 and 2000, identified macrohabitat characteristics using environmental GIS layers, and established a rule-based model to predict the potential distribution range of pitta. Finally, we applied the predictive map to design a field sampling protocol and used these results to evaluate the accuracy of the model and to pinpoint hotspots of the species.

## MATERIALS AND METHODS

### Species data

We extracted and compiled sighting data between 1982 and 2000 from the databases of Wild Bird Federation Taiwan and Endemic Species Research Institute. Due to the elusive nature of the species, there were only 59 records. All sighting records were recorded between mid-April and September, the breeding season of the species, thus the sighting locations represented the breeding grounds of the species in Taiwan. These were the best available distribution of Fairy Pitta in Taiwan in 2000. Using a 2 × 2 km GIS grid representation (9,388 in total, Lee et al., 2004), we mapped the occurrence data into 54 cells (Fig. 1).

### Environmental data

To explore macrohabitat characteristics of the Fairy Pitta, we applied 13 environmental variables derived from a GIS database of ecological factors in Taiwan (Lee et al., 1997). The 13 variables were chosen by consulting previous literature (e.g., Severinghaus, 1991) that mentioned the Fairy Pitta ecology and our field experience. The GIS layers were also in the 2 × 2 km grid system. These variables can be classified into three categories, i.e., topography, climate and human activity (Table 1). We calculated mean and minimum elevation layers based on a digital elevation model (DEM, 40 × 40 m in resolution) produced by the Aerial Survey Office of Forest Bureau, Taiwan. We also calculated the coefficient of variation of elevation. Through the river and dam maps, we calculated the nearest distance from each cell to the rivers. Climate variables included total annual precipitation and mean monthly temperature between 1959 and 1985. The 12 monthly total precipitation data were transformed into four PC variables (axes) by PCA (principal component analysis). The first PC variable, explaining 42% of the total variations in the 12 monthly total precipitation, represented characteristics of the precipitation between September and November. The second axis had the precipitation characteristics of May to September and explained 33% of the variations. The third (10%) variable characterized precipitation patterns from November to June, and the fourth (7%) variable represented precipitation of July. Warmth index reflected vegetation growth condition and was calculated by summing all the monthly mean temperature that was higher than 5˚C (Liu and Su, 1992). Urbanization index and nearest distance to 3,000 m a.s.l. or above was the only two variables representing human activity in our study. Distance to 3,000 m a.s.l. or above was derived from the mean elevation layer. Urbanization index was calculated by combining the structure of employment populations from each township compiled from the Directorate General of Budget, Accounting and Statistics of Executive Yuan, in particular, the index was calculated as a sum of a second (mining, water, electricity, and building industry etc.) and a third classes (business, transportation, communication and service etc.) of industrial population divided by a sum of a first (agriculture), a second and a third classes of industrial population (see Sun et al., 1988 for detail calculations).

### Model construction

We first examined the relationships between the occurrence records and the environmental variables by performing an overlay analysis, and later an exploratory data analysis. Based on prior understanding of the Fairy Pitta, we assumed that all variables we chose were

**Table 1. Environmental variables used in this study.**

| Category | Abbreviation | Variable description and unit |
|---|---|---|
| Topography | D2_RIVER | Nearest distance to main rivers and dams (km) |
| | ELEV | Mean elevation (m) |
| | ELEVMIN | Minimum elevation (m) |
| | ELEVCV | Coefficient of variation of elevation |
| Climate | P_TOTAL | Total annual precipitation (mm) |
| | P_PC1 | The first PC axis (explaining 41.9% of the total variations) of 12 monthly total precipitation |
| | P_PC2 | The second PC axis (33.0%) of 12 monthly total precipitation |
| | P_PC3 | The third PC axis (10.2%) of 12 monthly total precipitation |
| | P_PC4 | The fourth PC axis (6.5%) of 12 monthly total precipitation |
| | T_PC1 | PC axis (explaining 96.5% of the total variations) of 12 monthly mean temperature |
| | WARMTH | Warmth index which sums mean monthly temperature higher than 5˚C in a year (˚C) |
| Human activity | URBAN | Urban development index |
| | D2_3000 | Nearest distance to elevation 3,000 m and higher (km) |

