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Promoting bird conservation in wetland-associated landscapes: Factors influencing avian crop damage and farmers' attitudes

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A R T I C L E I N F O

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A B S T R A C T

Integrating agroecosystems as bird habitats are very important for long-term conservation planning because intensified agricultural land use has been a global threat to avifauna. To make agriculture compatible with conservation, farming communities play a vital role because the adoption of bird-friendly agricultural practices and involvement in bird conservation initiatives depends much on their acceptance and attitudes toward avian species. In this study, we interviewed 367 farmers surrounding the Indawgyi Wetland Ecosystem in Myanmar to investigate the distribution of avian damages to agricultural crops as well as farmers' perspectives about damage mitigations and bird conservation. Results showed that bird-inflicted crop losses were higher in fields close to water and farmers who experienced a higher level of crop damage were more supportive of the need for a compensation scheme and control management of exploiting species. However, when the level of crop damage increased, farmers living away from water became more negative toward the involved species than those living close to water. Findings also indicated that farmers' willingness to conserve birds decreased with increasing distance to water. Villages adjacent to the lake zone were more willing to conserve both exploiting and non-exploiting birds than those living along the stream. We suggest ecosystem-friendly damage mitigation measures and coexistence strategies, especially in areas close to the water, maintaining both bird conservation objectives as well as farmers' economic objectives.

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1. Introduction

Anthropogenic land use change is one of the major drivers of global biodiversity loss (IPBES, 2019). With growing food demand to feed burgeoning human population, most natural ecosystems have been increasingly modified exposing huge pressures to several taxonomic groups (Harfoot et al., 2021; IPBES, 2019). Agricultural cultivation is the most wide-spread form of land use change and has been the greatest threat to avian communities as well as it has provided humans the most important natural resources of all; food (Harfoot et al., 2021). At present, agricultural land comprises 11% (1.5 billion ha) of global land area and the rate of agricultural expansion has been increasing (Bruinsma, 2017). Consequently, more than half of wetlands of international importance have deteriorated, and remaining areas are at high risk of degradation due to agricultural intensification and pollution (Convention on Wetlands, 2021; Davidson, 2014). Sustainable agricultural practices and sustainable use of wetlands are thus crucial to prevent further deterioration of important bird habitats and mitigate species endangerment (Convention on Wetlands, 2021; Elphick, 2010).

Although agricultural lands may not replace natural habitats, they play a vital role for birds as resting and foraging grounds (Stafford et al., 2010). Avian use of agricultural landscape has been widely demonstrated by previous studies, mostly in rice, wheat, corn, and sunflower fields (Blount et al., 2021; Can-Hernández et al., 2019; Elphick, 2010; Merkens et al., 2012; Stafford et al., 2010). Paddy fields support more than 30% of bird species found in Korea and Japan (Fujioka et al., 2010) and 27% of birds in the Indian subcontinent (Sundar and Subramanya, 2010). Some waterbird species like Whistling Ducks (*Dendrocygna* spp.) and Swamphens (*Porphyrio* spp.) use rice fields as both feeding and nesting habitats (Pierluissi, 2010). In addition, crop land and stubble fields are important stop over sites for migratory birds (Blount et al., 2021). If sustainably managed, crop fields could be suitable habitats for globally threatened species like Sarus Crane *(Antigone antigone)* (Elphick, 2010; Fujioka et al., 2010; Sundar and Subramanya, 2010). Studies by Elphick (2000) and Reynolds et al. (2017) in Central Valley area of the United States concluded that seasonally flooded cultivated plains are managed wetlands and could function as useful bird habitats in areas where natural wetlands have deteriorated and some of these seasonally flooded cultivated plains have been protected as “Important Bird Areas” (Amano et al., 2008). The role of agricultural ecosystems as bird conservation areas is therefore increasingly recognized, and agri-environmental schemes are widely implemented in Europe and America (Amano, 2009; Herzon and Mikk, 2007; Kross et al., 2018).

Despite the recognition of agricultural ecosystems for avian conservation, such areas can easily experience high levels of conflict if human-wildlife interactions are not properly integrated in habitat management (Fox et al., 2017; Hong et al., 2021). Previous studies on human-wildlife conflicts have demonstrated that negative interaction between people and wildlife have led to population declines of wildlife species including threatened mammals (e.g., elephants) and carnivores (tigers, leopards, and wolves) (König et al., 2020; Redpath et al., 2013). Concerning avian species, crop depredation and trampling from large number of birds in agricultural fields have often resulted in human-wildlife conflicts worldwide (Araneda et al., 2022; Fox et al., 2017; Simonsen et al., 2016; Sundar and Subramanya, 2010). Typically, the most common species involved belongs to large grazing waterbirds like ducks, geese, cranes, and flamingoes as well as small granivorous birds such as weavers, doves, and blackbirds (de Grazio, 1978; Fox et al., 2017; Sundar and Subramanya, 2010; Tourenq et al., 2001). Bird consumption implies direct socio-economic costs on farmers’ livelihoods through the loss of crops or indirect opportunity costs (time and manpower) for guarding the crops (Araneda et al., 2022; Fox et al., 2017). Vulnerability to economic loss is more pronounced in subsistence farmers in less-developed countries, coupled with uncertainty in crop production with changing climate (Araneda et al., 2022). Economic losses from these socio-economic costs have frequently resulted in negative attitudes resulting in opposition by farmers toward the species and conservation initiatives (Canavelli et al., 2013; Jacobson et al., 2003; van Velden et al., 2016). As people’s willingness to coexist with wildlife is shaped by the magnitude of impact, attitudes, and values toward the involved species, understanding these attributes is pivotal for coexistence intervention (König et al., 2020; Redpath et al., 2013).

In lack of coexistence interventions, persecution of damage-inflicting species is often reported in highly affected areas due to reduced level of farmers’ tolerance toward the species. For example, Borad et al. (2001) showed that when the natural wetlands were highly degraded in India, the Sarus Crane occupied and extracted resources from nearby paddy fields, which caused severe human-wildlife conflicts resulting in population declines of cranes. The consequences of such conflicts are not only limited to the targeted species, but also to non-targeted animals when toxicants are deployed as control measures (Can-Hernández et al., 2019). Bennett et al. (2018) reported similar form of conflict with Red Crowned Cranes (*Grus japonensis*) in a wetland reserve in China where eco-compensation schemes are being developed as part of conflict resolution mechanisms. This evidence suggests that conservation of birds near wetlands needs to integrate the economic consequences for local livelihood and perspectives of nearby communities, especially in areas overlapping with migratory flyways (Fox et al., 2017; King et al., 2010; Montràs-Janer et al., 2020; Nilsson et al., 2016; Redpath et al., 2013).

