**Effects of breeding habitat loss on a threatened East Asia migratory forest bird**

Jerome Chie-Jen Ko\(^1,2\) | An-Yu Chang\(^1\) | Ruey-Shing Lin\(^1\) | Pei-Fen Lee\(^2\)

\(^1\)Endemic Species Research Institute, Jiji 552, Nantou, Taiwan
\(^2\)Institute of Ecology and Evolutionary Biology, National Taiwan University, Taipei 106, Taiwan

**Abstract**

Migratory landbird population trends and threats in the East Asian-Australasian Flyway (EAAF) are poorly understood. To fill this knowledge gap, we investigated the effect of breeding habitat loss on the population trend for the Fairy Pitta (*Pitta nympha*), a migratory forest-breeding bird in the EAAF categorized as Vulnerable on the IUCN Red List. It has been assumed that this species is declining rapidly due to deforestation in its breeding range in Taiwan. We analyzed the change in Fairy Pitta population density across Taiwan from 2001 to 2017, and tested the effect of forest cover change on the species’ abundance. We detected an average of 4.32 (95% CI: 1.96–6.68) individuals per km\(^2\) in 2001, which has declined at an average annual rate of \(-8.31\%\) (95% CI: \(-15.50\%\)–\(-1.16\%\)) during the study, and a minor change in forest cover \((0.22\%)\) in Taiwan during this period. We found no significant effect of the forest cover trend on the population trend of the Fairy Pitta. This suggests that the drivers of population decline may not be related to deforestation in the breeding range, but potentially to breeding habitat degradation, habitat loss in the non-breeding range, or factors unrelated to habitat loss. Further studies are required to assess the major threats to this globally threatened species.

**KEYWORDS**

endangered species, east asian-australasian flyway, deforestation, *Pitta nympha*

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**1 INTRODUCTION**

A lack of population trend and threat assessments is putting the migratory landbirds of the East Asian-Australasian Flyway (EAAF) under threat (Kim et al., 2021; Ueta & Uemura, 2021; Yong et al., 2021). Although it is highly species diverse, supporting the highest number of threatened species among the five global highways (Kirby et al., 2008), very little is known about the population trends of EAAF migratory landbirds (Kim et al., 2021; Newton, 2007; Yong et al., 2021). Such an information gap can result in the late detection of severe population decline (Stanton, 2014). For example, the conservation status of the once superabundant Yellow-breasted Bunting (*Emberiza aureola*) rapidly shifted from least concern to Critically Endangered (CR) in less than a decade (Birdlife International, 2021). The first scientific report of its population trends, however, was only available after rapid decline of the species has raised global concern (Kamp et al., 2015). Recent studies have also found that other species share similar fates, such as the Rustic...
Bunting (Emberiza rustica) (Edenius et al., 2017). The late discovery of population declines hinders proactive conservation, making it more expensive and less efficient for resource distribution for conservation interventions (Donlan, 2015). To date, repeated and quantitative monitoring of migratory bird populations has been scarce in the EAAF (Yong et al., 2015), and there is little knowledge of range-wide population trends. Regional reports of population status or monitoring reports remain a key information gap to provide evidence for prioritizing threats and action-needed locations.

The Fairy Pitta (Pitta nympha) is a globally threatened, long-distance migratory landbird species of the EAAF (Erritzoe, 2020; IUCN 2021; Severinghaus et al., 2019). It breeds throughout montane forests in southern Japan, South Korea, southeast China, and the island of Taiwan, while its wintering range is thought to be only in Borneo (Erritzoe, 2020; Lambert & Woodcock, 1996). As the deforestation rate of tropical forests in Asia is among the highest globally (Hansen et al., 2013), we believe that the effect of habitat loss through deforestation on migratory forest birds in the EAAF, such as Fairy Pitta, is an important issue to examine in the context of migratory species conservation. The Fairy Pitta’s Vulnerable Red List category is based on the justification that it is “in rapid decline owing to deforestation in its breeding range, principally for agriculture and timber, locally compounded by trapping for the cagebird trade” (Birdlife International, 2021); however, quantitative measures of decline are lacking. Further investigation of such claims is required since reports of potential threats—including habitat loss, hunting, and human disturbance—have been mostly anecdotal, and is restricted to local scale or individual scales.

