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Research article

A framework for identifying bird conservation priority areas in croplands at national level

Shuyu Hou [a,b], Rui Yang [a,b,*], Yue Cao [a,b], Zhicong Zhao [a,b], Qinyi Peng [a,b], Hao Wang [a,b], Yali Si [c,d]

[a] *Institute for National Parks, Tsinghua University, Beijing, 100084, China*
[b] *Tsinghua University, Beijing, 100084, China*
[c] *Institute of Environmental Sciences CML, Leiden University, Einsteinweg 2, Leiden, the Netherlands, 2333CC*
[d] *Ministry of Education Ecological Field Station for East Asian Migratory Birds, Department of Earth System Science, Tsinghua University, Beijing, China*

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ABSTRACT

Global biodiversity is declining at an unprecedented rate, and the Post-2020 Global Biodiversity Framework requires each country to fulfill the conservation targets in biodiversity-inclusive spatial planning. Croplands provide habitat and food for many species, making them crucial for biodiversity conservation in addition to food production. Assessing conservation priorities in cropland is a prerequisite to allocate conservation resources and plan actions for better conservation outcomes. Yet quantitative methods to assess cropland conservation priority for biodiversity conservation at a national scale are still lacking. We proposed a framework for identifying the conservation priority in cropland for bird species at a national scale and applied the framework in China. We calculated the suitable habitat for each species and used a complementarity-based approach to designate the irreplaceable conservation priority areas considering richness, threatened level, and conservation percentage targets. We identified cropland taking up 6.76% of China's land area as a bird conservation priority, partially covering the suitable habitat of all the study species. By analyzing the landscape pattern of the priority areas and species' foraging traits, we provided policy-making suggestions according to area-specific characteristics. This framework can be used to identify priority areas for large-scale biodiversity conservation for different countries.

1. Introduction

Owing to the ongoing sixth mass species extinction, global biodiversity is declining at a faster rate than at any time in human history (Hassan et al., 2005). Protected areas (PAs) are the cornerstones and critical components of biodiversity conservation (Pimm et al., 2018), yet they are insufficient to halt the decline of species (UNEP-WCMC and IUCN, 2020; Venter et al., 2017). To better reduce the species extinction risk, countries are required to take urgent actions on biodiversity conservation outside PAs. The first draft of the Post-2020 Global Biodiversity Framework (GBF) lists reducing the species extinction risk as Goal A, and lists 21 associated action targets for 2030, including "all land and sea areas globally are under integrated biodiversity-inclusive spatial planning" and "ensure all agriculture areas are managed sustainably" (CBD, 2021).

Croplands provide essential habitats and are used as one critical food source for many species (Morganti et al., 2021; Si et al., 2018, 2020; Zhang W. et al., 2018). They also affect the quality of conservation of nearby PAs (Kremen and Merenlender, 2018; Volenec and Dobson, 2019). Therefore, countries could consider taking biodiversity-inclusive conservation measures in croplands to achieve their 2030 goals. Birds use cropland intensively and are suitable taxon as a biodiversity indicator (Fraixedas et al., 2020). We thereby used birds as the study object to carry out the research. Studies have revealed the cropland's usage and bird conservation requirements (Baudron et al., 2019; Nilsson et al., 2019; Si et al., 2018, 2020; Wu et al., 2020) or analyzed the effects of certain management techniques on croplands (Arizaga et al., 2020; Giralt et al., 2021; Siriwardena et al., 2000). These researches provided supportive evidence for croplands' importance in bird conservation and possible ways for inclusive management. However, methods to identify conservation priority cropland at large scale that are applicable to most countries remain unclear. This may be caused by the following research

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* Corresponding author. Institute for National Parks, Tsinghua University, Beijing, 100084, China.
E-mail addresses: housy18@mails.tsinghua.edu.cn (S. Hou), yrui@tsinghua.edu.cn (R. Yang), caoyue@tsinghua.edu.cn (Y. Cao), zhaozc@mail.tsinghua.edu.cn (Z. Zhao), pqy17@mails.tsinghua.edu.cn (Q. Peng), wang-g22@mails.tsinghua.edu.cn (H. Wang), y.si@cml.leidenuniv.nl (Y. Si).

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gaps.

First, previous studies identifying hotspots, key sites, or conservation priorities have often not considered cropland a critical element or simply excluded it to formulate low-cost plans. For example, studies identified areas that span the breeding range of endemic species (Stattersfield et al., 1998), crucial areas where endemic species are experiencing exceptional loss of habitat (Myers et al., 2000), priority areas that represent irreplaceable habitats for given species (Brum et al., 2017), and areas that have higher biodiversity value and lower potential agricultural productivity (Dobrovolski et al., 2014; Zhao J. et al., 2021, 2022).

Second, the studies focusing on cropland are mainly based on species-specific or site-level data (Doxa et al., 2010, 2012; Gao et al., 2021; Si et al., 2020), limiting their implementation to guide the decision process for species in general at a country level, which is necessary and urgent for the post-2020 biodiversity conservation actions. Hence, a framework based on general open data applicable to various species and countries is essential.

Third, some studies (Chiatante and Meriggi, 2016; Gilroy et al., 2014; Li et al., 2020) have considered all bird species occur in croplands at a national scale but mainly focused on identifying hotspots. These methods based on the alpha diversity approach may omit the differences in composition among sites (Kukkala and Moilanen, 2012). Recent conservation planning studies use a complementarity-based approach to identify priority areas (Brum et al., 2017; Peng et al., 2021). Based on beta diversity, this method identifies areas that cover irreplaceable habitats for all species rather than only areas with high species richness, thus providing conservation plans with more comprehensive factors.