indicators of the bird's distribution in Taiwan. Some variables, such as elevation, might represent an upper limit to the distribution; some were a minimum requirement and some, such as temperature, showed an optimal range. We then determined the macrohabitat characteristics of the Fairy Pitta by examining the mean, standard deviation, minimum and maximum values of these variables through descriptive statistics. Based on the environmental characteristics of previous sighting data, we used the minimum and maximum values of these 13 environmental variables as the boundaries to develop 13 initial suitability map for the Fairy Pitta. Each map differentiated suitable and unsuitable habitat areas for the bird. These maps were then intersected to derive a map with predictive areas that met all the requirements. Since the birds mainly distributed in forests, our final predictive map excluded unforested areas by using a forested cover map.

### Model evaluation

In order to evaluate prediction accuracy of the predictive map, in March 2001 we designed a field sampling protocol based on the predictive map (Fig. 2). We identified three types of sampling areas from the map: (1) random cells within predictive areas, (2) active selection cells within predictive areas, and (3) active selection cells outside predictive areas. The random cells were randomly chosen within the predictive areas. The active selection cells were selected based on known sighting locations (Fig. 1) and our field experience. These active sites concentrated in the Shimen Reservoir watershed of Taoyuan County and the proposed Fushan Dam (Linnei) of Yunlin County. We also used our knowledge to choose the active selection cells outside predictive areas, although they might represent marginal habitats for pittas. The first two types were designed to evaluate the accuracy of predicting the presence of the Fairy Pitta, and the third one was helpful in checking the model's omission error. A total of 378 cells, including 208 random cells, 63 active selection cells within predictive areas, and 107 active selection cells outside predictive areas, were selected. Together, those cells covered 4% of Taiwan. Within each cell, we selected at least 3 sampling points to conduct the field survey. A total of 4,239 points, including 2,596 in random cells, 526 in active selection cells within predictive areas, and 1,117 in active selection cells outside predictive areas, were surveyed.

The field survey was conducted at each point from late April to early July in 2001. A total of more than 250 volunteer surveyors participated in the field survey. Each surveyor was trained with standardized sampling protocol before the field surveys. For the surveys, we applied a playback-response method (Lin et al., 2007) to get quick responses of the Fairy Pitta. The method greatly helped in detecting the presence of birds (Lin et al., 2007).

We calculated the mean number of cells with pitta detected and the mean number of sampling point per cell in three sampling selection by using complete data. Since low sampling efforts, unequal spatial coverage, and incorrect survey timing might reduce the detection probability of Fairy Pitta (Lin et al., 2007), we further adjusted the survey data by deleting those cells with < 6 sampling points, less spatial coverage (< 50% of the areas) and surveyed outside the preferred survey period (late April to end of May) and calculated the same parameters.

We performed GIS operations in IDRISI and ArcGIS environments. All statistical analyses were conducted using SYSTAT and SAS.

## RESULTS

### Macrohabitat Preferences

Most known distributions of the Fairy Pitta occurred in forested lowland hills of western Taiwan (Fig. 1). Out of the 54 grid cells, only two sightings were located in the eastern Taiwan. The birds distributed islandwise but concentrated in the regions near Shimen Reservoir of Taoyuan and Hisichu County, and Tsengwen Reservoir of Chiayi County.

Comparing the sighting data with the environment ranges of the whole Taiwan, the Fairy Pitta preferred some environmental characteristics (Fig. 3 and Table 2). Since Fig. 3 showed the whole range value in Taiwan, the sighting records were mostly located in low elevation, moderate temperature, relatively high annual precipitation, and low urban development. In particular, the elevation ranges were between 0 and 980 m with 75% of the sightings occurred below 280 m a.s.l (Fig. 3a). The areas where the birds were found had higher temperature (Fig. 3b), and annual total precipitation ranged from 1,417 to 3,190 mm with a mean of 2,309 mm (Fig. 3c). These locations were also close to the rivers and dams (< 7.6 km), low urban development (Fig. 3d), and low warmth index.