Taiwan supports the Fairy Pitta’s largest known breeding population (Birdlife International, 2021). The species’ breeding distribution is associated with tropical and subtropical forests between 0 and 1000 meters above mean sea level (mamsl) on Taiwan Island, including primary forests, and naturally regenerated secondary forests (Lin, 2002). It is currently protected under Taiwan’s Wildlife Conservation Act as an Endangered species (COA, 2009). Studies on the effectiveness of survey methods (Lin, Lee, Ding & Lin, 2007), breeding ecology (Lin, Yao & Lee, 2007), and population distribution (Ko et al., 2009) have improved our knowledge of the species. However, population trends have only been reported in local areas of conservation conflict, such as the dam construction site in the Huben-Hushan IBA of Yunlin County (Lin & Chih, 2015; Lin & Pурсner, 2020). To date, regional assessment of the Fairy Pitta’s breeding population status, and associated habitat trends has yet to be undertaken by the scientific community.

Forest loss has long been considered a major threat to the Fairy Pitta breeding population in Taiwan (BirdLife International, 2001; Lin, Lee, Ding & Lin, 2007). The flooding of 422 ha. of key habitat in the Huben-Hushan IBA, the location with the largest known breeding population of the species (IUCN 2021), largely contributes to this belief. Since then, island-wide survey of Fairy Pitta in Taiwan was undertaken to find other potential breeding populations in response to the proposition of the Hushan Dam Project proposal (Lin, 2002). As breeding populations of Fairy Pitta are gradually found to be widespread across the island’s low-elevation forested areas (Lin et al., 2009), conservation focus has turned toward the forest cover change of this 12,172 km² square potential breeding habitat between 0 and 1000 mamsl and its effect on the Fairy Pitta’s population.

In the present study, we analyzed the breeding population trend of the Fairy Pitta by island-wide monitoring efforts across a 17-year timeframe in Taiwan. Furthermore, to improve our knowledge of how deforestation in the breeding range may impact the species, we tested the hypothesis that the Fairy Pitta population trend is affected by changes in forest cover in Taiwan. By compiling the results of this study and previous assessments (Birdlife International, 2021), we re-assessed the threats to the Fairy Pitta, providing critical information for the protection of this migratory songbird in the EAAF. To the best of our knowledge, our study is the first regional assessment of a globally endangered East Asian migratory forest species based on fine-scale abundance data from extensive field surveys.

2 | METHODS

2.1 | Fairy Pitta survey data

The data used for this study were obtained from surveys carried out across the forested area below 1000 mamsl on the island of Taiwan between 2001 and 2017 (Figure 1). This forested area is mainly composed of tropical and sub-tropical forests, with a mean temperature of 21°C, and mean total annual precipitation is c.2500 mm. A total of five rounds of island-wide Fairy Pitta population surveys, composed of six breeding seasons in 2001, 2002, 2005, 2009, 2013, and 2017, were conducted. The 2001 and 2002 surveys were designed as a 2-year complementary project; hence, we combined these 2 years into a single sampling round, resulting in a total of five sampling rounds between 2001 and 2017.
In each round, we conducted the island-wide population surveys in a two-step sampling design. First, a set of 1 km² sampling grids was selected following a grid-based system defined by Lee et al. (1997). We used this grid system as it links to a comprehensive ecological and environmental database in Taiwan. Second, in each sampling grid, we located a set of survey points with a 100 m radius separated by 200 m to avoid repeated counts. Each sampling grid has a range of 1–22 survey points due to topography accessibilities. Survey point is the smallest sampling unit in our dataset and is each sampled once per year. Across all rounds, a total of 24,297 survey point repeats (2502–7273 points per round) within 4900 sampling grid repeats (613–1865 grids per round) were surveyed (Table 1).