Myanmar is located within two major migratory flyways: East-Asian-Australasian Flyway and Central Asian Flyway and support thousands of migratory birds (BirdLife International, 2022). The country hosts 1034 including 58 globally threatened, avian species in its diverse habitats (BirdLife International, 2022). Many of these inhabit biodiversity rich habitats such as wetlands and coastal areas. Resulting from agricultural-based economy, these habitats are threatened by further conversion into agricultural land including drainage, logging, and infrastructure, as well as pesticide application and human disturbances from adjacent areas (Chan et al., 2004). These threats have been intensified by people’s reluctance to adopt conservation practices because of conservation conflicts. Such conflicts involve direct impacts of wildlife species to local economy, for instance, wildlife depredation to crops and indirect impacts from the clash of interests between those seeking to protect species or habitats e.g., land use conflicts (Htay et al., 2022). Therefore, in areas near wetland reserves where such conflicts arise, local farmers are the primary stakeholders to reduce threats and conservation goals should be reconciled with farming interests (Ahnström et al., 2009; Sundar and Subramanya, 2010; Wright et al., 2012).

Although avian research has been limited in Myanmar, available literature has consistently identified that agricultural lands are important habitats for bird communities including threatened species (Platt et al., 2021; Shwe et al., 2021; Win et al., 2020). Despite this, agricultural land has not been integrated into bird conservation areas. One reason is that integration of agricultural landscapes into avian conservation areas without compromising agricultural production targets of farmers has been a challenge. Addressing this challenge is key to prevent severe declines in bird abundances with intensified agriculture (Platt et al., 2021). In this study, we investigate avian impacts on agriculture and farmers economic concerns, in Indawgyi Wetland Ecosystem, one of the six flyway sites of Myanmar. Specifically, we aimed to investigate and identify the avian species causing crop losses, to quantify the distribution and severity of crop damage and farmers' perspectives about crop damage and mitigation measures. To the best of our knowledge, this is the first study investigating socio-biological perspectives of avian conservation in agricultural landscapes of Myanmar and findings from this study should contribute to better and informed decisions for practitioners in developing appropriate conflict resolution mechanisms, as well as targeted conservation efforts.

Previous literature has demonstrated that bird species' use of agricultural fields is determined by landscape features, habitat structures, distance to major roosting sites, abundance, and quality of food (Amano et al., 2008; Araneda et al., 2022; Fox et al., 2017; King et al., 2010; Merkens et al., 2012; Nilsson et al., 2016). We therefore hypothesized that 1) the severity of bird damages (i.e., the proportion of crop lost) in agricultural land depend on farm location in relation to distance to water (e.g., distance to lake or streams) and village type (lake vs. stream), as well as farm characteristics such as land size and crop type. Additionally, we predicted that 2) bird

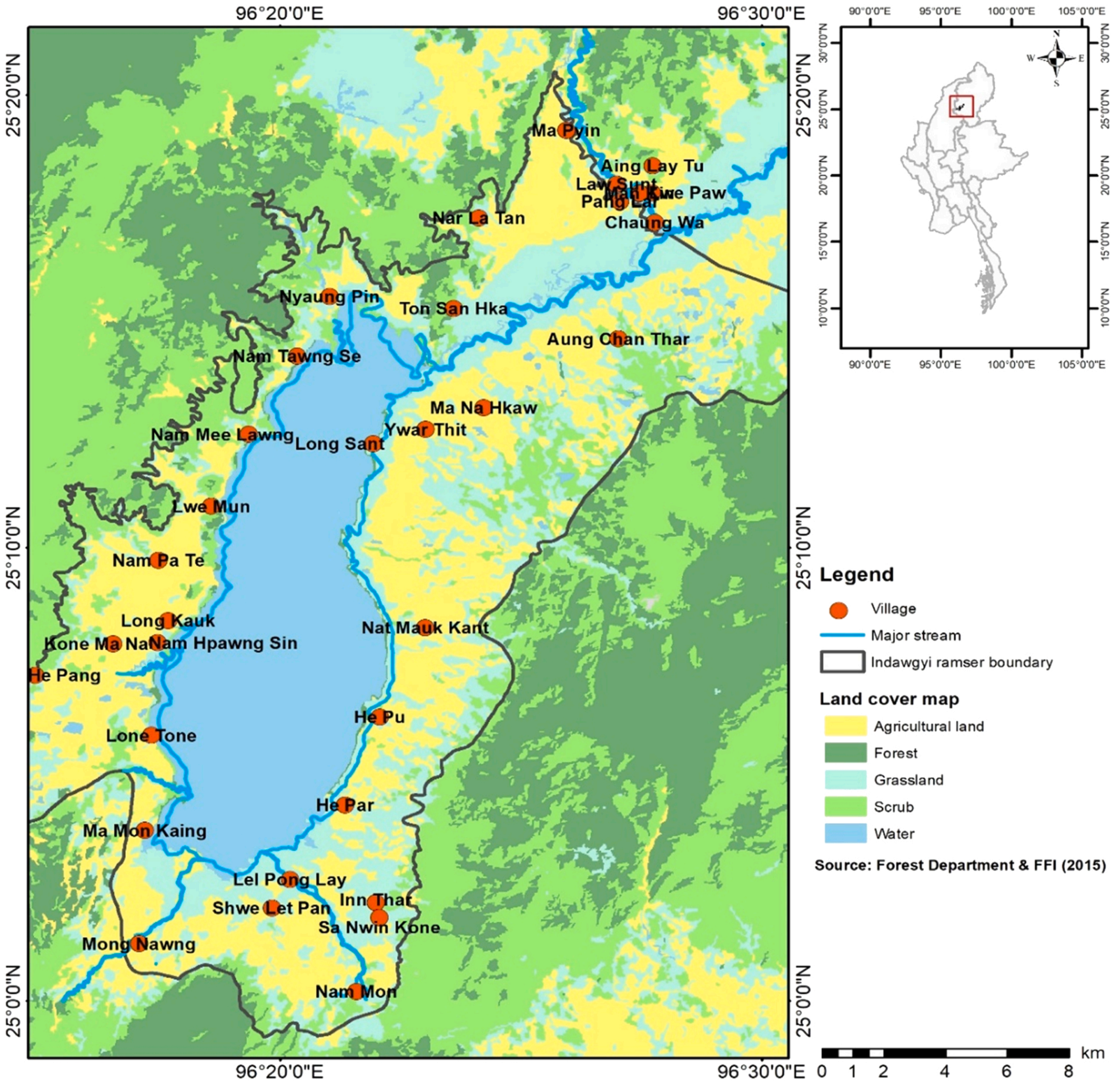

Fig. 1. Map showing the location of Indawgyi Wetland in Myanmar (upper right panel) and distribution of sample villages (red dots; main panel).

