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Mapping winter waterbird biodiversity hotspots for conservation prioritization: Bridging gaps using citizen science data

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ABSTRACT: Declining waterbird populations and increasing overlapping habitats with human activities necessitate the identification and conservation management of biodiversity hotspots to ensure sustainable utilization of natural resources and preservation of biodiversity. We conducted a comprehensive analysis of an eBird dataset, a global citizen science initiative, to systematically assess the winter waterbird biodiversity hotspots at a 1-km grid scale throughout Taiwan. This assessment considered five criteria: species richness, abundance, and national, regional, and local importance values. We identified 994 grids as hotspots, with 132, 154, 137, 205, and 366 grids meeting all five, four, three, two, and one of the five criteria, respectively. The hotspots are located in the coastline region, and only 32.60% are located within the protected areas, implying that winter waterbird hotspots extend beyond the protected areas and significantly overlap with anthropogenic activity area. Our findings highlight the limitations of traditional protected areas in effectively conserving winter waterbird hotspots, thereby demanding the adoption of more proactive and strategic management approaches to promote sustainable coexistence between humans and nature. By analyzing the crowdsourced scientific data, this study fills spatial gaps and provides a systematic method for rapidly assessing biodiversity distribution, generating up-to-date information for biodiversity management that aligns with the current status.

KEY WORDS: Citizen Science, conservation management, environment protection, spatial conservation planning.

INTRODUCTION

The Kunming-Montreal Global Biodiversity Framework and 2030 Global Targets 1-3 emphasize spatial conservation planning to reduce threats to biodiversity. Prioritizing areas with high ecological integrity is essential, and these important biodiversity areas should be effectively restored (CBD, 2022). The benefits and costs of restoration depend on the chosen site. Highlighting the need for priority areas for restoration efforts, prioritizing biodiversity conservation and cost minimization (Brooks *et al*., 2006; Strassburg *et al*., 2020), and identifying key areas of waterbird along the flyway could offer valuable insights for conservation (Kirby *et al*., 2008; Runge *et al*., 2014). These important biodiversity areas and waterbird hotspots harbor high species richness and large proportions of species populations in a few key areas, making them critical for conservation efforts (Myers, 1990; Clemens *et al*., 2014).

Migratory waterbird populations along the East Asian-Australasian Flyway (EAAF) are rapidly declining due to human-induced habitat changes, a trend that has been observed globally. This decline has raised concerns, particularly for migratory shorebirds that rely heavily on specific stopover habitats during long-distance migrations (Amano *et al*., 2010; Conklin *et al*., 2014; Studds *et al*., 2017). These threats to waterbird habitats include intensified agriculture and aquaculture, and the conversion of tidal flats and coastal wetlands for human infrastructure development (Sutherland *et al*., 2012). Over the past century, there has been a significant increase in the loss and degradation of coastal habitats and the environment, which poses a severe challenge to waterbird conservation (Murray *et al*., 2015; Melville *et al*., 2016; Chen *et al*., 2024).

The EAAF, the largest global flyway, is a critical route for over 50 million migratory waterbirds belonging to 492 species (Conklin *et al*., 2014). Unfortunately, the populations of these migratory birds have been declining, with the highest proportion (23%) of threatened waterbirds in the global flyways, of which 36 are listed as globally threatened according to the International Union for Conservation of Nature (IUCN) (Lees *et al*., 2022). Alarmingly, 91% of these migratory bird species lack protection within designated protected areas (Runge *et al*., 2015).

Migratory waterbirds have vast ranges encompassing their breeding, stopover, and wintering habitats, resulting in interdependencies among sites owing to migratory connectivity. Stopover sites, which are the refueling areas, are critically important for their successful migration (Kirby *et al*., 2008). Waterbirds often congregate in significant numbers, and these sites are vital for the success of their migratory journeys. Therefore, losing even a single site can have potentially devastating consequences (Baker *et al*., 2004; Kirby *et al*., 2008). As waterbird populations continue to decrease and their habitats overlap with human activities, it is crucial to identify and manage biodiversity hotspots.