Table 1. Number of 1 km² sampling grids; playback survey points; detected Fairy Pitta individuals within a 100 m radius; individuals per survey point; and individuals per km² of each survey round between 2001 and 2017

| Survey Round | Survey year | Number of sampling grids | Number of surveyed points | Total count of individuals | Individuals per km² (95% CI) |
|--------------|-------------|--------------------------|---------------------------|---------------------------|-----------------------------|
| 1            | 2001, 2002  | 1865                     | 7114                      | 605                       | 4.32 (1.96–6.68)            |
| 2            | 2005        | 657                      | 2502                      | 84                        | 3.18 (1.19–5.17)            |
| 3            | 2009        | 1149                     | 7273                      | 191                       | 1.52 (0.38–3.41)            |
| 4            | 2013        | 613                      | 3696                      | 155                       | 2.04 (0.41–4.49)            |
| 5            | 2017        | 616                      | 3712                      | 156                       | 0.82 (0.00–2.45)            |
| Total        |             | 4900                     | 24,297                    | 1191                      |                             |
| Mean         |             | 980                      | 238                       | 238                       | 2.04 (0.00–5.89)            |

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We selected sampling grids based on predicted suitable habitats of the Fairy Pitta across the island in all survey rounds. Predicting models for suitable habitats and spatial distribution of sampling grids differed between years as new methods were adopted and requirements of financing agencies diverged. In the first round (2001 and 2002), we defined the predicted suitable habitats by a rule-based model, using elevation, precipitation, temperature, urban index, and distance to rivers as environmental factors (Lin, 2002). Sampling grids were then arbitrarily selected to be distributed as evenly as possible within predicted suitable habitats across the island. In the second round (2005), although still following the same predicted suitable habitats as in the first round, we selected a new set of island-wide sampling grids but focused more on low-elevation forested reservoirs, which were targets of conservation management at the time (Lin, 2005). In the third round (2009), we renewed the predicted suitable habitats by a logistic regression model with the same source of environmental factors as in the rule-based model in 2001 (Lin et al., 2009). Another new set of sampling grids was selected following this new model by hierarchical random sampling (Lin et al., 2009). After 2009, we started to aim for long-term monitoring but faced the challenge of shortening financial support. Hence in the latter two rounds (2013 and 2017), we used a randomly selected subset of sampling grids in the third round. Overall, sampling grids surveyed in the first two rounds (before 2009) are rarely resampled in the following three rounds (after 2009), and the number of sampling grids differed between rounds. The disparity of sampling
grid characteristics (Figures S1, S2, S3, S4) and survey efforts between rounds thus presents a challenge for population trend assessment.

On the other hand, we applied a standard survey protocol to count the number of Fairy Pitta at each survey point throughout all five survey rounds. All surveys were conducted from late April to mid-May, which is the Fairy Pitta’s prenesting to early nesting period. At each survey point, we adopted a 5-minute duration playback-method protocol described by Lin, Lee, Ding & Lin (2007). Playback surveys conducted at this time period with this method have a 90% detection rate of the individuals occupying the site (Lin, Lee, Ding & Lin, 2007). Surveys were conducted by experienced birders, who received training in workshops and tutorials on the playback method, to ensure consistent data quality. For every pitta individual detected by both vocal and visual cues, we recorded the individual’s distance and angle from the survey point. We used this information to avoid potential double counting. As Fairy Pittas are sexually monomorphic, and both sexes respond to playbacks with similar songs indistinguishable to the human ear, all single counted individuals were included in the count data used in the following analysis. The consistency of the Fairy Pitta counting method at each survey point thus provides a more promising basis for between-year analyses such as population trends.

### 2.2 Population trend analysis of Fairy Pitta

We used log-linear Poisson regression models (ter Braak et al., 1994) to analyze the population trend of Fairy Pitta from 2001 to 2017. The response variable of the model is the count number of the Fairy Pitta at each survey point in each year, and the explanatory variable is the corresponding survey year of the survey event. All the six individual years (2001, 2002, 2005, 2009, 2013, 2017) were used in the model, irrespective of each year’s corresponding survey rounds.