damage to agricultural crop would have negative impact on farmers attitudes toward the involved species (Canavelli et al., 2013; van Velden et al., 2016). Therefore, farmers who suffer higher level of damage are more likely to ask for damage mitigation measures and more supportive toward control management of the exploiting species (Herzon and Mikk, 2007; Kross et al., 2018; Smith et al., 2021). Likewise, these farmers will be less supportive to enable positive conservation of birds and damaging species (Silva-Andrade et al., 2016; Smith et al., 2021). Thus, identifying characteristics of farms underpinning attitudes toward wildlife are of utmost importance when managing vulnerable biodiversity rich wetland habitats.

2. Method

2.1. Study area

The study area, Indawgyi wetland, is located within Moehnyin Township, Kachin state in northern Myanmar (25°09'N, 96°21'E, Fig. 1) covering an area around 47,884 ha (Convention on Wetlands, 2022). The Indawgyi lake is the largest freshwater lake in Myanmar and the third largest in Southeast Asia (Forest Department, 2018). This ecosystem consists of a large open lake surrounded by floating vegetation areas, as well as herbaceous marsh, semi-inundated swamp forests and seasonally flooded grasslands. The vast areas of rice paddies surrounding the natural wetlands form part of the wetland ecosystem and provide extended feeding grounds for waterbirds. A total of 312 bird species have been recorded in the lake and its diverse habitats, and the area regularly supports more than 20,000 waterbirds (Forest Department, 2018). Thus, this area is of major strategic importance for bird conservation and has been designated as an Important Bird Area, a Ramsar site and an East Asian Australasian Flyway network site (Forest Department, 2018).

The region has a subtropical monsoon climate, with a mean annual rainfall about 1705 mm and a mean temperature 24.9 °C. More than 50,000 people in 36 villages inhabit the area around the wetland and are engaged in agriculture as the primary livelihood (Forest Department, 2018). The local agricultural system is mainly characterized by rice cultivation in a single cropping. The rice production cycle begins with preparation of the fields in May, followed by flooding and sowing from the second half of June until the end of July. Germination, growth, flowering, and ripening continue through August to September, and harvesting is in October and the first half of November (Forest Department, 2018). Due to favorable soil conditions in eastern and northern parts, villages in these areas are practicing double cropping in which rice harvest is followed by cultivation of peanuts or beans. Because of pressure from a growing human population, the region has experienced large-scale land-acquisition, deforestation and conversion of natural wetland and grassland into rice paddies (Chan et al., 2004).

2.2. Data collection

The study was conducted from April to July 2021. Before conducting the study, we first informed the village administration office about the study objectives and survey protocol and obtained agreement to conduct interview surveys. We then carried out informal discussions with the village authorities to learn more about wildlife crop damage and bird depredation on crops in each sample village. The minimum sample size required for the study area to obtain 95% precision (alpha - 5%) is 380 (Taro Yamane Formula, $n = N/1 + Ne^2$, where n = sample size, N = total number of households available, and e = margin error of sample (Yamane, 1967). Accordingly, we randomly selected 12 households from the village register of each of 33 villages around the Indawgyi wetland, a total of 396 households. In each of the selected household, we interviewed a household head or family member who was above 18 years old and agreed to participate in the survey. For ethical reasons, respondents were assured that their identity would be anonymous, and results would be used only for research purpose. Thereafter, we collected socio-economic data from inhabitants in the local villages using a questionnaire survey. A pilot survey was also conducted with a few local farmers to test questionnaire was clear and some adjustments were made, as necessary. A study permit to carry out this research was granted from the Ministry of Natural Resources and Environmental Conservation, Myanmar prior to data collection.

The survey questionnaire was structured into four parts (Supplementary Table 1). In the first part, we collected socio-economic background data, provided by the respondents; age (years), gender (male, female), education (number of years of education completed), household size (number of individuals in a household), household income (annual income in Myanmar Kyats) of each respondent. In the second part, respondents were asked if they had experienced any bird damage on their agricultural crops during the last year (12 months), their perceived extent of crop damage (in hectare), and their farmland size (hectare) and crop type (rice or mixed). Third, respondents were requested to identify the three bird species that caused the most severe damage for their crop. For each bird species, we recorded damage season, type of crop, stage of crop and mitigation measures. During interviews, we used printed photos of a set of bird species which are found in Indawgyi to help identify the involved species correctly. The photo set included 40 bird species that are both risky and non-risky to agricultural crops.

In the last part, we asked respondents concerning their attitudes toward bird species causing crop loss, crop damage mitigation, compensation, and future bird conservation. Regarding attitudes toward crop-exploiting birds, we asked respondents 1) whether they like the presence of those birds in their farms, and 2) whether they support control management of damaging-causing birds to control crop loss. Regarding attitudes toward crop damage mitigations, we asked 3) whether farmers perceive themselves as responsible to protect their own crop from bird damage and 4) whether they consider the park office to be responsible for the problem. Concerning attitudes toward compensation, we asked 5) whether the government provides economic compensation or other damage mitigation measures for farmers' economic loss, and 6) whether they support the need for compensation mechanisms. Regarding bird conservation, we asked 7) whether respondents want to protect birds of Indawgyi in the future and 8) whether they want to protect birds which have caused crop damage.