Biodiversity hotspots for waders along the EAAF were systematically identified using range maps of 55 species (Li *et al*., 2019). However, this identification process primarily focused on species richness, overlooking the fact that some waterbirds tend to congregate in large numbers at specific locations. Although species richness is an essential aspect of biodiversity, the total abundance of birds and the presence of endangered species should also be considered in the estimation of waterbird biodiversity hotspots (Sebastián-González and Green, 2016; Li *et al*., 2019). Although species richness is important, prioritization approaches do not solely rely on species richness because it includes common species, potentially overlooking those threatened species most in need of conservation (Orme *et al*., 2005; Brooks *et al*., 2006). Hotspots of migratory waterbirds are usually identified based on three main criteria. Firstly, an area is deemed significant if it surpasses a certain threshold in terms of total abundance. Secondly, it qualifies as significant if it exceeds a specific threshold for the percentage of a particular population. Lastly, an area can be considered significant if it surpasses an index value calculated using a combination of measures related to diversity and abundance (Lamoreux *et al*., 2006; Clemens *et al*., 2010; Clemens *et al*., 2014). The criteria of Important Bird and Biodiversity Areas (IBAs) were also used to define important global, regional, and sub-regional areas, which included the numbers of a globally threatened species, species population importance in the flyway, and large congregations of waterbirds (BirdLife International, 2020).

Taiwan is located at the midpoint of the EAAF and supports migration stopover and wintering habitats for migratory waterbirds. It is also among the top three waterbird biodiversity hotspots in the EAAF region. Sandy/muddy shores on the western coast support thousands of migratory birds and provide essential stopover sites and wintering habitats (Li *et al*., 2019; Kasahara *et al*., 2020; Lin *et al*., 2023). Resident and wintering species constitute a significant portion of Taiwan's waterbird populations. While summering and transient species contribute to waterbird diversity, their numbers and distribution can vary widely. Studying waterbirds during winter is crucial, as many consistently gather in specific areas during this season. Therefore, our analysis focused on resident and wintering species to evaluate waterbird biodiversity hotspots in Taiwan.

According to criteria that include globally threatened, restricted-range and biome-restricted species, and the total bird congregations, 54 Important Bird Areas (IBA) have been confirmed in Taiwan (Lyu *et al*., 2015). Of the area of Taiwan, 77% IBAs were covered by legally protected areas such as national parks, wildlife refuges, major wildlife habitats, nature reserves, forest reserves, and nationally important wetlands. However, some IBAs which are mostly vulnerable coastal wetlands, are not legally protected (Lyu *et al*., 2015). These IBAs, which are located in the coastal regions, are known to harbor significant numbers of birds. However, the homes and workplaces of millions of people are also located in these areas. Over the last century, industrial and commercial development has caused the natural coastline to shrink drastically; 60% of tidal flats have been lost, and only 5% of the original coast remains in the western part of Taiwan (National Land Management Agency, 2021; Chen *et al*., 2024). Given the declining winter waterbird populations (Lin *et al*., 2023) and their increasing overlap with human activities in their habitats, it is imperative to identify and manage biodiversity hotspots to ensure the sustainable use of natural resources and preservation of biodiversity. Nevertheless, the entire area of Taiwan has not yet been systematically assessed. Therefore, we need to develop a framework for a complete estimation of winter waterbird hotspots for spatial conservation management and planning.

Harnessing citizen science data is crucial for fulfilling the information requirements for shaping worldwide policies to protect invaluable natural resources (Ruiz-Gutierrez *et al*., 2021). eBird (http://ebird.org/) is the world’s largest biodiversity-related citizen science project and serves as the largest species occurrence and counts database, which vastly improves our understanding of the distribution and ecology of birds, and has also been used extensively in conservation planning (Wood *et al*., 2011; Kelling *et al*., 2012; Walker and Taylor, 2017). The regional portal eBird Taiwan was introduced in 2015, effectively eliminating language barriers and becoming popular among birdwatchers in Taiwan. As of the end of 2023, there are more than 6,000 birders who have submitted 972,000 checklists of their bird observations in Taiwan with data pertaining bird distribution and abundance, which has filled the spatial and temporal biodiversity information gaps (eBird, 2023). This dataset was used to estimate the winter waterbird hotspots in Taiwan.