To account for the disparity of sampling grid characteristics and survey effort between survey rounds, we assessed the degree of disparity between site characteristics and survey effort between years. We first categorized the total set of survey points of all rounds into different levels of habitat suitability. Levels of habitat suitability were based on the eight habitat suitability classes defined by Lin et al. (2009), which forms the basis of the sampling grid selection scheme in 2009. These eight classes were determined by categorizing the predicted probabilities of occurrence from a logistic regression model used to predict the suitable habitat of Fairy Pitta (Lee et al, 2005). The eight classes are each equally sized with approximately 2660 grids. The average density of individual birds increased with class level (Lin et al., 2009), hence, it could be used as a summary index for habitat suitability. Second, in addition to habitat suitability, we also considered the six climate ecoregions defined by Su (1992), as different monsoon seasons in the southwest and northeast resulted in different rainy seasons across parts of Taiwan (Chen & Chen 2003). A large difference in survey effort was found to be obvious between survey rounds, habitat suitability classes, and climate ecoregions (Figure 2). Accordingly, the minimum consistent survey effort is one sample size (i.e., bird individual count of one survey point) per round across every combination. This criterion of sample size was then used in the resampling procedure described in the following trend analysis progress.

To account for the disparity in survey effort between survey rounds, habitat suitability, and climate ecoregions described above, we used a spatial–temporal resampling procedure as a nonparametric bootstrapping method to acquire the confidence interval of model coefficients. For each subsample, we randomly selected one survey point from each spatial combination (including climate ecoregion and habitat suitability class), temporal division (i.e., the survey rounds), and presence or absence category. The presence and absence data were defined for every sampling grid according to whether the sampling grid has detected Fairy Pitta in any of the survey rounds. Adding this category accounted for the disproportionately high amount of zero data that is common in rare species’ monitoring data. Only one of the spatially repeated survey points were used as the individual count of each sampling grid. This resampling procedure alleviates the spatial biases of survey effort caused by the different sampling schemes between years and uses case–control sampling to improve data balance between detection and non-detection cases (c.f. Fink et al., 2020). The 95% confidence interval of the population trend was then acquired by obtaining the 2.5% and 97.5% percentile values of the model coefficients of the year variable from 1000 subsamples. The trend is considered significant if both values were lower than zero or vice versa, and a non-significant trend was determined when zero was included within the 95% confidence interval. The above bootstrapping method is also used to acquire the mean and confidence interval of the Fairy Pitta densities in each survey round.

### 2.3 Effect of forest cover change on Fairy Pitta

To test the hypothesis that the Fairy Pitta population is affected by the change in forest cover in Taiwan, we used
forest cover data from the European Space Agency Climate Change Initiative’s Land Cover (ESA CCI LC). The ESA CCI LC provides global land cover data, gathered between 1992 and 2019, with a resolution of 300 m (ESA 2017). We combined tree cover and mosaic tree-related land cover types that are present in Taiwan in the ESA CCI LC (Table 2) to represent the area of forest cover (km²) in each year. The degree of forest cover change was calculated by subtracting the amount of forest cover in each year from the baseline year of 2001. Hence, we obtained the total forest cover change in our study area, which is the forested area of Taiwan within 0–1000 m asl, and the mean forest cover change in our sampling grids.

To directly relate forest cover to the number of Fairy Pitta, we applied a resampling scheme of three different grid sizes: the original 1 km² sampling grid, and two additional grids of 5 km² and 10 km². The additional resampling schemes were based on our knowledge of Fairy Pitta breeding behavior in Taiwan, where the

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**TABLE 2** Value and label of land cover types in ESA CCI LC categorized as forest cover in this study

| ESA CCI LC Value | Label                                                                 |
|-----------------|----------------------------------------------------------------------|
| 50              | Tree cover, broadleaved, evergreen, closed to open (>15%)            |
| 70              | Tree cover, needle leaved, evergreen, closed to open (>15%)          |
| 80              | Tree cover, needle leaved, deciduous, closed to open (>15%)          |

*Values that are related to tree cover in the ESA CCI LC legend but not included here are for land cover types that were not present in our study area.
nesting site of an individual has been found to be within 4 km of its first ringed location (unpublished data from R. S. Lin). Thus, we assumed that besides the original 1 km² sampling grids, forest cover change within 5 km² grids or 10 km² grids (assuming the 4 km movement as diameter and radius, respectively) also affects the Fairy Pitta breeding population within. Furthermore, to reduce the disparity in survey effort between survey rounds and focus on the Fairy Pitta occupied sites, we excluded grids that have repeated less than four rounds and have never detected Fairy Pitta in each resampling scheme. Although this procedure significantly reduced sample size, for instance, the total sample size reduced from 24,297 to 2427 on the 1 km² scale, it improved the data quality to test our hypothesis.