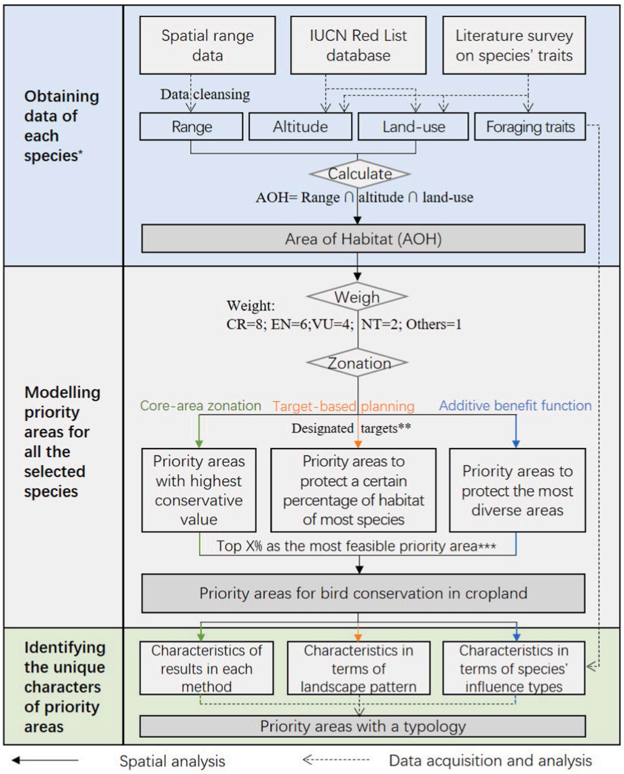
To bridge this knowledge gap and guide countries in developing their conservation actions to achieve 2030 goals of biodiversity-inclusive spatial planning and sustainable agriculture, we proposed a framework to map the priority cropland for bird conservation using a complementarity-based approach at a national scale. This research addressed three questions: (1) what is the distribution and land-use composition of suitable habitats for each cropland-dependent bird species? (2) where are the bird conservation priorities on cropland? (3) what are the priority croplands' spatial patterns, species-related characteristics, and appropriate conservation measures for different types?

2. Material and methods

2.1. Workflow

We developed a framework for identifying conservation priority areas in cropland considering factors in three aspects comprehensively, i.e., species threatened level, richness level, and conservation target (Fig. 1). First, we gathered the data on each species, including its distribution range, habitat, foraging patterns, and threatened status, and then performed descriptive statistics including frequency and central tendency analysis. Second, we cleansed the range data to obtain the distribution within the study area, including breeding, wintering, and passage areas and utilized the Area of Habitat (AOH) model (Rondinini et al., 2011) to refine the distribution data for each species by selecting suitable habitats. Next, we run the Zonation model (https://www2.helsinki.fi/en/researchgroups/digital-geography-lab/software-developed-in-cbig) to calculate the priority areas for bird conservation in three methods, focusing on species' threatened status, richness, and conservation target, and generate three continuum maps separately. Finally, we aggregated the three dimensions and overlapped it with the cropland area to assess the priority. We also analyzed the spatial pattern and typology of the priority areas with different traits to determine appropriate managing modalities.

2.2. Data source and pretreatment



*: It could be any aggregate of species according to analysis purpose, e.g., any species taxon, species that use certain land-use types, or with certain foraging traits.
**: Assign an conservation-percentage target for each input feature according to analysis purpose.
***: "X" is determined considering extinction risk and conservation feasibility of each country.

Fig. 1. Framework for assessing land conservation priority at a national level.

We chose China as an example to demonstrate this framework. China possesses the geographical distribution of 1491 bird species (Liu and Chen, 2021), accounting for around 13.4% of all bird species reported worldwide (http://datazone.birdlife.org).

We obtained the species list from Bird Report Center with 1480 species recorded in China (http://www.birdreport.cn). We employed the range data of each bird species from BirdLife International as the initial distribution range, and extracted 1353 range data within China's boundary. The habitat types and altitude ranges for each bird were determined by using three widely recognized texts on birds in China (MacKinnon et al., 2000; Zhao Z. 2001; Zhao X. 2018), and supplemented them with the information on the IUCN Red List (derived from the IUCN Red List of Threatened Species, https://www.iucnredlist.org). We derived a list of cropland-dependent birds from the literature with 560 species. The land-use data was obtained from the remote sensing monitoring data of China's land-use status in 2015 (https://www.resdc.cn) with seven categories and 21 sub-categories [Table S1]. The spatial distribution data of China's elevation was Digital Elevation Model (DEM) data with 1 km spatial resolution (https://www.resdc.cn). The foraging attributes of species were extracted from the AVONET dataset (Tobias et al., 2022). It contains the primary diet categories of 11,009 bird species, including all the species we studied.

2.3. Calculation of the area of habitat (AOH) of each species

The BirdLife data described the potential range of species approximately according to presence records (Brooks et al., 2019); In order to obtain a more credible geographic distribution of species within their initial ranges, we adopted a widely used AOH model that combines land cover and elevation data (Beresford et al., 2010; Brooks et al., 2019; Rondinini et al., 2011).

First, we cleansed the source data. Among the 1353 species' range data, 261 species are lacking passage information. We employed the minimum convex polygon method to estimate their likely migratory ranges from their breeding and wintering ranges. Then we refined each species' range to AOH. Next, we excluded species whose distribution range in China does not cover suitable altitudes and land use. Finally, we outlined 1215 species in China that have suitable habitats [Table S2].

In order to harness the species' AOH, we assessed three factors: the types of land use, the composition of AOH, and the potential for richness. First, we analyzed the land-use composition of AOH, calculated the percentage of cropland in the AOH for each species. Then, we conducted frequency analyses and central tendency summary to reveal the attributes of different cropland-dependent species, including the threatened level, foraging patterns, and cropland percentages in their AOH. As a result of overlaying the species' AOH, we were able to gain an understanding of the potential richness of birds and their spatial distribution peculiarities.

2.4. Modeling and mapping the conservation priority area with the zonation methods

Zonation provides a complementarity-based approach for assessing conservation priority by iteratively eliminating a certain number of grids from the input features while minimizing the marginal loss. The later a grid is removed, the higher conservation priority it has. We chose the Core-area Zonation (CAZ), the Additive Benefit Function (ABF), and the target-based planning (TBF) method to address diverse scenarios. As we took conservation in cropland as an example, we input the AOH of all the 552 species that might use cropland. Species are allocated the weight of 8, 6, 4, 2, and 1, correlating to their IUCN status classified as CR, EN, VU, NT/DD, and LC according to Montesino Pouzols et al. (2014). Considering the analyzing scale, we choose the "no edged removal" technique and set the warp factor to 200. We used the same weights and settings in all the three methods.