Among the respondents, 22 farmers did not own land and were therefore not able to describe the damaged area, were excluded from the analysis. Furthermore, our land size data included seven outliers, which were greater than three standard deviations of the mean (i.e., Z-score > 3) and we dropped out them from the analysis (Benhadi-Marín, 2018). Therefore, our final sample size included 367 farmers. Study villages were categorized into lake villages or stream villages depending on their location in the lake area or stream area, representing contrasting areas (see Fig. 1), where the stream area hosts lower bird abundances and these areas having different agricultural regimes (Htay et al., 2022). Each village distance to water was measured in kilometer as the minimum distance to the lake or stream based on digital map (Google Earth) and topographic maps provided from the Forest Department, Myanmar.

2.3. Statistical analyses

The given proportion of crop damage area (the ratio of crop damage area to farmland size) included an excess number of zeros and did not fit a binomial distribution. We, therefore, used a zero-inflated generalized linear mixed model (GLMM) using the beta family to quantify the distribution and severity of crop damage. The proportion of damaged area was included as a response variable and assumed to follow a beta distribution, whereas explanatory variables included distance to water (in km), farm size (in ha), crop type (rice or mixed crop), and village type (stream village or lake village). Village identity was included as a random factor to account for spatial autocorrelation among villages. We constructed a set of biologically relevant candidate models from different combinations of explanatory variables. First, we constructed separate models for each predictor variable, subsequently we added more predictors and finally we included interaction terms. In order to reduce the complexity of the models, we only allowed for two-way interactions. Zero-inflated GLMMs were fitted using *glmmTMB* package (Brooks et al., 2017).

To assess how crop damage influenced farmers' attitudes toward birds that exploited crops, we performed a GLMM with binomial distribution errors. Each attitude statement ("agree" or "not agree") was set as a response outcome (i.e., 1/0) and as explanatory variables we included crop damage and farm characteristics (proportion of crop damage, farmland size, crop type, distance to water and village type) as well as socio-economic variables (age, gender, education, income, and family size). For each attitude statement, we first constructed a global model which included all predictors. Then, we constructed alternative models in which crop damage was combined with different relevant predictors and interactions to test how socio-economic factors moderated the relationship between crop damage and farmers' views toward bird species causing crop damage. The variance among local villages was accounted for as a random factor in all fitted models. For each explanatory variable, we report their 95% confidence intervals (CI), which were calculated using *MASS* package in R (Venables and Ripley, 2002).

Before constructing the candidate models, a Pearson correlation matrix between all predictors were checked to avoid high intercorrelation. Due to high intercorrelation between farm size and family income level ($r_{pearson} > 0.800$, $P < 0.01$, n = 367), we used residuals from a regression model including farm size (explanatory variable) and income level (response variable). Moreover, collinearity among predictors was also checked for each model using the R package *performance* ver. 0.9.0 (Lüdecke, 2021).

In this study, we applied an information-theoretic approach to obtain multi-model inference based on Akaike's information Criterion for restricted sample size (AICc) (Burnham and Anderson, 2002). We only included candidate models that were biologically sound and relevant (i.e., avoiding data dredging). Thus, we employed the AICc model selection procedure to identify minimum adequate models and evaluated the performance of each model using AICc, AICc weights and AICc evidence ratio, given each model's support in the data and candidate models. We considered models with ΔAICc scores < 2 to be the best supported models (Burnham and Anderson, 2002). We assessed the appropriateness of the top-ranked models using residual diagnostics in the *DHARMa* package in R (Hartig, 2018). We also carried out power analyses to test if our sample size is large enough to detect the effects of variables found in the selected models. All statistical analyses were performed using R software ver. 4.1.1 (R Core Team, 2021).

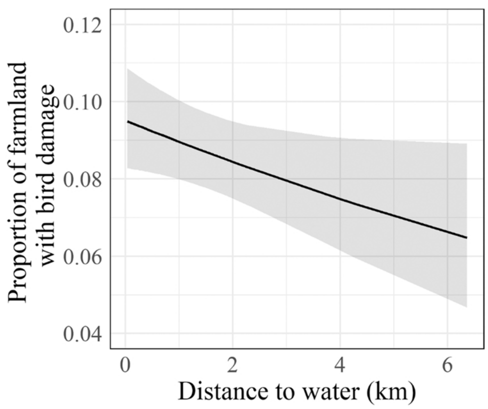

Fig. 2. Bird damage in agricultural crops around the Indawgyi wetland in relation to distance to water, based on estimates from Model 1 presented in Supplementary Table 3b.

3. Results

3.1. Factors influencing avian crop damage

Study villages were located within 0.03–6.36 km from the lake or stream (median = 0.86 km, n = 367). While 67.3% of households were situated around the lake area, 32.7% were located near the stream. Farm size per household ranged from 0.40 to 20.23 ha (median = 4.86 ha, n = 367). Among the households, 75.7% cultivated rice only, while the remaining 24.3% cultivated mixed rice with soya beans or peanuts.

When respondents were asked "Have you suffered avian crop damage during the last 12 months?"; 87.5% of respondents answered "yes" and 12.5% responded "no". Among households who had suffered crop damage, the proportion of damage area to the total land area varied from 0.001 and 0.750 (median = 0.04, n = 321) (Supplementary Fig. 1). Rice was the most affected crop type while the most challenging species causing crop damage were the Scaly-breasted Munia, *Lonchura punctulata* (39.9%), the Lesser Whistling Duck, *Dendrocygna javanica* (39.9%) and the Spotted Dove, *Spilopelia chinensis* (33.0%), the Baya Weaver, *Ploceus philippinus* (24.6%), and the Purple Swamphen, *Porphyrio porphyrio* (18.4%) (see Supplementary Table 2 for a complete overview).

We predicted that the proportion of bird damage area was related to distance to water, farm size, crop type and village type. Among the 19 candidate models, 4 models had AICc < 2 (Supplementary Table 3a). The most parsimonious model had AICc $_{weight} = 0.29$ given the data and set of candidate models. This model indicated that distance to water was the only important predictor of crop damage (Supplementary Table 3b), and the level of crop damage decreased for farms with increasing distance to the water ($\beta_{\text{Distance to water}} = -0.066$, $SE = 0.033$, CI: −0.131, −0.001) (Fig. 2). Alternative models also confirmed the effect of distance (model 2, 3 and 4, Supplementary Table 3b). We found no evidence that village type (i.e., lake or stream), farmland size or crop type influenced on the severity of crop damage. Evidence ratios among the best model and other high rank models showed that model 1 was 2.25 times more likely than model 2, 2.68 times better than model 3 and 2.70 times better than model 4 (Supplementary Table 3a).