### Predictive map

The predictive areas of the Fairy Pitta included 21.6% of the main island of Taiwan with 78% occurring in the western part of Taiwan (Fig. 2). Totally there were 2,031 cells predicted to have pittas. Overall, our prediction indicated the bird distributed in the forested region below 1,000 m a.s.l and away from high human

**Table 2. Summary of environmental characteristics of Fairy Pitta (*Pitta nympha*) sighting locations (n = 54).**

| Variables | Mean ± SD | Minimum | Maximum |
|---|---|---|---|
| D2_3000 | 42.4 ± 11.8 | 24.7 | 94.7 |
| D2_RIVER | 1.8 ± 1.6 | 0 | 7.60 |
| ELEV | 268 ± 231.7 | 0 | 981 |
| ELEVMIN | 150 ± 149.2 | 0 | 650 |
| ELEVCV | 2.15 ± 1.15 | 0 | 5.67 |
| P_TOTAL | 2,308 ± 369 | 1,417 | 3,190 |
| P_PC1 | -81.4 ± 110.8 | -266.4 | 205.5 |
| P_PC2 | 96.8 ± 160.8 | -226.7 | 506.1 |
| P_PC3 | -31.7 ± 103.2 | -205.3 | 159.3 |
| P_PC4 | 50.1 ± 102.6 | -128.7 | 214.0 |
| T_PC1 | 431 ± 62.5 | 235 | 540 |
| WARMTH | 200 ± 21.1 | 135 | 234 |
| URBAN | 52.8 ± 17.5 | 17 | 95 |

**Table 3. Field survey results of Fairy Pitta in 2001. The adjusted data were modified by deleting the cells with < 6 sampling points, less spatial coverage (< 50% of the cell area) and outside the preferred survey period (late April to end of May).**

| Types of dataset and sampling | Total number of cells sampled | Number of cells with Pitta detected | Total sampling points | Number of sampling point per cell (mean ± SD) | Number of Pitta detected | Number of Pitta detected per sampling point (mean ± SD) |
|---|---|---|---|---|---|---|
| **Complete data** | | | | | | |
| Random cells within the predictive regions | 208 | 69 (33%) | 2,596 | 12.7 ± 4.0 | 226 | 0.09 ± 0.20 |
| Active cells within the predictive areas | 63 | 28 (44%) | 526 | 8.4 ± 7.5 | 237 | 0.31 ± 0.61 |
| Active cells outside the predictive areas | 107 | 17 (16%) | 1,117 | 10.6 ± 4.9 | 48 | 0.06 ± 0.21 |
| **Adjusted data** | | | | | | |
| Random cells within the predictive regions | 177 | 60 (34%) | 2,376 | 13.4 ± 3.2 | 192 | 0.08 ± 0.17 |
| Active cells within the predictive areas | 29 | 23 (80%) | 449 | 15.5 ± 5.0 | 223 | 0.43 ± 0.42 |
| Active cells outside the predictive areas | 84 | 13 (16%) | 1,036 | 12.3 ± 3.3 | 40 | 0.04 ± 0.16 |

disturbed regions. In contrast to the very few sighting records in eastern Taiwan, our model predicted 22% of these areas were potential habitats for pitta. However, no area within Ilan County was predicted.

### Model evaluation

A total of 511 pittas within 114 cells was detected during the 2001 survey (Fig. 4, Table 3), with a mean of 30.2% detection probability per cell.

Despite similar sampling efforts in the three sampling categories (Table 3), the active selection cells within predictive areas had significantly higher number of pitta detected per point than the random cells within predictive areas and the active selection cells outside predictive areas (H = 50.3, Kruskal-Wallis test, $p < 0.001$). The percentage of the number of cells with pitta detected was also the highest in the active selection cells within predictive areas (Table 3). In contrast, the active selection cells outside predictive areas had the lowest percentage. Using sampling point as the basis, the mean detected individual per point was 0.12. The overall accuracy of our predictive model was 35.8%.