First, to determine the priority area for the most threatened species, we used the CAZ method (Moilanen et al., 2005; Moilanen, 2007). In this method, a grid with a higher level of threatened species is removed later.

Second, the ABF method (Moilanen, 2007) is used to identify the most important areas for all of the input species. According to this method, a grid that can accommodate more species with a higher total weight is considered as more valuable.

Third, we applied the TBF method to determine which areas provided sufficient habitat for most species. We set a target percentage of AOH and cropland for each species, and removed grids while avoiding species losing their AOH below the target level. The targets could be designated by considering the conservation goals of the policymaker, the total area of the AOH, and the approximate minimum requirements of the species. Thus, we set the conservation target at 5% for both the cropland and the total AOH layers of each species.

Based on the three methods described above, three continuum maps were generated and combined for a comprehensive assessment of conservation priorities. Our first step was to add up the three continuum maps to obtain a priority assessment result at the national level. Following that, we selected a certain percentage of land from each map to identify the priority land area with clear spatial boundaries for management. There are intervals in each method where the slope of the extinction-risk curve steepens; that is, if the conservation percentage keeps dropping down, every additional removed grid causes a server loss of biodiversity (Fig. S1). When considering the overall conservation goals as well as the feasibility of conservation, targets should be set higher than this interval. We selected 8% as target and reclassified the map of each method into 1 and 0. Finally, we aggregated them into a map with seven combinations of the three results.

2.5. Analyzing the characteristics of priority area

In accordance with the priority area, we conducted frequency and central tendency analyses at the provincial level to identify those administrative units with the greatest priority for cropland biodiversity conservation.

We identified the characteristics of each priority area and summarized a typology of priority areas in three aspects as a means of offering management suggestions. (1) We compared the spatial distribution of the three original results to analyze the land-use composition and AOH-coverage of each method and made crossover comparisons with the IUCN threatened levels. (2) We analyzed the priority area's spatial pattern to guide policymaking. Statistics on the number of priority area patches, the land use variety and the majority land use type around each grid were collected. (3) We preliminarily analyzed the species' distribution regarding their positive and negative impact on production to reveal potential management feasibility. In this study, we focused specifically on the groups of "granivores" and "invertivores" (derived from the AVONET dataset (Tobias et al., 2022)), representing those helping control insect populations or decreasing crop production, respectively. We then overlaid the AOH of the species on the two lists separately to obtain maps of potential richness for granivores and invertivores. By superimposing the results of each aspect, we were able to summarize the characteristics of the priority area.

3. Results

3.1. The distribution and land-use composition of species' AOH

In terms of the AOH maps for each species of bird recorded in China, one of the key findings is that birds occur in a variety of habitats with a high degree of spatial heterogeneity. In total, 552 bird species (45.39%) have cropland in their AOH, including 60 threatened species.

We overlaid the layers of the AOH of each species to obtain the potential richness of all the cropland-dependent birds, granivorous birds, and cropland-dependent insectivores separately (Fig. 2). Yunnan, southeast of Tibet, middle and southern Gansu Province, Huabei Plain, Northeast Plain, and northern Xinjiang areas are with great richness. A grid of 1 km^2 may support up to 463 species of birds in Yunnan.

Cropland percentages in the AOH of each species vary across families and orders, but they are similar across different foraging patterns. For example, the average area of cropland per species in *Anserformes* (50%)*, Charadriiformes* (37.56%)*, and Gruiforms* (33.19%) are exceptionally high, while the overall average is 25.59% (Fig. 3). At the species level, 87 species, among which 15 are threatened ones, have more cropland than other land-use types in their AOH, and 47 species, among which 8 are threatened ones, have cropland occupying more than half of their AOH [Table S.2].

3.2. The spatial pattern of the priority area and critical administrative units

A spatially heterogeneous of the conservation priority for cropland-dependent birds was observed (Fig. 4a). Three types of provinces were of exceptional importance: (1) Provinces with the highest coverage of the priority cropland (Fig. 4b). In total, four provinces account for 50.30% of the priority areas, namely Yunnan, Hebei, Xinjiang, Shandong, Heilongjiang, and Guangdong. These provinces generally have large areas of cropland and a high importance for birds. (2) Provinces with the highest priority level of cropland. Xinjiang, Yunnan, Tibet, Qinghai, and Sichuan possess the largest areas with the highest conservation priority when considering all land use types (Fig. 4c). (3) Provinces with relatively fewer croplands but a higher coverage of priority area across all their croplands. Hong Kong, Taiwan, Hainan, Qinghai, Tibet, Fujian, Shanghai, Guangxi, and Zhejiang are among the provinces that over 90% of which croplands are in priority area in spite of less total cropland (Fig. 4d).