3.2. Attitudes toward the presence of exploiting bird species

When respondents were asked about their opinion on the presence of damage-causing birds in their farms, the majority (78.7%, n = 367) responded that they were not satisfied with the situation. The remaining 21.3% said that they appreciated the presence of birds in their environment. We constructed 29 candidate models to predict the effects of crop damage and socio-economic factors on farmers' attitudes toward avian species that caused crop loss. Only one model had AICc < 2, and this model had AICc $_{weight} = 0.89$ given the data and candidate models (Supplementary Table 4a). Results showed that crop damage, distance to water and the interaction term were important predictors (Supplementary Table 4b). Attitudes were less positive in areas close to water independent of bird damage ($\beta_{\text{Distance to water}} = 0.275$, $SE = 0.107$, CI: 0.066, 0.485). However, with increasing distance to water, there was a stronger negative effect of bird damage, where farmers that had low proportion of damage were more positive, but affected farmers were more negative than close to water ($\beta_{\text{Bird damage * Distance to water}} = -7.232$, $SE = 2.329$, CI: −11.797, −2.667) (Fig. 3).

Among respondents, 47.1% (n = 367) responded that damage-causing avian species were perceived as pests and should be

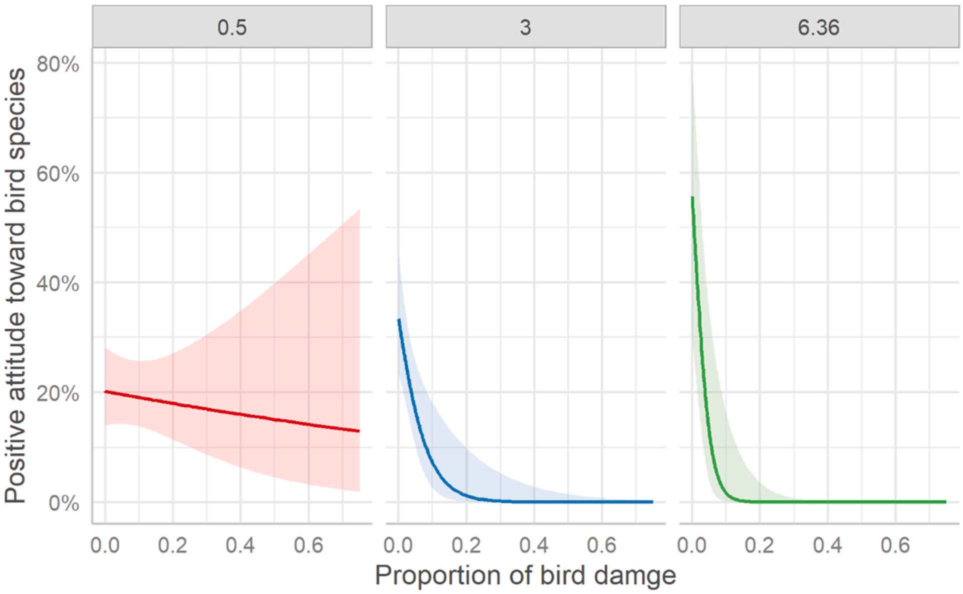

Fig. 3. Effects of crop damage on farmers' attitudes toward bird species which caused crop damage in relation to distance to water. Sub figures are presented according to increasing distance to water (km, showed in gray). The figure is based on the model presented in Supplementary Table 4b.

managed. However, 52.9% said birds should be tolerated and were opposed to the killing of crop-exploiting birds as a mitigation measure. Among 29 candidate models that predicted farmers' attitudes toward management of bird species involved in crop damage, two models had AICc < 2 (Supplementary Table 5a and 5b). The best model had AICc $_{weight}$ = 0.28 and indicated that the likelihood to agree with management of problem bird species (i.e., negative attitude toward the species) increased with the proportion of the damage of the farm ($\beta_{Bird\ damage}$ = 5.304, *SE* = 1.332, CI: 2.693, 7.916, Supplementary Table 5b; Fig. 4a) and farmland size ($\beta_{farm\ size}$ = 0.076, *SE* = 0.030, CI: 0.017, 0.136, Supplementary Table 5b; Fig. 4b). The evidence ratio between the top model and its lower-ranked model showed that the best model was 1.70 times more likely to be the best approximating model than the second-best model (Supplementary Table 5a).

3.3. Attitude toward crop damage mitigation

Almost all respondents (99.5%, n = 367) supported that they should be responsible for protection of their crops and mitigation of crop damage themselves. While 44.1% supported that park authority should be responsible, the remaining 55.9% assumed that park office had no responsibility for this matter. We constructed 29 candidate models to predict whether farmers considered that the park office should be responsible for the crop damage mitigation. Five models had AICc < 2, where the top model had AICc $_{weight}$ = 0.27 given the candidate models and the data (Supplementary Table 6a). The best model showed that bird damage and distance to water were the main predictors (Supplementary Table 6b). Respondents who experienced high level of crop damage ($\beta_{Bird\ damage}$ = 4.438, *SE* = 1.231, CI: 2.025, 6.850, Supplementary Fig. 2a) and lived closer to water ($\beta_{Distance\ to\ water}$ = −0.261, *SE* = 0.082, CI: −0.422, −0.101, Supplementary Fig. 2b) were more likely to agree that the park office should be responsible in controlling problem bird species. Model 4 showed that women were less likely to accuse the park office concerning bird damage problems ($\beta_{Gender\ (female)}$ = −0.693, *SE* = 0.237, CI: − 1.157, − 0.229, Supplementary Fig. 2c). Other alternative models (model 2, 3 and 5) also indicated the effects of bird damage, distance to water and gender. The evidence ratio among the top-ranking models demonstrated that the best model was 1.33 times more likely than model 2, 1.42 times more likely than model 3 and 1.8 times better than model 4 and 2.3 times better than model 5.