Analyses on the adjusted data indicated that the overall accuracy of our model was increased to 40.3% with 290 qualified cells (Table 3). The detection probability per cell also increased to 33.1%. The three sampling types showed significant difference in the number of pitta per point (H = 53.1, Kruskal-Wallis test, $p < 0.001$). The percentage of the number of cells with pitta detected and the number of pitta detected per point were the highest in the active selection cells within predictive areas, and similarly, the active selection cells outside predictive areas had the lowest values. However, due to the high number of sampling points, the mean number of pitta detected per sampling point in the adjusted data was significantly lower than that of all data (0.10 vs. 0.12, Mann-Whitney U test, $p < 0.05$).

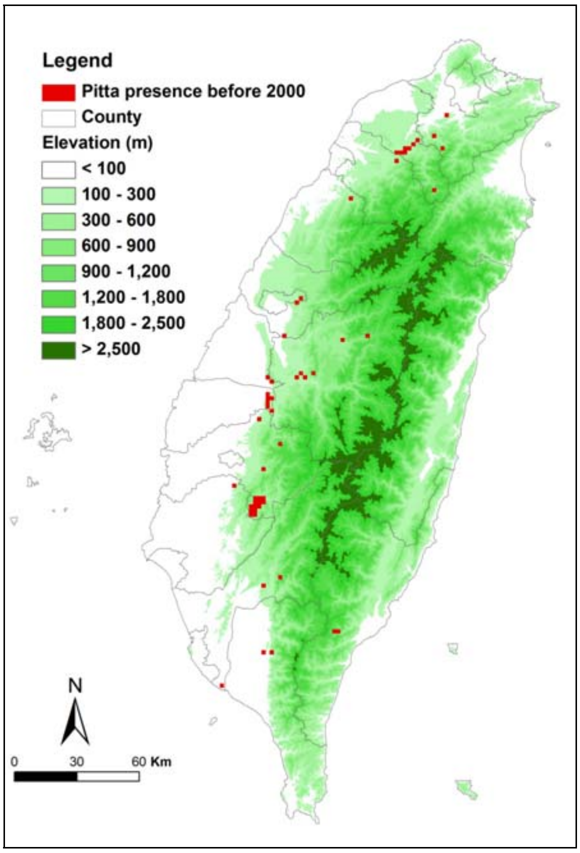

**Fig. 1. Known distribution of the Fiary Pitta (*Pitta nympha*) based on the sighting data compiled by Wild Bird Federation Taiwan and Taiwan Endemic Species Research Institute between 1982 and 2000.**

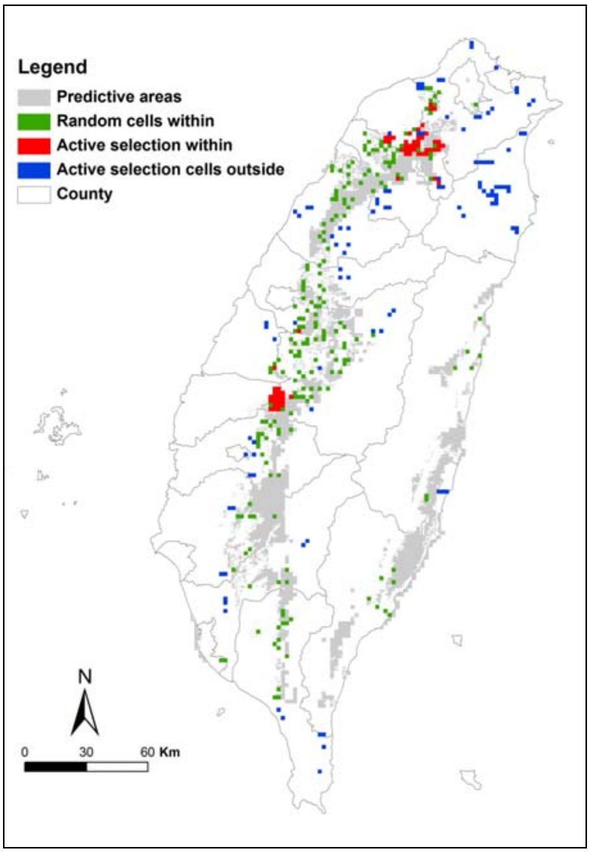

**Fig. 2. Predictive distribution of the Fairy Pitta (*Pitta nympha*) and field sampling design. Three categories of sampling cells were included: i.e., random cells within: random cells within the predictive areas, active selection cells within: active selection cells within the predictive areas, and active selection cells outside: active selection cells outside the predictive areas. All the selections were based on the predictive areas and were used to conduct field surveys.**