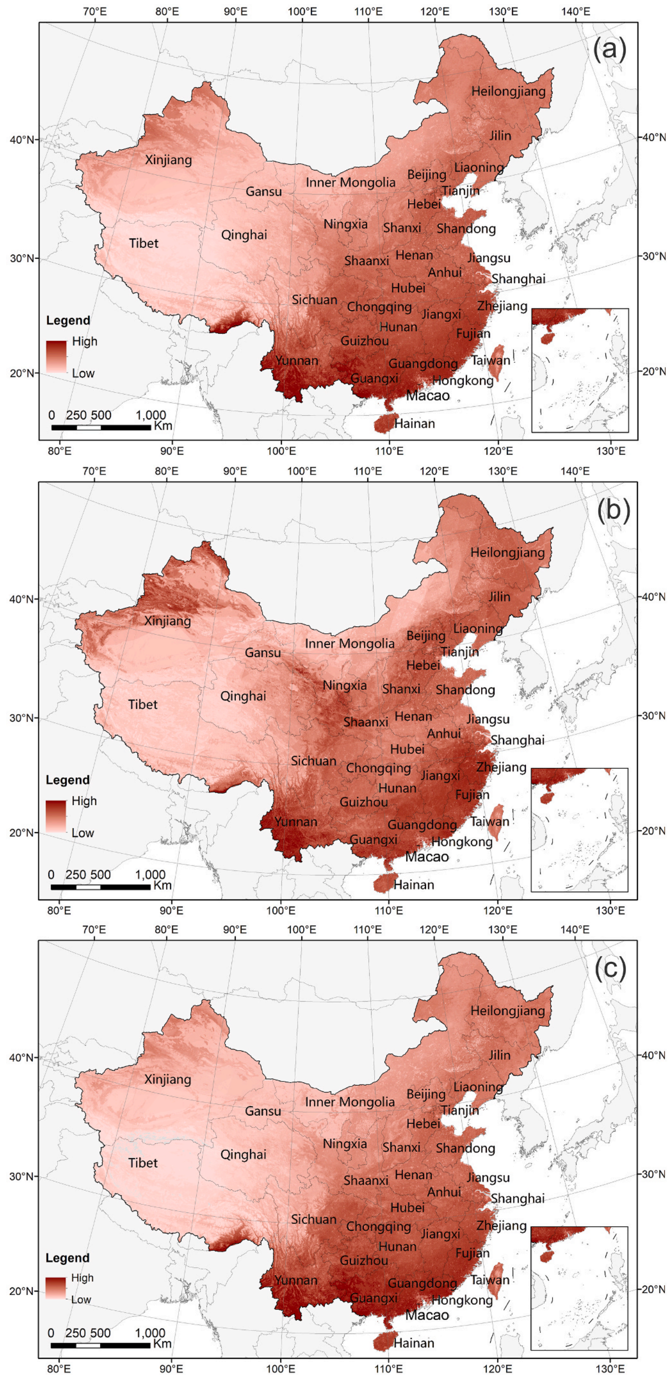


Fig. 2. Potential richness of bird species based on areas of habitat. (a) All cropland-dependent bird species; (b) granivores; and (c) insectivores.

3.3. *Types of the priority area in terms of the three methods*

In total, 15.33% of China's land surface is the conservation priority area, partially covering the AOH of all cropland-dependent bird species, mainly composed of cropland (44.06%), forest (26.28%), and grassland (24.08%). The priority cropland covers 36.25% of the total cropland and taking up 6.76% of the total terrestrial area. Based on the spatial distribution of the priority cropland as determined by the three methods, the priority cropland was classified into seven types (Fig. 5a). Currently, PAs cover 15.93% of the priority cropland, taking up 1.08% of China's terrestrial area.

We calculated the priority area coverage for each species' AOH respectively (Fig. 5b). For the CR, EN, and VU species, the CAZ method performs better by covering a larger area for most species than the two others. The ABF method performs relatively stable across all the species categories, and has the largest average coverage for species other than CR and EN. Areas identified in ABF and TBF methods together covers all the study species. It should be noted that the TBF method retains a relatively higher minimum percentage of AOH for most species. In TBF, the minimum coverage of one species is 5.01%, while in CAZ and ABF it is 0.16% and 1.36%. The combination of the three approaches would allow a satisfactory coverage of threatened species while considering all the species.

3.4. *Types of the priority area in terms of landscape pattern and foraging traits*

The priority area contains 137,037 plots of cropland, including 45 continuous areas larger than 1000 km^2 and 5921 patches larger than 10 km^2. Based on the size of the cropland patches, we classified the priority area into four types to map its landscape pattern (Fig. 6a-d).

An overview of the land-use conditions around each grid can be used to describe the heterogeneity of that area. 49.28% of the priority area is in a landscape mosaic status with its neighboring grids in another land-use type, and 40.08% is a mosaic comprising three or more land-use types (Fig. 6e). About 68.51% of priority areas are in cropland-dominated areas, while 21.50% of priority areas are forest-dominated and 8.16% are grassland-dominated (Fig. 6f).

Our priority areas were classified by overlaying the potential richness of granivores and invertivores. There are areas with a high level of invertivores and a low level of granivores, areas with a low level of invertivores and a high level of granivores, and areas with a similar level of both (Fig. 6g–i).

4. Discussion

This study proposed a framework to evaluate the conservation priority with general open data on the national scale, considering species richness, threatened status, and conservation targets. By applying a complementarity-based approach, we applied the framework in China and identified priority cropland that partially covered the habitat of each cropland-dependent bird species. Our analysis of landscape patterns and foraging traits identified the peculiarity of the conservation priorities, which are spatially heterogeneous with different characteristics. According to the peculiarity of each area type, we proposed corresponding management approaches including organic farming, multifunctional agriculture, agroforestry, dynamic conservation strategies, and other compatible management measures.

4.1. *Improvement to the previous study*

Our study contributes to the literature in the following three aspects.

First, we quantitatively analyzed the importance of crops for birds in spatial aspects. The results provided an overall assessment of each bird species' dependence on cropland in their available habitat. The species with higher percentage of cropland in their AOH are in accord with those given more attention in previous studies (Grishchenko et al., 2019; Morganti et al., 2021; Si et al., 2020) and also implicates those worth further attention in making science-based management plans.

Second, we developed a framework that provides a more comprehensive coverage of irreplaceable habitats for species rather than hotspots with high diversity, as in previous study by Li et al. (2020). We also identified the priority areas with a detailed spatial boundary rather than depicting approximate hotspots, thus being more practical for policymaking. Three additional areas were identified as particularly significant, namely parts of the Northeast Plain, the Yunnan-Kweichow Plateau, and the southern part of Gansu province. This might be due to the exceptional value of these areas for specific birds, such as endemic