To examine the effect of forest cover change on the population of Fairy Pitta in the 17-year time frame in our study area, we used a generalized linear mixed model with Poisson error distribution using the glmmTMB package (Brooks et al., 2017). The number of Pitta counted at each survey point in each year was the response variable. The year of survey, area of forest cover (km²) at the survey year, and their interaction were included as explanatory variables. Sampling grid ID was added as random effects, together with random slope and intercept of year for each sampling grid, allowing grid-specific variation in Fairy Pitta trends. This was done for each of the 1, 5, and 10 km² resampling schemes, with the size of the sampling grid changing respectively. We did not detect significant spatial autocorrelation in all three resampling schemes according to semivariograms (Figure S5). We expected to see a decline in the Fairy Pitta population in grids with a declining forest cover if the main threat to the species is breeding habitat loss, as found by previous assessments (Birdlife International, 2021).

All statistical analyses were performed using R version 4.1.1 software (R Core Team, 2021).

3 | RESULTS

3.1 | Breeding population trend of Fairy Pitta

In the five survey rounds between 2001 and 2017, we detected a total of 1191 Fairy Pitta individuals from 24,297 playback survey points. This result equals a mean of 2.04 (95% CI: 0.00–5.89) individuals per km² of Fairy Pitta detected across our study time. The overall number of Fairy Pitta appear to have decreased from over 4.32 (95% CI: 1.96–6.68) individuals per km² in the first survey round before 2002, to 0.82 (95% CI: 0.00–2.45) individuals per km² in 2017 (Table 1). This observation was supported by the population trend analysis, which revealed an overall −8.31% annual rate of decline (95% CI between −15.50% and −1.16%) for Taiwan Island.

3.2 | Effect of breeding habitat change on Fairy Pitta

Forest cover in the 0–1000 mamsl region of Taiwan experienced an annual rate of decline of −0.22% in the 17-year study period. This is a loss of 3.67% (446.0 km²) of the total forest cover (12,172 km²) in the breeding region of Fairy Pittas since 2001. For sampling grids in the three resampling schemes, the annual rate of forest cover loss for the 17-year study period was −0.22%, −0.15%, and −0.20% for the 1, 5, 10 km² resampling schemes, respectively. These numbers closely matched the changes for 0–1000 mamsl in all of Taiwan. Furthermore, we did not find consistent, significant effects of forest cover either on the Fairy Pitta numbers, or effect of forest cover on the Fairy Pitta population trend (through interaction between year and forest cover), in all three resampling schemes (Table 3, Figure 3).

4 | DISCUSSION

We found a significant decline of −8.31% per year in the Fairy Pitta breeding population, along with a decline of −0.22% per year in forest cover in Taiwan during the 17-year survey period. However, both the total amount of forest cover change in Taiwan and the effect of forest cover change in each sampling grid cannot explain the level of Fairy Pitta population decline. Although our model inference is on an index of the Fairy Pitta population size without accounting for imperfect detection, as the playback method we adopted have an on average 90% detection rate (Lin, Lee, Ding & Lin, 2007), we believe our findings reflect the true population trend and changes in population size. Thus, the hypothesis that the population trend of Fairy Pitta is affected by changes in forest cover in Taiwan is not supported. This contradicts the predictions that breeding habitat loss due to deforestation is the main threat to this endangered species (Birdlife International, 2021). Here we discuss the implications of our findings for local and regional habitat conservation and threat management.