The hotspots, based on the mean number of pitta detected per gird in the adjusted data, included three regions: the watershed of Shimen Reservoir within Hsinchu and Taoyuan Counties, Linnei of Yulin County and the watershed of Wusanto Reservoir in Tainan County. The detection probability reached 0.9. These sites also had higher complexity of topography and secondary forested cover.

## DISCUSSION

Conservation of rare and endangered species often faces urgent challenge to gather sufficient data for policy making in a short time period. In this study we demonstrated a simple and quick approach to obtain adequate distribution data for a globally vulnerable species, the Fairy Pitta. By integrating sighting data from all possible sources, we developed a species predictive model and designed a standardized sampling protocol to evaluate the model effectiveness. The rule-based model applied niche concept and assumed all the potential variables had equal contributions. The resulting 40% overall predictive accuracy indicated that our model and the overall approach was straightforward and valuable. We also conducted similar field work in 2002 and 2005, the results suggested that the model accuracy could reach over 50% (R. S. Lin, unpublished data). In addition, the gathered information provides sufficient pitta presence data for decision makers and further insight on the model refinements (Lee et al., 2006).

We further applied the sampling results (i.e., Fig. 4) to develop more sophisticated models using logistic regression, discriminant function analysis, GARP, fuzzy logic and artificial neural network using a 1 × 1 Km grid dataset. Instead of treating all explanatory variables as equal, these new models tried to weight the variables differently. Our results indicated that overall accuracies ranged from 63% to 85% and the GARP model had the highest predictive power (Lee et al., 2006). With the