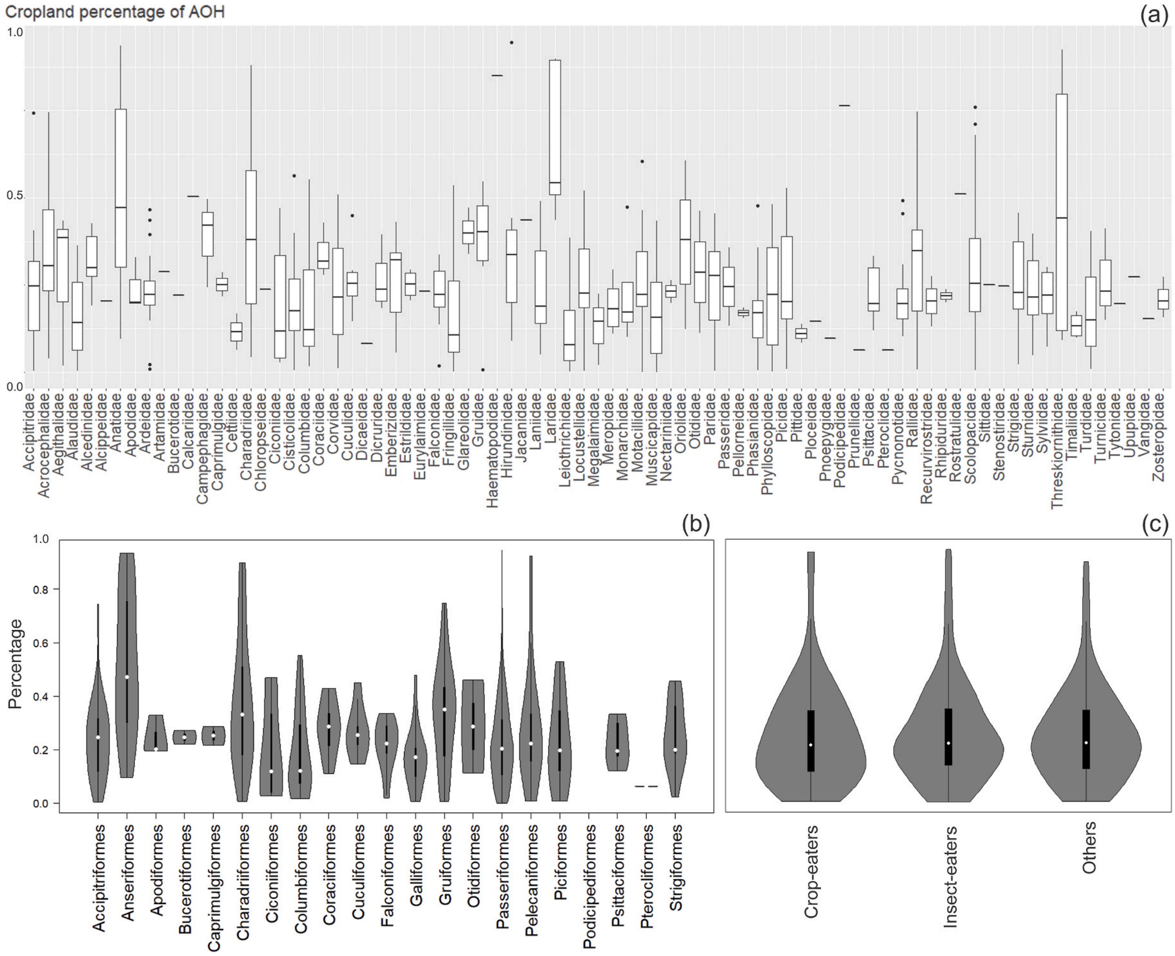


Fig. 3. (a) Proportion of cropland percentage in each species' AOH by family. (b) Proportion of cropland percentage in each species' AOH by order. (c) Proportion of cropland percentage in each species' AOH by foraging pattern.

species and threatened species with more cropland in their AOH. Alternatively, neither the Sichuan Basin nor the Hanjiang Plain were considered as top priority areas in our study, possibly because birds in these areas are more likely to have various alternative habitats.

Additionally, although some studies have indicated the necessity for officially designated PAs to facilitate bird conservation efforts in critical areas (Acosta et al., 2010; Grishchenko et al., 2019; Si et al., 2020; Yamaguchi et al., 2012), we analyzed spatial characteristics for different regions and recommended corresponding alternative management approaches.

4.2. *Biodiversity-inclusive management are needed with different emphasis*

The priority areas selected by ABF method are generally contained in the identified diversity hotspots and irreplaceable areas in previous studies (Eken et al., 2004; Myers et al., 2000) while the areas in CAZ method contains presence sites of many threatened species (http://www.birdreport.cn). TBF represents a satisfactory percentage of cropland for most species. Our results indicated that bird conservation priority in cropland is heterogeneous, and the following highlighted sites should be taken into consideration as urgent priorities for recognizing species habitat and applying compatible management.

(1) Areas recognized as priority by all the three methods, taking up 1.08% of China's terrestrial land area, are regarded as the most important croplands for bird conservation. The characteristic feature of these areas is that they are crucial to a great deal of biodiversity, including endangered species, therefore they should be preferentially included in PAs or OECMs. This could be achieved by applying organic farming, multifunctional agriculture, agroforestry, or other biodiversity-inclusive agricultural approaches under appropriate conditions (Dudley et al., 2018; Gassner et al., 2020; IUCN, 2018; Maier et al., 2001). For example, previous studies have shown that croplands with lower human pressure may provide suitable habitat for birds (Fox et al., 2016; Si et al., 2020).

(2) Regions of high conservation value as habitat for most threatened species, i.e., the Type-C, CA and CT areas from results 3.3. When designing assessment and adaptive management plans for these areas, specific species requirements must be considered.

(3) Conservation priority areas for most bird species, i.e., Type-A and AT areas from results 3.3. Areas primarily in the North China Plain around the Bohai Rim and extending into the Yangtze Delta that are crucial for migratory birds in their seasonal migration and require dynamic conservation (Si et al., 2018; Zhang et al., 2018).

(4) Regions where certain species place a high value on retaining the last of their croplands within their AOH, i.e., Type-T areas from results 3.3. The listed areas typically are in proximity to the three types of regions mentioned above, taking up 3.01% of China's land area, and are mainly located along the migration routes. It is in these areas that the government or landowners should consider adaptive management techniques such as OECMs (Dudley et al., 2018), or dynamic conservation strategies based on the demands of birds' annual life cycles (Reynolds et al., 2017).