As the cost of restoration and protective measures is substantial, we urgently need to enhance our understanding of the priority areas for the conservation of resources (Brooks *et al*., 2006; CBD, 2022). To bridge the existing knowledge and conservation gaps in the EAAF, our approach encompassed three essential components. First, we aimed to identify winter waterbird biodiversity hotspots. Second, we conducted a comparative analysis between these hotspots and the officially designated protected areas to evaluate their respective conservation statuses. This includes an assessment of the land-use patterns within the hotspots. Finally, we focused on identifying priority sites that warrant targeted conservation efforts and holistic landscape management. These strategic initiatives were designed to deepen our understanding of the EAAF, inform national and local conservation policies, and foster effective landscape-level management practices.

Table 1. The five criteria used for identifying winter waterbird hotspots in Taiwan.

Criteria	No. of hotspot grids	Threshold of hotspot	Mean ± SD (n)	Median	Range	No. of hotspot grids which outside the protected areas
1. Species richness	677	25 species	9.36 ± 11.23 (6,179)	5	1–81	409 (60.41%)
2. Abundance	321	1,000 individuals	241.69 ± 934.53 (6,165)	22	1–29,623	174 (54.21%)
3. Global importance	276	1) 15 individuals (CR, EN global population >1500) 2) individual (CR, EN global population ≤1500) 3) 30 individuals (VU)	28.10 ± 76.97 (763)	4	1–928	134 (48.55%)
4. Regional importance	586	0.1% of EAAF population	34.26 ± 204.85 (6,115)	4	1–20,000	336 (57.34%)
5. Local importance	603	1% Taiwan population (National threatened species)	70.10 ± 257.97 (1,608)	8	1–5,045	364 (60.36%)

METHODS

Our study area was the main island of Taiwan (the outlying islands were excluded), at 21.5° to 26.5° North latitude and between 120° to 122° East longitude. Taiwan's maximum elevation is 3,952 m. Geographically, Taiwan can be broadly categorized into two regions: the western plain, characterized by its flat terrain that has undergone extensive development; and the mountainous areas of central and eastern Taiwan, which account for 65% of the total land area and have experienced comparatively less development. We divided the study area into 39,780 1 × 1 km grid cells for systematic analysis.

Species

The target species in this study comprised waterbirds from various families, including Anatidae, Podicipedidae, Rallidae, Recurvirostridae, Charadriidae, Rostratulidae, Jacanidae, Scolopacidae, Laridae, Ciconiidae, Phalacrocoracidae, Ardeidae, and Threskiornithidae (Kirby *et al*., 2008). A total of 118 species, primarily inhabiting wetlands in Taiwan, were selected for this study. The focus was on birds that were either residents (species that remained year-round in specific regions), or winter visitors (species that spent only the winter in these areas). Pelagic birds were excluded from the analysis (Ding *et al*., 2023) (Appendix 1).