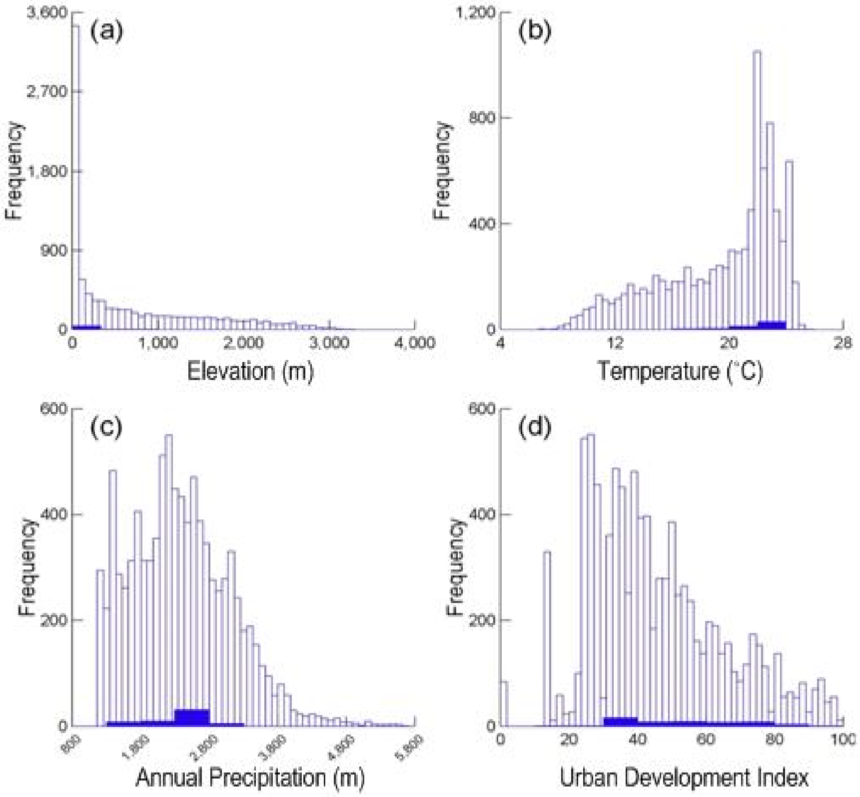

**Fig. 3. Overall ranges of environmental characteristics in Taiwan (in open bar) and macrohabitat characteristics of Fiary Pitta (*Pitta nympha*) (in solid bar) based on the sighting data compiled by Wild Bird Federation Taiwan and Taiwan Endemic Species Research Institute between 1982 and 2000: (a) mean elevation (m), (b) mean temperature (°C), (c) total annual precipitation (mm), and (d) urban development index. The data clearly indicated that the distribution of Fairy Pitta was restricted to some specific range.**

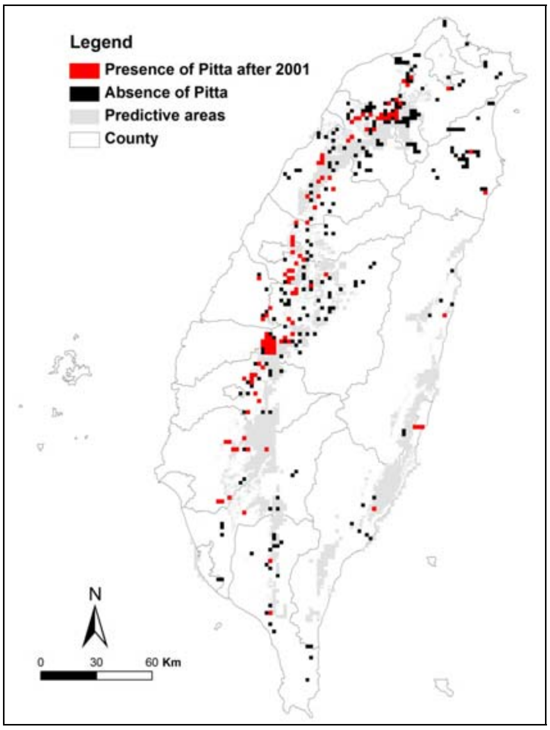

**Fig. 4. Presence data of the Fiary Pitta (*Pitta nympha*) in Taiwan after the 2001 survey that covered 4% in Taiwan or 14.3% in predictive areas.**

ensemble forecasting approach (Araújo and New, 2007), we further developed a robust predictive model for Fairy Pitta. The combined model yielded a narrower predictive range than the rule-based model in our study, though the overall pattern was similar.

A vulnerable species is usually characterized with low population and easily threatened by extrinsic factors (Smith et al., 2003; Mitchell and Wilson, 2007). In the Fairy Pitta case, its elusive nature leads to difficulties in detecting presence in the field (Severinghaus et al., 1991; Lin et al., 2007). Their occurrence records are usually too few to build strong predictive models. Our rule-based model is simple to construct once the environmental dataset is available. As we demonstrated, the model acted as the initial guidance to design a systematic field sampling strategy. With the help of the playback-response method (Lin et al., 2007) and more than 250 field surveyors, the results of the field work provided more distribution data (108 cells) than those accumulated for almost 20 years (54 cells). Although these research efforts were different, our approach indicated that a systematic sampling design based on this rule-based model prediction substantially improved our knowledge on the distribution of the Fairy Pitta (Lin et al., 2007).

The number of pitta detected per sampling point or the number of pitta detected per cell in the active selection cells outside predictive region was significantly lower than those in the random cells and active selection cells within predictive regions. Furthermore, within the predictive areas, the results that the active selection cells had far better detection probabilities than the random cells also indicated the effectiveness of the predictive model. These results clearly suggested the model provided better predictive power than random selection. Finally, species abundance distribution can be applied to integrate the single species prediction and environmental indicators (McGill et al., 2007).

As expected, the current model did not predict all possible occurrence areas of the Fairy Pitta in Taiwan. The number of pitta detected per cell in the active selection cells outside predictive areas clearly indicated that the potential omission error in the model. In particular, the Ilan County was completely missing in the prediction. Part of the reasons for the error was the few sighting records available to frame our selection rules. In contrast, some areas predicted by the current model, though not verified in the 2001 survey, were found to have pitta presences in either 2002 or 2005 surveys or in some scattered news reports (L. T. Chao, personal communication).