3.4. Attitudes toward compensation

All respondents supported that there was no involvement or assistance from the government concerning crop damage mitigation. Concerning attitudes toward compensation for crop damage, 33.2% (n = 367) of respondents requested a need for compensation mechanisms. However, 66.8% responded that such programs were not required. We fitted 29 models to investigate what factors determined the preference for compensation. Two models had AICc < 2, where the top model had AICc $_{weight}$ = 0.48 (Supplementary Table 7a). The best model showed that crop damage and gender were important predictors for compensation opinions (Supplementary Table 7b). Farmers who suffered higher economic loss due to crop damage ($\beta_{Bird\ damage}$ = 4.333, *SE* = 1.203, CI: 1.975, 6.690, Supplementary Fig. 3a) and men ($\beta_{Gender(female)}$ = −0.672, *SE* = 0.263, CI: − 1.187, − 0.157, Supplementary Fig. 3b) were more likely to agree with compensation. Model 2 also confirmed the effect of avian crop damage on respondents' preferences for compensation mechanism (Supplementary Table 7b). Evidence ratio between the two models showed that the model 1 was 1.94 times more superior than model 2.

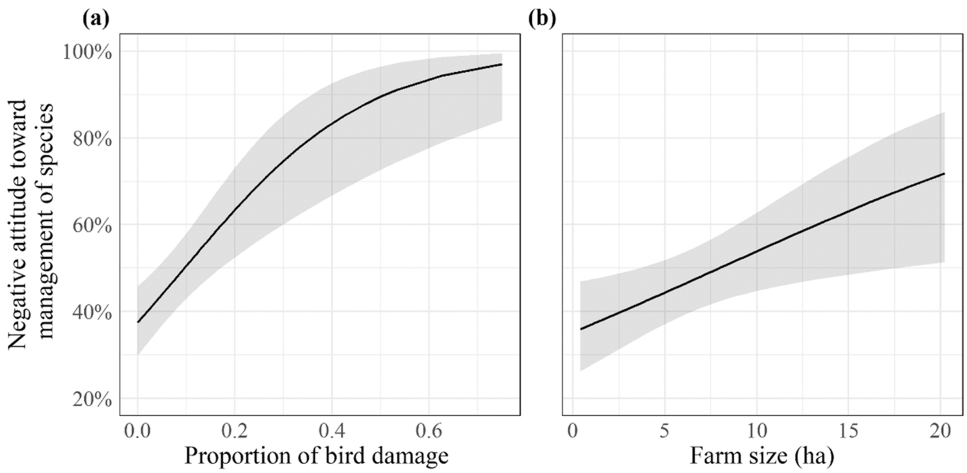

Fig. 4. Farmers' attitudes toward the management of bird species that caused crop losses in farms around Indawgyi wetland in relation to a) proportion of bird damage area and b) farmland size, based on estimates from Model 1 presented in Supplementary Table 5b.

3.5. Attitude toward future bird conservation

Concerning a more general protection of all bird species of Indawgyi, (including both damage-inflicted species and non-damage-inflicted species), 39.5% were positive while 60.5% were negative (n = 367). Out of 29 models fitted with different predictors, only one model obtained AICc < 2 (Supplementary Table 8a). Given the set of candidate models and data, the best model constituted 51% of AICc weight. The best model suggested that village type, distance to water, farmland size and gender were important predictors of support for bird conservation (Supplementary Table 8b). Villages closer to the lake as opposed to streams, were more likely to host positive attitudes toward protection of birds in general ($\beta_{\text{Village type (lake zone)}} = 0.792$, $SE = 0.265$, CI: 0.273, 1.312, Supplementary Fig. 4a). Farmers living away from water ($\beta_{\text{Distance to water}} = -0.190$, $SE = 0.079$, CI: −0.345, −0.034, Supplementary Fig. 4b), larger land holders ($\beta_{\text{farm size}} = -0.079$, $SE = 0.032$, CI: −0.141, −0.016, Supplementary Fig. 4c) and women ($\beta_{\text{Gender(female)}} = -0.667$, $SE = 0.247$, CI: − 1.151, − 0.182, Supplementary Fig. 4d) were less supportive to bird conservation. Although bird damage negatively influenced on conservation support, its effect was uncertain (Supplementary Table 8b).

Only 23.4% (n = 367) were positive to the protection of bird species causing crop damage. However, the remaining 76.6% said they were not willing to conserve those species. Among 29 models, there were two models with AICc < 2 (Supplementary Table 9a). The best model contributed to 45% of AICc weight and showed that village location was the only important predictor of people willingness to conserve exploiting bird species. Villages located near the lake were more willing to protect damage-inflicted species than those located near the stream ($\beta_{\text{Village type}} = 0.801$, $SE = 0.293$, CI: 0.227, 1.376, Supplementary Fig. 5). The second-best model also supported the effects of village type on farmers' support toward exploiting bird (Supplementary Table 9b). Despite negative effects of bird damage on conservation support toward damage-causing bird species, the effects were not certain (Supplementary Table 9b). The best model was 2.24 times more supported by data than model 2.

4. Discussion

The study demonstrates that avian crop damage as well as attitudes toward damage-inflicted species varies spatially and are shaped by complex multiple socio-economic factors, in a protected wetland area in Myanmar. The results raise the discussion of factors associated with uneven distribution of crop damage (King et al., 2010; Montràs-Janer et al., 2020; Nilsson et al., 2016) and possible management options to create shared landscapes focusing on relevant studies about avian use of agricultural land and sustainable management of protected wetlands area (Araneda et al., 2022; Glikman et al., 2021; König et al., 2020; Redpath et al., 2013).

4.1. Factors influencing avian crop damage

Our study showed that distance to water had the strongest effect on bird-inflicted crop losses and damage area was higher in fields closer to the lake or stream than those located relatively far. Severity of crop damage near water is likely to be associated with the abundance and distribution of damage-causing species, as most of the involved species were waterfowl and wetland-dependent birds (Amano et al., 2008; Sundar and Subramanya, 2010). Selection of a crop field could be attributed to optimizing their foraging behavior, where birds balance energy trade-offs and choose foraging sites where they optimize the food intake according to the travel efforts (Fox et al., 2017; Montràs-Janer et al., 2020; Nilsson et al., 2016). As the studied crop fields surrounded the wetland reserve with diverse habitat structures, farms located near water and major bird roosting sites may have attracted more birds and therefore suffered disproportionate costs of crop damage (King et al., 2010). Moreover, structural configuration of agricultural land cover may have influenced the spatial variation of crop damage (King et al., 2010; Stafford et al., 2010). The agro-ecosystem in Indawgyi is mainly characterized by rice cultivation with a single crop growing cycle. Although peanuts and beans are cultivated in some villages, crop fields in most villages are prepared after rice harvest until the next rice growing season. The agricultural landscape is therefore homogenous in each growing season and the type and surface area of crop seem not to be as important as flight distance for the birds in making foraging decision (Fox et al., 2017). Foraging near natural habitats may as well reduce the risk of predation, leading to a higher concentration of avian damage in areas where risk of predation is low (Subramanya, 1994; Whittingham and Evans, 2004).