Data preparation

We downloaded the eBird Basic Dataset (EBD) of Taiwan dataset released in May 2023 (ebd_TW_relApr-2023), which provided data through April 2023 (eBird, 2023). First, we filtered the data from the past five winters, which is the main season for migratory waterbirds. In Taiwan, the winter season spans from November of a year to February of the following year. Therefore, we selected data from November 2018 to February 2023 and labeled the winter year based on the observation dates. For instance, data collected on November 1, 2018, and February 28, 2019, were both considered part of the 2018 winter season. We also restricted the complete checklists with the survey protocol type to "traveling" and "stationary." Taking into account the mobility of waterbirds and the spatial precision of the data, we kept the checklists with the survey effort to distance ≤ 5 km, area ≤100 ha, and duration ≤ 240 min (Strimas-Mackey *et al*., 2020). The final dataset comprised 780,354 records for 115 species. These records were spatially linked to 1 × 1 km grid cells (39,780 grids in Taiwan), and the species richness, abundance of each species, and the total abundance of waterbirds were calculated for each grid. The species richness value represented the number of species per grid. The abundance of each species was defined as the maximum value recorded for that species in each grid. The total abundance of waterbirds was calculated by first summing the maximum number of individuals of all species in the grid for each winter. The maximum sum of individuals in the five winters was used as a representative value.

Mapping winter waterbird hotspot areas

We identified winter waterbird hotspots based on five criteria (Table 1) and analyzed the correlations. If a grid cell met any of these criteria, it was designated a winter waterbird hotspot.

1. Species richness: a grid's species richness ranks in the top 10% or higher among all grids.
2. Abundance: a grid that supports at least 1,000 waterbird individuals.
3. Global importance: the category bases on The IUCN Red List of Threatened Species, where a grid that supports (1) at least 15 individuals of a Critically Endangered (CR) or Endangered (EN) species with a global population of >1,500 individuals, (2) at least one individual of a CR or EN species with a global population of 1,500 individuals or fewer, or (3) 30 individuals of a species classified as Vulnerable (VU) (IUCN, 2019, 2020).
4. Regional importance: a grid that supports at least 0.1% of the EAAF population for any single species (Jackson *et al*., 2021; Wetlands International, 2023).
5. Local importance: the category bases on The Red List of Birds of Taiwan, where a grid that supports at least 1% of Taiwan's nationally threatened species