Although there are some advocacy in promoting the further applications of predictive model (e.g., Rodriguez et al., 2007), most species predictive mappings stopped after the prediction models were compared and the best one singled out (e.g., Maynard and Quinn, 2007). To our knowledge, our efforts represented a successful application to fully use the predictive model to obtain ecological distribution data on the Fairy Pitta in its breeding range. Without further affirmation, both predictive model and mapping cast doubts about their accuracy and usability (Loehle and LeBlanc, 1996; Travis, 1996). In our study, we showed the applicability of the model by extensive field work, and the probability to detect the Fairy Pitta was higher within predictive areas than non-predictive areas.

Given the results of our analyses, we proposed that it is critical and important to design an immediate conservation strategy for this vulnerable species. According to the model prediction (Fig. 4), the Fairy Pitta widely distributed at low elevation of the evergreen broad-leaved forest in Taiwan. Further gap analysis using all protected areas in Taiwan, including national parks, nature reserves, wildlife refuges and important wildlife habitats, indicated that only less than 2% of the currently known distributions of the Fairy Pitta were protected (Lee et al., 2006). Most of the distributions are located in the relatively high human disturbance zone and within the private lands. These lands suffer excessive developments and have numerous predators, such as snakes, mammals, birds and ants (Chen, 2007). Clearly these situations complicate the conservation of this species.

The current hotspots for the Fairy Pitta are located in the low elevation forests of highly complex topography. We identified three regions based on the number of pitta detected per cell. All sites were close to rivers or dams. Since the watersheds of dams are protected by laws, it is possible that Fairy Pitta habitats in these regions can receive better protection. Since our sampling efforts were not complete, we suspected there are many more similar unidentified hotspots in Taiwan. To effectively protect the species, we suggested land managers avoid planning large-scale development projects in similar habitats.

The rule-base model and sampling protocol developed in this study can be applied to conduct survey in other countries where the Fairy Pitta breeds. Since the playback-response approach is an effective method for surveying the species (see Lin et al., 2007), with the abundant spatial and land cover data already available (Global Land Cover Facility, 2008), the only modification of the methodology may be the survey period because the birds breed at other latitudes have different timing comparing to those in Taiwan.

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# 臺灣八色鳥(*Pitta nympha*)之規則化分布預測模式

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摘要：確認稀有性物種的分布和其適宜性棲地是生物多樣性保育的基本工作。本研究展現利用地理資訊系統，針對臺灣的全球易危性物種—八色鳥 (*Pitta nympha*)，發展一個簡易又快速的分布預測模式。收集 1982 至 2000 年的觀察記錄，建立八色鳥的規則化分布預測模式，並利用預測圖設計野外調查，以標準化的方法評估此模式的效能，建立熱點位置。結果顯示，八色鳥分布於低海拔且有森林覆蓋的丘陵地區。預測圖估計台灣約有 21.6%的區域，可能會有八色鳥的出現，其中約有 78%處在西部。在 2001 年的調查（調查區域約佔全台 4%，或預測區的 14.3%）中，共發現 511 隻八色鳥，平均每一個 2 × 2 公里網格的發現機率為 30.2%，以比較嚴格篩選的網格資料（共 290 格），模式準確度則為 40.3%。新發現有八色鳥出現的網格分布，大致與預測模式的型態相似，且 93.9%出現在臺灣西部。每網格內的發現機率，以在預測區域內的刻意選擇區最高。以網格的出現機率為標準，八色鳥熱點出現在新竹與桃園縣石門水庫附近、雲林縣的林內鄉、臺南縣烏山頭水庫附近的山區。本模式特別適合稀有性物種，方法簡易又有效，可以協助瞭解物種的可能分布範圍，進而提供更適宜的保育策略。

關鍵詞：生態棲位、規則化模式、空間取樣、易危物種、巨觀棲地。