Landscape mosaic plays a critical role in sustaining biodiversity (Kremen and Merenlender, 2018). About 90% of the priority croplands

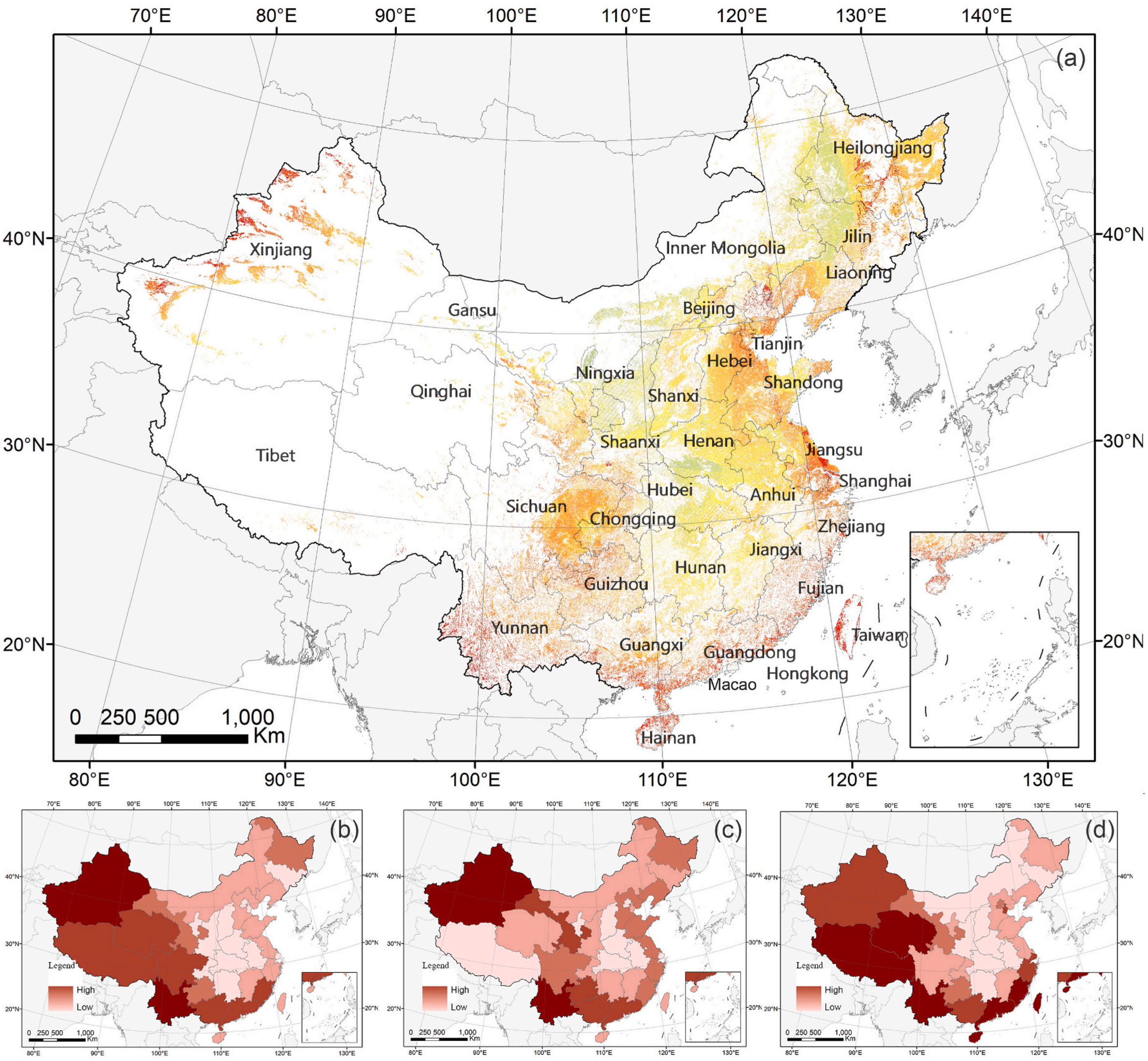


Fig. 4. Cropland priority distribution and notable provinces. (a) The distribution of priority in cropland. (b) Total area of priority cropland in provinces. (c) Total area of priority area in provinces. (d) Priority area percentage among all the croplands in provinces.

identified in this study are in mosaics with other types of land-use, primarily forest and grassland, providing potential roosting areas for birds. We suggest conservation measures for the following types of areas. First, the scattered plots of small croplands with high importance. Small cropland patches surrounded by intact natural vegetation can be considered as alternative conserved areas (Freemark and Kirk, 2001; Perfecto and Vandermeer, 2010). In these areas, communities can adopt site-specific management practices for their cropland and landscape mosaic, such as long-term monitoring, village regulations and agreements, or the establishment of Indigenous Community Conserved Areas. The second category consists of clusters of medium to small size croplands. In these regions with relatively high landscape heterogeneity, the natural habitats around croplands might be crucial in providing appropriate roosting areas (Ekroos et al., 2016; Perfecto and Vandermeer, 2010). Therefore, the landscape pattern must be considered when planning and designing at the landscape scale and the site level. Third, the region consists of vast areas of continuous areas dominated by cropland. A systematic approach to agriculture production is required in order to cultivate these croplands. This should be coordinated with biodiversity policies at the national level and with the cooperation of related provincial government agencies.

The current biodiversity management policies put more emphasis on natural habitats than croplands in China (General Office of CCCPC and SCPRC, 2017;2019), despite the fact that some croplands exist within PAs and ecological redlines. Meanwhile, the Wildlife Protection Law of China requires national departments to develop a list of essential habitats (Wildlife Protection Law of the People's Republic of China, 2016), despite that the designation outside protected areas has not yet been effectively implemented. Our study has provided approaches to identify conservation priority and conserve biodiversity in croplands, supporting the implementation of this law.

In conclusion, in order to ensure food production and biodiversity conservation in the key areas simultaneously, priority croplands should be considered in the establishment of PAs/OECMs or other inclusive conservation measures (Kremen and Merenlender, 2018; Yang et al., 2020). China's conserved area coverage would increase to 23.86% if the priority croplands identified in this study were included in PAs, OECMs, or managed sustainably as biodiversity-inclusive croplands.