Our study also found that species causing most damages were the Scaly-breasted Munia, the Lesser Whistling Ducks, the Spotted Dove, the Purple Swamphen and the Baya Weaver and these species affected rice fields most in the sowing stage and ripening stage. These species are also found to cause yield loss in agricultural fields in most parts of Asia (de Grazio, 1978) including India (Sundar and Subramanya, 2010), Sri Lanka (Horgan and Kudavidanage, 2020) and Malaysia Peninsula (Avery, 1979). Stafford et al. (2010) documented that exploiting waterfowl bird species particularly prefer rice for its high level of true metabolizable energy. Although weaver birds and munia are not very selective, they are more likely to favor milky rice and grains that are starting to ripen which are high in protein content (Avery, 1979; Jayasimhan and Padmanabhan, 2019). We found that farmers' observations of bird species in our study were similar to bird community analyses in other rice growing landscapes in a neighboring region of Indawgyi (Platt et al., 2021), Tamil Nadu of India (Jayasimhan and Padmanabhan, 2019) and northern Malaysia Peninsula (Munira et al., 2014). However, few birds were reported to cause damage in other crops (e.g., beans and peanuts). Availability of alternative feeding resources could also be a plausible reason for the reduced damage in other crops as observed by Amano et al., (2007, 2004). After the rice cultivation season, spill grains, weed seeds and other vegetation in harvested rice fields are freely available to birds until the next growing season (Platt et al., 2021). These fallow rice fields are being used by birds and subsequently reduce species accumulation and damage in other types of crops. The same phenomenon was found in Japanese rice lands around lake Miyajimanuma in which geese switch their diets to wheat only when the waste rice grains are depleted (Amano et al., 2007).

4.2. Farmers' attitudes toward crop-exploiting birds and crop damage mitigation

Our study demonstrated that bird damage negatively influenced farmers attitudes toward damage-causing species depending on farm distances to the wetland. When there was no bird damage, farmers living far from water were more positive toward these species. However, these farmers soon became less tolerant toward the species when the damage level increased (Fig. 3). This finding suggests that the level of exposure and coexistence with wildlife positively influenced farmers' attitudes and sensitivity toward birds in areas close to water (van Velden et al., 2016). Farmers living close to water reported that they were used to avian crop raiding and that it occurs annually in crop fields near the wetland reserve. They explained that they shared crops with birds because they are unable to scare all birds away. On the other hand, some farmers also expressed sympathy toward birds for their hunger and lack of food and regarded the losses as donation according to the principles in Buddhism. Can-Hernández et al. (2019) observed similar findings and these authors reported that farmers sympathized and tolerated the species for eating their food although they did not like the species.

Bird damage, however, is positively related to farmers' support toward the management and mitigation measures of the species in question (Fig. 4, Supplementary Fig. 2 and 3). Farmers suffering high level of damage are more receptive of managing damage-inflicted species (Canavelli et al., 2013). Farmers claimed that the cost of time and manpower to guard rice fields during the sowing stages and ripening stages are very high (see Supplementary Table 2). Furthermore, they reported that bird depredation on crop was highest during the rice ripening time as it coincides with bird migration season (Sundar and Subramanya, 2010). Farmers also claimed that birds become more abundant because of conservation and visual repellents are not effective to scare them away. They elaborated that, back in time, bird damage at the sowing stage was not a serious problem because rice was traditionally grown using transplantation method in which seeds were sown first in nursery bed and then seedlings were transplanted (Supplementary Table 2) to rice fields (Platt et al., 2021). However, due to intensive labor requirement in transplantation method and industrial development, the farmers nowadays practice a direct seeding method and birds that feed on rice seeds become problem. After the rice seeding period, unprotected fields are susceptible to seed loss also during the germination period. Also, second growing late in season is not preferable because rice cultivation is rainfall dependent (Sundar and Subramanya, 2010). Moreover, birds are unevenly distributed later in the growing seasons, accumulating on fields not yet germinated. Farmers said they shared the cost of damage by coordinating with other farmers to synchronize the cultivating and harvesting time to be the same time. For these reasons, larger land holders who require more efforts to bird repelling seem to be more aggressive and more supportive toward the management of the exploiting species (Fig. 4b).

Owners of the farms bordering the wetland reserve reported that they suffered more losses than farmers with more distant farms from the wetlands because some bird species like Lesser Whistling Ducks raid crops during the night, while other species are damaging during the day which also has been documented by Fujioka et al. (2010) in rice fields of Korea and Japan. In response to this, some farmers in the Indawgyi wetland area set up traps and net fences around the edges in most affected fields to hinder birds from entering the crop fields when human were not present. Even though such nets are illegal, respondents claimed that they must protect their farms using whatever method they think is effective. Some respondents said that trapping is somewhat effective, and birds usually avoid such areas. However, nets and traps cannot be installed during the day because the park patrolling team prohibit such lethal control activities (Forest Department, 2018). They criticized that park administration only educate farmers to protect the species and never consider the impact of the species they conserve (Supplementary Table 1). Farmers who suffer high levels of damage argued that park office is responsible for damage mitigation measures or compensation if they want farmers to conserve the species (Supplementary Fig. 2a and 3a). However, farmers living more distant to water and experienced a low level of damage, considered neither that park office is responsible for the birds, nor compensation is needed as bird damage is a natural disaster.