4.1 | Local conservation implications in Taiwan

Deforestation was once a major conservation issue in Taiwan. Large-scale industrialized deforestation activity
in the mid-20th century has brought forest areas to a historical low point of 51% uncleared (Chen et al., 2019). However, after a ban on forest harvesting since 1992, forest cover has recovered remarkably to 67% in the late 20th century (Forest Bureau, 2015). Using 300 m resolution land cover data from the ESA CCI LC, we identified a −0.22% annual loss of forest in total potential breeding habitats across Taiwan since the start of our study. Such declines, mostly in the southwest region of Taiwan, were caused by landslides in the mountains after extreme climate events such as the Typhoon Morakot in 2009, which brought a record-setting 2965 mm rainfall in just 4 days (Wu, 2013). Nevertheless, the −8.31% population trend of Fairy Pitta was more severe than can be explained by breeding habitat loss. Furthermore, our grid-based analyses showed that the changes in the Fairy Pitta population did not significantly relate to the changes of forest cover. Hence, we cannot find the support of population decline due to deforestation in the scale of our study. Alternative hypotheses, such as breeding habitat degradation, along with other major threats in Taiwan and its wider distribution are then to be considered.

Breeding habitat degradations will affect the Fairy Pitta in factors not reflected in our 300 m resolution for- est cover data. Potential factors include changes in forest understory structure, changes in forest vegetation composition, and reduced food availability due to changes in external factors such as climate. Regretfully, such habitat data are not available island-wide in Taiwan, hindering our ability to test these alternative hypotheses. Potential

| Resampling Schemes | Number of samples (i.e., grids) | Number of repeated survey points | Model variables | Effect of forest cover on Fairy Pitta numbers |
|--------------------|---------------------------------|---------------------------------|-----------------|---------------------------------------------|
| 1 km² grid         | 112                             | 2427                            | Intercept       | Estimate  Std. error  Z-value  p-value  Significance |
|                    |                                 |                                 | Year            | −1.788     0.332   −5.379  <.001  ***            |
|                    |                                 |                                 | Forest Cover    | −0.052     0.031   −1.667  .096               |
|                    |                                 |                                 | Interaction between Year and Forest Cover | 0.040     0.041   0.991  .322               |
| 5 km² grid         | 96                              | 4524                            | Intercept       | −0.838     0.250   −3.349  .001  **             |
|                    |                                 |                                 | Year            | −0.116     0.028   −4.131  <.001  ***            |
|                    |                                 |                                 | Forest Cover    | −0.024     0.017   −1.446  .148               |
|                    |                                 |                                 | Interaction between Year and Forest Cover | 0.002     0.002   1.112  .266               |
| 10 km² grid        | 75                              | 5519                            | Intercept       | −0.867     0.226   −3.829  <.001  ***            |
|                    |                                 |                                 | Year            | −0.088     0.029   −2.979  .003  **             |
|                    |                                 |                                 | Forest Cover    | −0.004     0.004   −0.948  .343               |
|                    |                                 |                                 | Interaction between Year and Forest Cover | 0.000     0.000  −0.031  .976               |

Note: p < 0.05; **p < .01; ***p < .001.
supporting evidence of such a view will be that if the population decline of the Fairy Pitta is caused by habitat degradation, it will affect other sympatric species that share the same ground-nesting and insect-foraging niche with the Fairy Pitta. Two species, the Dusky Fulvetta (Schoeniparus bruneus) and the Taiwan Scimitar-Babbler (Pomatorhinus musicus), are known to share such characteristics with the Fairy Pitta in Taiwan (Chen et al., 2015). Although there are no wildlife monitoring projects in Taiwan that have the same survey period as our study, an island-wide breeding bird monitoring project from 2009 to 2020 reveals that the breeding population of the two species is either relatively stable (Dusky Fulvetta) or even slightly increasing (Taiwan Scimitar-Babbler) (Fan et al., 2021). We thus cannot find relevant data and evidence of large-scale breeding habitat degradations in Taiwan.