4.3. *Exploring ways to a multi-functional cropland for both birds and crop*

Some birds use cropland as a food source causing potential conflict between birds and crop yield (Delzeit et al., 2017; Fox et al., 2016) while some invertivores may help with pest control (Biddinger et al., 2014; Bouvier et al., 2011). Our results categorized three types of croplands in

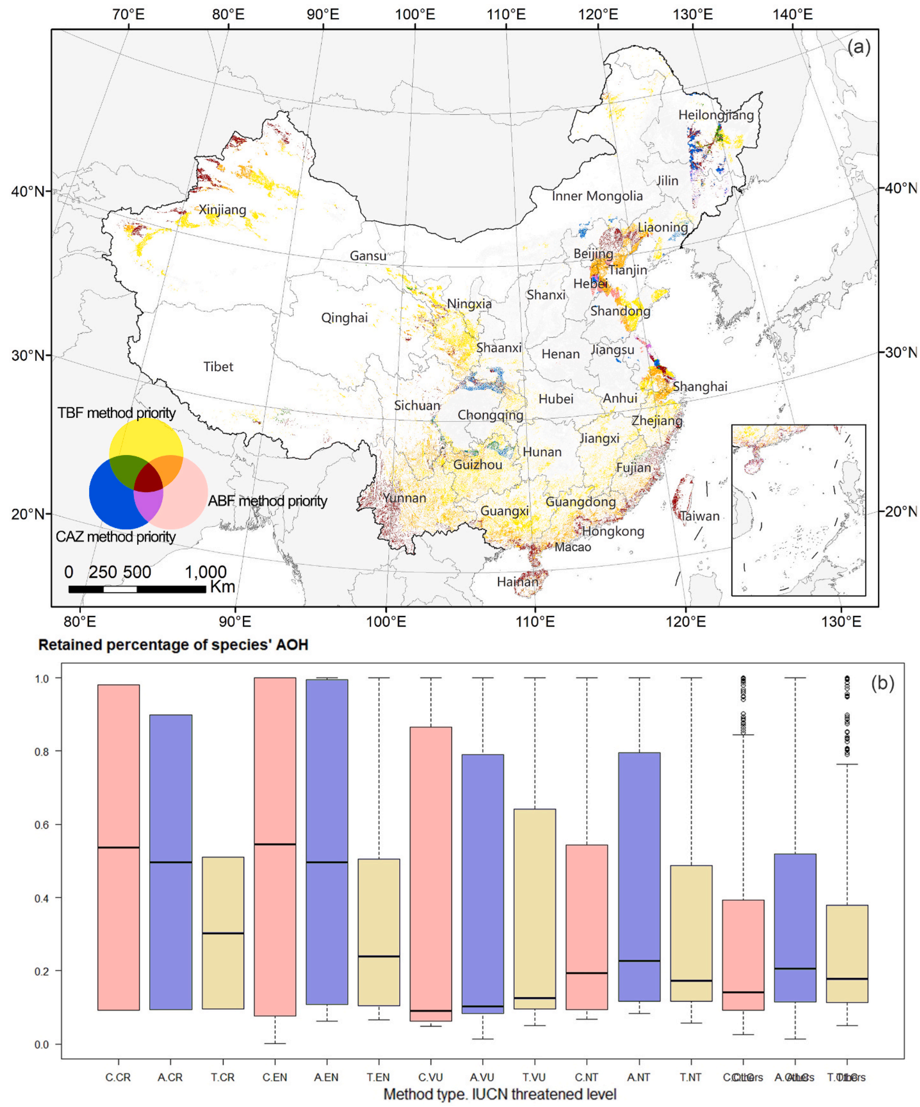


Fig. 5. The priority areas identified by the three methods. (a) The coverage of species AOH for each IUCN Red List class in each method. (b) The priority areas identified by different methods. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

terms of species richness of different foraging traits to provide an overall view of the spatial pattern. First, those regions where invertivores are more abundant than granivores. We recommend that further studies to evaluate the effectiveness of bird-friendly farming for pest control in these areas (Biddinger et al., 2014; Bouvier et al., 2011). Provided it works, governors could make more efforts to promote the implementation of these measures to provide mutual benefits for both agriculture and birds (Ekroos et al., 2016). Secondly, the regions where more granivorous species are likely to present than insectivores. There are higher risks of human-bird conflicts in these areas with birds feeding on crops, thus requiring detailed assessments, ecological compensation, and substitute livelihood when landscape-scale planning designates specific areas that reduce chemical usage (Ekroos et al., 2016; Perfecto and Vandermeer, 2010). In the third category of regions, where both kinds are at similar levels of richness, site-level experiments and investigations for specific approaches to balance the competing objectives are recommended.

In conclusion, biodiversity conservation in cropland does not necessarily result in a yield reduction. There are areas where birds may have a positive influence on cropland, and the fact that some birds only consume leftover grains after harvesting also minimizes the impact on yield. With proper management measures, croplands could be used to preserve biodiversity and maintain satisfactory food production. Although certain areas of exceptional importance must be strictly protected by exclusive mechanisms, it is possible to establish disciplined OECMs or apply flexible measures for a more compatible cropland in the priority areas.

4.4. Limitations and prospects

So far, the number of bird species with cropland-covering AOH ($n = 552$) was slightly smaller than that reported in the literature ($n = 560$) [Table S.2], with other 62 species with record in China but no AOH in this study. This deviation comes from two sources. One is that the BirdLife data is an approximate range that may omit areas that rarely have records, resulting in some species in China's list being absent from the BirdLife data. The other is the 1-km-resolution's deficiency in detecting small, scattered areas causing limited cropland omitted from the calculated AOH. Another uncertainty is a possible overestimation of the potential food sources causing by insufficient information regarding specific crop types. However, this can be ameliorated by appropriate agricultural management in practice.