4.3. Farmers' attitudes toward conservation of birds

Although we found that bird damage had strong effects on farmers' attitudes toward birds that exploited crops, our study also showed that farmers' willingness to conserve birds were relatively weak. The location of the village matters most on attitudes toward the conservation of birds in general as well as conservation of damage-inflicting species. Farmers located close to water are more willing to conserve birds (both exploiting and non-exploiting species) (Supplementary Fig. 4a, 4d and 5). This may be associated with more favorable attitudes (Silva-Andrade et al., 2016; Smith et al., 2021) and higher tolerance to birds near the main conservation zone (van Velden et al., 2016). Exposure to conservation awareness programs, higher level of acknowledgment of benefits from the park and its species in villages closer to the lake could also be some reasons (Herzon and Mikk, 2007; Htay et al., 2022). Kross et al. (2018) also found that farmers opinions about bird species reflect their conservation behavior and people with positive attitudes are more likely to attract birds and engage in provision of nest boxes and wildlife friendly management. Similarly, Canavelli et al. (2013) found that farmers in Argentina with negative attitudes are more supportive toward lethal control of Monk Parakeets, *Myiopsitta monachus* whereas those with positive attitudes favors less invasive methods like habitat management or changes in agricultural practices. Our study also found that larger land holders who expressed support toward strict management of damage-inflicting birds are less willing to conserve birds (Supplementary Fig. 4b). Additionally, farmers' support toward birds dropped from 39.5% to 23.4% when they were asked if they were positive to conserve exploiting species.

Although socio-economic factors are often important in explaining people's attitudes in human-wildlife conflicts studies, our study found less variation among such factors, attitudes being more related to spatial factors (Fig. 3, Supplementary Figs. 2b, 4a, 4d and 5). Gender was the only important variable in some of the models for attitudes toward crop damage mitigation and bird conservation. Females were less likely to support the requirement of compensation (Supplementary Fig. 3b) and that the park office should be responsible for damage mitigation (Supplementary Fig. 2c). These gender differences may be related to human psychological nature well known from the literatures, where males are dominated by utilitarian wildlife value orientations and females are influenced by protectionist wildlife value orientations. Therefore, females usually hold greater affection to animals and are less likely to accept killing wildlife species even though they might perceive higher risk of wildlife attack or related socio-economic losses (Zinn and Pierce, 2016). For instance, Gore and Kahler (2012) and Loyd and Miller (2010) found that anti-hunting sentiment is more prevalent among women than men in human-wildlife conflict studies. In our study, female willingness to be involved in conservation was lower than that of men (Supplementary Fig. 4c) because they considered men, as the head of the households to be more suitable to be involved in conservation programs.

5. Conclusion and Management Implications for the Indawgyi wetland area

Our study revealed that negative consequences of bird damage for farmers households in the Indawgyi wetland area increased in areas bordering the wetland reserve. We found three aspects of conflicts regarding the management of the wetland reserve that need to be solved for future conservation effectiveness. The first focuses on the potential for finding good management regime regarding socio-economic aspects. If the target is that farming and wildlife should coexist, management strategies should be expected to minimize socio-economic costs and maximize the level of tolerance toward the species (König et al., 2020; Redpath et al., 2013). Therefore, farmers near the source of water who suffer higher level of bird damage should be provided with effective coexistence strategies. Despite high level of damage, people in these areas are found to be tolerant to the birds because of high level of conservation awareness and recognition of ecosystem services received from the lake and birds (e.g., water supply, fishery, forest products and insect pest control), as well as benefits from the park conservation programs (e.g., tourism, community forestry, waste management and sanitation) (Htay et al., 2022). This indicates a high potential for future conservation of the bird community if their tolerance toward birds is maintained or improved through sharing conservation benefits with local communities (Glikman et al., 2021).

The second aspect is the technical aspect to find the right mitigation tools for ecosystem-friendly coexistence mechanisms that reduce negative impacts of birds on humans and vice versa in farming landscapes (Glikman et al., 2021; König et al., 2020; Redpath et al., 2013). With a perspective of a socio-ecological model where eco-friendly coexistence between farming and bird community is established, neither active control methods (lethal measures, netting, and trapping) nor passive control methods (non-lethal deterrents, visual and auditory scaring) are socio-ecologically desirable management solutions (Araneda et al., 2022; König et al., 2020). Such strong mitigations involve the risk of reducing population viability and local extinction of bird species (König et al., 2020). A compensation program which involves subsidizing economic loss is one relevant mitigation mechanism where policies and standardized procedures are clearly defined (Karanth and Vanamamalai, 2020; König et al., 2020; Redpath et al., 2013). This has been used as a conflict resolution strategy to foster coexistence in both developed and developing world (Eythórsson et al., 2017; Karanth and Vanamamalai, 2020). Accordingly, wildlife conservation legislations in Myanmar should seek room to include damage compensation schemes. Implementation of such compensation schemes should be adapted to local context, and its effectiveness should be monitored and improved dynamically according to adaptive management planning theory (Eythórsson et al., 2017; Karanth and Vanamamalai, 2020; König et al., 2020; Redpath et al., 2013). In addition, conservation incentives like wildlife-friendly rice production systems should be investigated and implemented for conflict mitigation (Elphick, 2010; Simonsen et al., 2016). Farmers who are involved in such a program and adhered to conservation principles should be paid a premium price for their crop. This is a promising strategy because sustainable wet-rice agriculture through organic farming has been initiated in Indawgyi (Forest Department, 2018).

The education of people in local communities is crucial for successful conservation (Jacobson et al., 2003). Such conservation outreach will contribute to change negative attitudes toward conservation into positive ones, which is needed as almost half of the respondents interviewed had the opinion of killing inflicted species and some farmers reported poisoning of birds in cropland. Knowledge about importance of farmland for bird conservation and avian species contribution to agriculture as well as environmentally benign bird control measures still need to be raised among farmers (Elphick, 2010; Lindell, 2020; Wright et al., 2012). The education program should also engage in the distant villages because of their sensitivity to increased level of damage and lower level of conservation willingness as demonstrated in the present study. Increasing awareness would help not only to alleviate negative attitudes toward birds but also to promote conservation efforts (Czajkowski et al., 2021; Herzon and Mikk, 2007). Therefore, we suggest that a management approach that integrates 1) socio-economic compensations to farmers, 2) implementing eco-friendly mitigations that enhance coexistence between bird community and farming practices and 3) educating people in the villages about conservation advocating positive coexistence would enhance the viability of the bird community and also resolve economic concerns of farmers in Indawgyi wetland (Baynham-Herd et al., 2018).

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Declaration of Competing Interest

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02212.

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