Besides habitat loss, hunting was also once a major threat to Fairy Pittas in Taiwan. To date, the largest known single count of this species being traded is the 294 individuals found in the Sun Moon Lake specimen shops of central Taiwan in July 1967 (Severinghaus, 1970). However, recent surveys of the wild bird trade in Taiwan have revealed that the number of illegal hunting cases has largely decreased, with remaining trades mostly focused on non-forest and common species for “mercy release” in religious ceremonies (Lin & Pursner, 2020). Hunting, along with other human disturbances, is also assessed to have a very low impact (less than 1%) on Fairy Pitta’s nest failure, based on the breeding outcome of 54 videotaped nests in a hill-side forest close to human settlements (Chen et al., 2015). The significant decline of Fairy Pitta, at least for the Taiwanese population, may have had very little influence from hunting under current circumstances. As major threats of this migratory species in its breeding ground have been ruled out locally, threats from regions other than Taiwan may need to be considered.

5 | REGIONAL CONSERVATION IMPLICATIONS IN EAST ASIA

Habitat loss is a major threat to migratory birds of the world’s flyways, including landbird species in the EAAF (Bairlein, 2016; Vickery et al., 2014; Yong et al., 2021). In particular, loss of forest breeding habitat is considered a major concern in the EAAF, because many endangered migratory landbirds are forest breeding birds, including the Fairy Pitta (Birdlife International, 2021). The patterns of deforestation accompanying economic development in East Asia, such as the increasing deforestation and degradation of forests in many parts of Mongolia, eastern Russia, and southeast China (Hansen et al., 2013), are believed to be the major sources of forest breeding habitat loss. Due to limited monitoring data, the population trends of the majority of forest-dependent migratory birds in EAAF are unavailable. Exceptions are studies in Japan and South Korea, where the distributions of several forest-dependent long-distance migrants are declining based on breeding atlas data (Amano & Yamaura, 2007; Kim et al., 2021; Yamaura et al., 2009). Notably, in these studies, the population decline of migratory birds were seldomly identified with corresponding forest loss in its breeding area, which are consistent with our findings.

Considering the conservation of migratory species, in addition to habitat loss in its breeding range, the impact of habitat loss in the wintering range has also been identified as a significant cause (Bairlein, 2016; Kirby et al., 2008; Newton, 2004). Population declines in European and North American breeding migratory landbirds have been attributed to land-use and land cover changes in its wintering ranges (Taylor & Stutchbury, 2016; Walthé, 2016). In the EAAF, the impact of broadleaved evergreen forest loss is gaining attention, with large-scale forest loss in Southeast Asia being identified during the last two decades (Hansen et al., 2013). This forest type is known to be the wintering habitat for more than 50 species of migratory landbirds in the EAAF (Yong et al., 2015). Although there have been warnings about the severe impact of forest loss on threatened migratory species (Sodhi et al., 2010), direct observations of the effect of wintering habitat loss on migratory landbirds are still scarce (Yong et al., 2015). Earlier studies from Japan provide indirect evidence; for example, seven species of summer visitors including the Japanese Paradise Flycatcher (Terpsiphone atrocaudata), have largely declined when no serious habitat destruction has been observed (Higuchi & Morishita 1999). Further, Yamaura et al. (2009) found that the observed population dynamics of breeding birds in Japan may be affected by land-use changes from other countries. For example, deforestation in Southeast Asia, the region where most of the forest-dependent long-distance migratory birds of the EAAF overwinter, will result in fewer breeding individuals in Japan.

Although studies in Japan and other countries have not included our target species, we suggest that the Fairy Pitta may encounter very similar circumstances. The Fairy Pitta’s currently known wintering habitat type on Borneo is mostly in lowland rainforest (Birdlife International, 2021). Borneo is an island with one of the highest deforestation rates in the world (Hansen et al., 2013). There was an estimated 14% (6.04Mha) decline in Bornean forests between 2001 and 2017 (Gaveau et al., 2019). This negative impact on the Fairy Pitta’s wintering range is expected to be reflected breeding population numbers, in which we have observed a drastic decline. Nonetheless, the wintering distribution of the Fairy Pitta is still very poorly understood because of the
species’ notoriously elusive behavior and a lack of data collection in this region. Recently, new records of immature Fairy Pittas found outside Borneo, in Java and Sumatra, in late October and November 2019 (Aminuddin et al., 2021), suggest either the possibility of effects from decreasing forest habitat, or that the wintering distribution of Fairy Pitta maybe wider than previously thought. Furthermore, threats other than deforestation, such as hunting, may also be an important threat to the Fairy Pitta.