All countries with IUCN species range, land cover, and altitude data could apply this framework to identify their priority cropland for

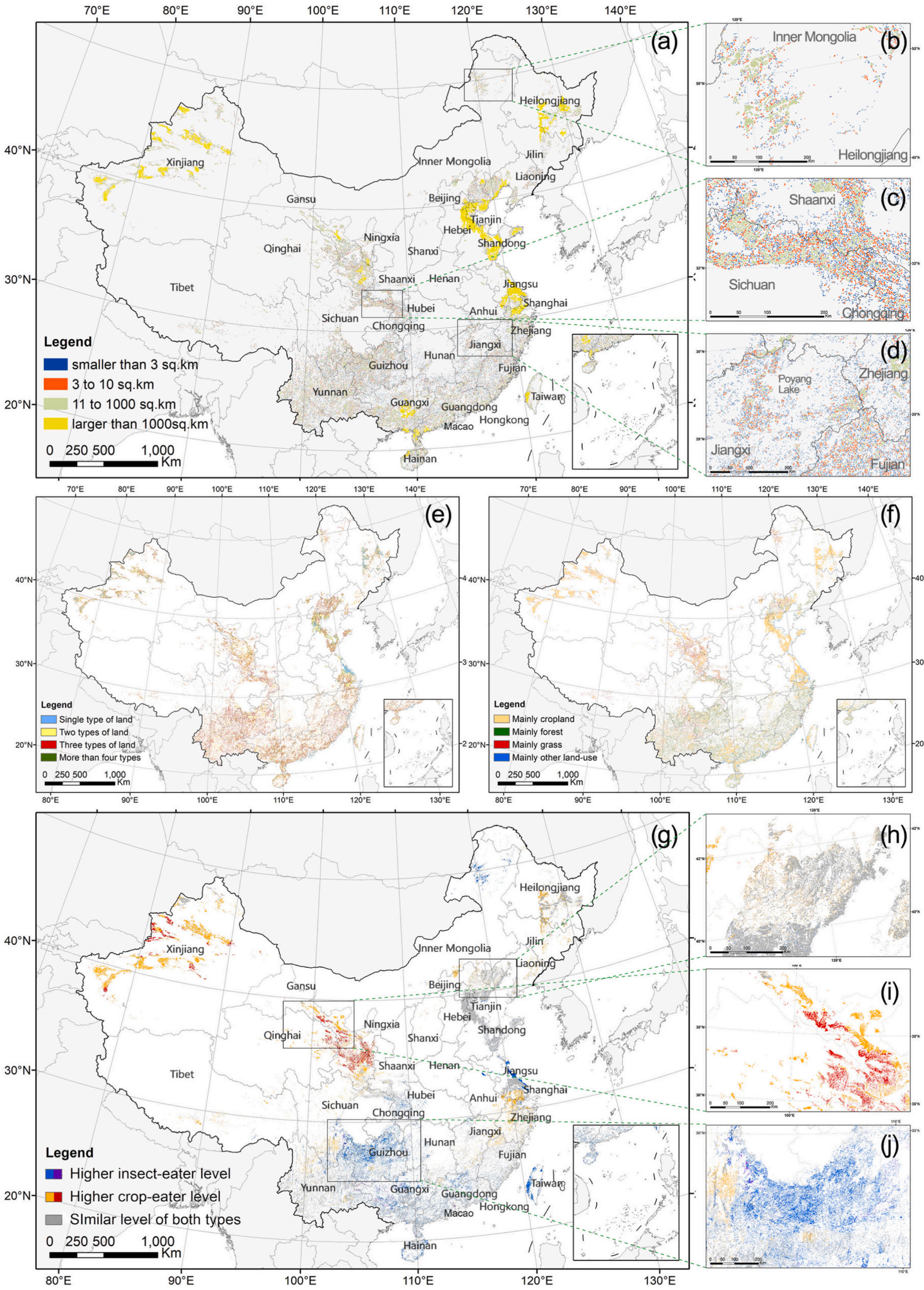


Fig. 6. Types of priority areas. (a) Priority cropland in various patches size. (b), (c), and (d) are amplified typical areas with scattered cropland. (e) The number of land-use types around each grid of the priority area. (f) The dominate land-use type around each grid of the priority area. (g) The potential birds' diet types of the priority area. (h), (i), and (j) depict typical areas with different granivores-invertivores proportion.

biodiversity conservation. Future studies could quantify the cropland importance based on more comprehensive indicators such as crop types and seasonal scenarios where applicable. As the land cover and birds' range keep changing over time, future studies might adopt datasets that update more frequently to minimize the deviation between the simulation results and the birds' actual distribution. Using bird occurrence data, future studies can consider the species' preferences in choosing habitats to further validate and refine our findings. Since some species use cropland during migration rather than in wintering areas, and some might prefer natural habitats over croplands (Si et al., 2020), studies could provide a more comprehensive cropland bird conservation plan or dynamic conservation measures based on farmland locations and migration times (Reynolds et al., 2017).

5. Conclusions

Our study developed an approach for identifying the priority croplands to guide biodiversity conservation policies and actions using open data at the national level. We took China as an example and identified 137,037 priority cropland patches for bird conservation considering species richness, threatened status, and conservation percentage of suitable habitats. Using a complementarrity-based approach, we identified the areas that are irreplaceable to minimize the extinction risk for most of the cropland-dependent bird species. We have analyzed the priority area's characteristics for policy-makers in terms of the land-use composition, landscape pattern, and species' foraging traits. According to the results, the priority cropland taking up 6.76% of China's terrestrial area could support most bird species with biodiversity-inclusive management by combining PAs/OECMs or other compatible conservation measures. Results also supported that bird conservation may not necessarily result in crop yield reduction given appropriate management strategies. Furthermore, this serve as an example for other countries to designate biodiversity-inclusive cropland by using open data to meet their post-2020 targets.

Authors' contributions

Shuyu Hou: Conceptualization; Data curation; Formal analysis; Methodology; Investigation; Software; Validation; Visualization; Writing - original draft; Writing - review & editing. **Rui Yang**: Conceptualization; Methodology; Funding acquisition; Resources; Supervision; Writing - review & editing. **Yue Cao:** Methodology; Formal analysis; Writing - original draft; Writing - review & editing. **Zhicong Zhao**: Resources; Funding acquisition; Supervision; Writing - review & editing. **Qinyi Peng**: Data curation; Software; Writing - review & editing. **Hao Wang:** Writing - review & editing. **Yali Si**: Methodology; Resources; Supervision; Writing - original draft; Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.116330.

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