Hunting migratory landbirds at stop-over or wintering sites is a historical and ongoing critical threat in the EAAF (Heim et al., 2021; Li & Wilcove, 2005). For example, the sharp decline of the Yellow-breasted Bunting was mostly due to the heavy hunting load that occurred at its stop-over sites in China (Heim et al., 2021; Kamp et al., 2015). Historically, pittas have been known to be widely traded, and this appears to be an ongoing phenomenon (Chng & Eaton, 2016; McClure & Chaiyaphun, 1971; Round, 1990). However, information regarding the level of hunting pressure outside the Fairy Pitta’s breeding range is scarce. Confirmed cases of hunting in the last two decades at non-breeding sites include records from a village on Hainan Island in 2003–2005 (Liang et al., 2013). The findings of several other surveys of the bird trades in Lao and Java Island did not report finding the Fairy Pitta (Santi, 2018; Shepherd et al., 2015). Combined with recent surveys in Taiwan, we cannot find evidence of a strong impact of hunting on the Fairy Pitta, both in and outside its breeding range. The dramatic loss by hunting of the Yellow-breasted Bunting, and other similarly affected Emberiza species (Choi et al., 2020; Heim et al., 2021; Tamada et al., 2017), occurred in mostly grassland species, suggesting that forest migratory landbirds may be declining due to different threats.

6 | CONCLUSION

Habitat loss, hunting, and climate change are the three globally recognized threats to migratory species (Bairlein, 2016). In this study we focused on the effect of habitat loss on the Fairy Pitta breeding population in Taiwan and found no significant effect while the species’ population declined rapidly. Additionally, we were unable to find strong evidence that hunting, the other major threat used to justify the IUCN Vulnerable Red List status of a species (IUCN 2021), affects the Fairy Pitta. Due to a lack of empirical data, the effects of climate change on not only the Fairy Pitta, but all migratory landbirds in the EAAF, is unknown (Yong et al., 2015). However, compared to the declining breeding population in Taiwan, the latest Report of the Breeding Bird Atlas of Japan revealed that the Fairy Pitta’s range is expanding significantly at higher latitudes (Ueta & Uemura, 2021). If this is the response of Fairy Pitta to climate change, it may have critical conservation implications for future studies. Nonetheless, only with sufficient data monitoring, such as that undertaken in Taiwan, Japan, and South Korea, can we unveil the causes of population dynamics of threatened species. The lack of distribution and abundance data in the Fairy Pitta’s wintering ground, as well as in other breeding regions such as Southeast China, is the critical data gap that needs to be addressed to successfully halt the decline of this globally threatened species. Therefore, this study highlights and supports the call for full annual cycle research of migratory birds (Marra et al., 2015), especially on range-wide population trends (Yong et al., 2021), stressing its vitalness to conserving endangered migratory landbirds in the EAAF. Future climate change related studies are also needed, particularly for forest birds, as interaction between non-breeding forest loss and rising temperature is a further sign of susceptibility to global change (La Sorte et al., 2017).

AUTHOR CONTRIBUTIONS

Pei-Fen Lee and Ruey-Shing Lin conceived the idea. Ruey-Shing Lin and Jerome Chie-Jen Ko jointly designed the study. Jerome Chie-Jen Ko and An-Yu Chang analyzed the data. Jerome Chie-Jen Ko and Ruey-Shing Lin wrote the first draft of the manuscript. All authors reviewed, edited, and accepted the final version of the manuscript.

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CONFLICT OF INTEREST

The authors report no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data supporting the results of the study can be accessed upon reasonable request from the corresponding author.

ORCID

Jerome Chie-Jen Ko https://orcid.org/0000-0002-8343-604X

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**SUPPORTING INFORMATION**

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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