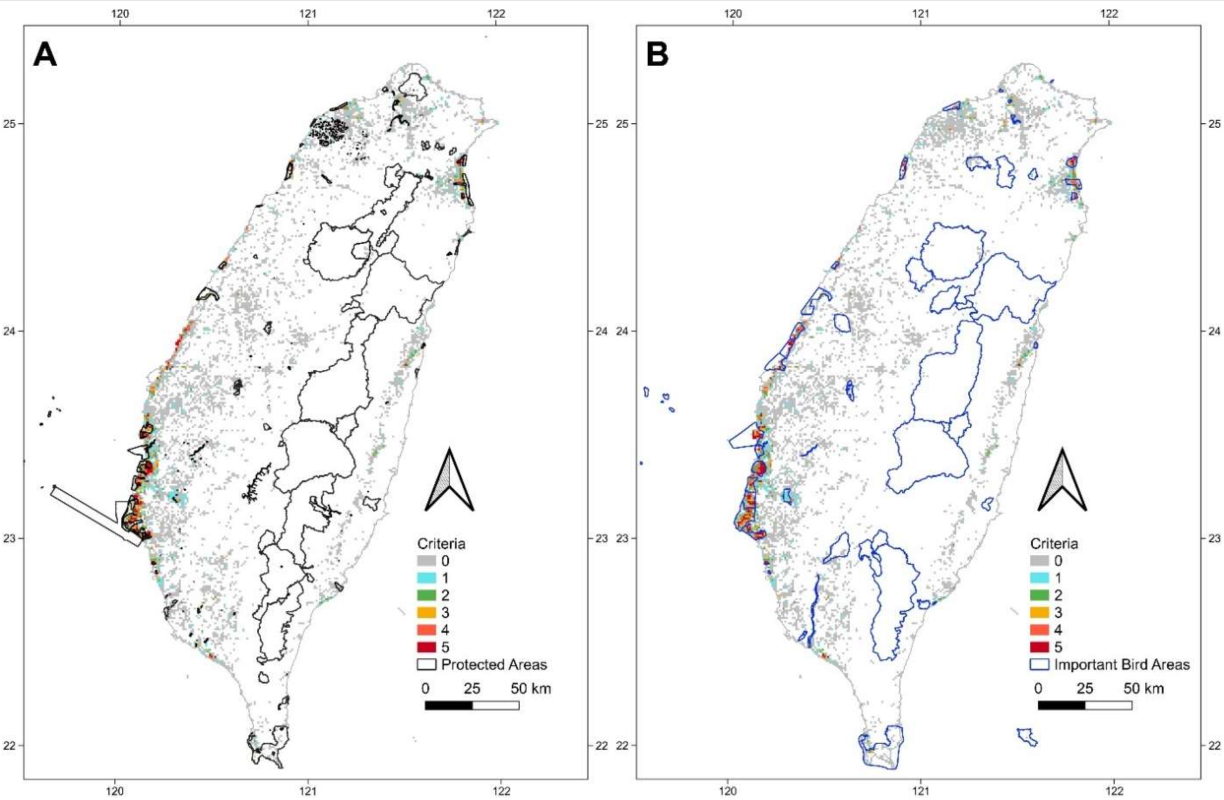

Fig. 1. The distribution of winter waterbird hotspots with the mask of protected areas (**A**) and IBAs (**B**) in Taiwan. The gray grids were data available grids, but they did not meet any of the five criteria used in this study, the blue grids met one criterion, the green grids met two criteria, the yellow grids met three criteria, the orange grids met four criteria, and the red grids met all five criteria.

(Nationally Critical Endangered [NCR], Nationally Endangered [NEN], and Nationally Vulnerable [NVU]) population for any single species (Lin *et al*., 2016).

Comparison of hotspots with protected areas and IBAs

We compared the distribution of winter waterbird hotspots with Taiwan's protected areas (including national parks, nature reserves, forest reserves, wildlife refuges, major wildlife habitats, and important wetlands) to assess the status of the protected hotspots. We also assessed the overlap between the winter waterbird hotspots and IBAs to assess the representativeness of the hotspots.

Hotspot locations and land-use types

The original area of land-use types was derived from the Taiwan Land-use Map, and we merged the original types into agriculture (rice fields, orchards, farms), aquaculture, paved surfaces and buildings (residential areas, embankments, roads), forests, wetlands (rivers, ponds, channels, wetlands), and tidal flats. To assess the human disturbance in winter waterbird hotspots, we overlapped the hotspot area map, coastal area, and land-use maps, and calculated the area of each land-use type in each grid (Ministry of the Interior, 2022, 2023).

All data processing and analyses were performed using R version 3.5.3 (R core Team, 2023) and QGIS version 3.10.14 (QGIS Development Team, 2023).

RESULTS

The winter waterbird distribution data covered 15.53% (6,179 grids) of the total area of Taiwan, covering 21.77% of the coastline area (1,620/7,441 grids). We identified 994 winter waterbird biodiversity hotspots, with 132 hotspots meeting five criteria simultaneously, 154 hotspots meeting four criteria, 137 hotspots meeting three criteria, 205 hotspots meeting two criteria, and 366 hotspots meeting only one criterion (Fig.1, Appendix 2, Data can be downloaded at https://pid.depositar.io/ark:37281/k57302t0v).

In the species richness criterion, 1.70% (677 grids) area was covered, and each grid covered at least 25 species in Taiwan, and the hotspot area with the highest value for species richness covered 81 species in a grid. For the abundance criterion, there were 321 grids with more than 1,000 individuals, which covered 0.81% area of Taiwan (Table 1).

In the global importance criterion, there were 276 grids covering six IUCN threatened species, including one CR species, *Aythya baeri* (20 grids), four EN species, *Calidris tenuirostris* (12 grids), *Platalea minor* (240 grids), *Saundersilarus saundersi* (20 grids), and *Tringa guttifer* (eight grids), and one VU species, *Aythya ferina* (14 grids). According to the regional importance criterion, there were 586 grids covering 40 species, and each grid represented the habitat for at least 0.1 population of species in the EAAF.

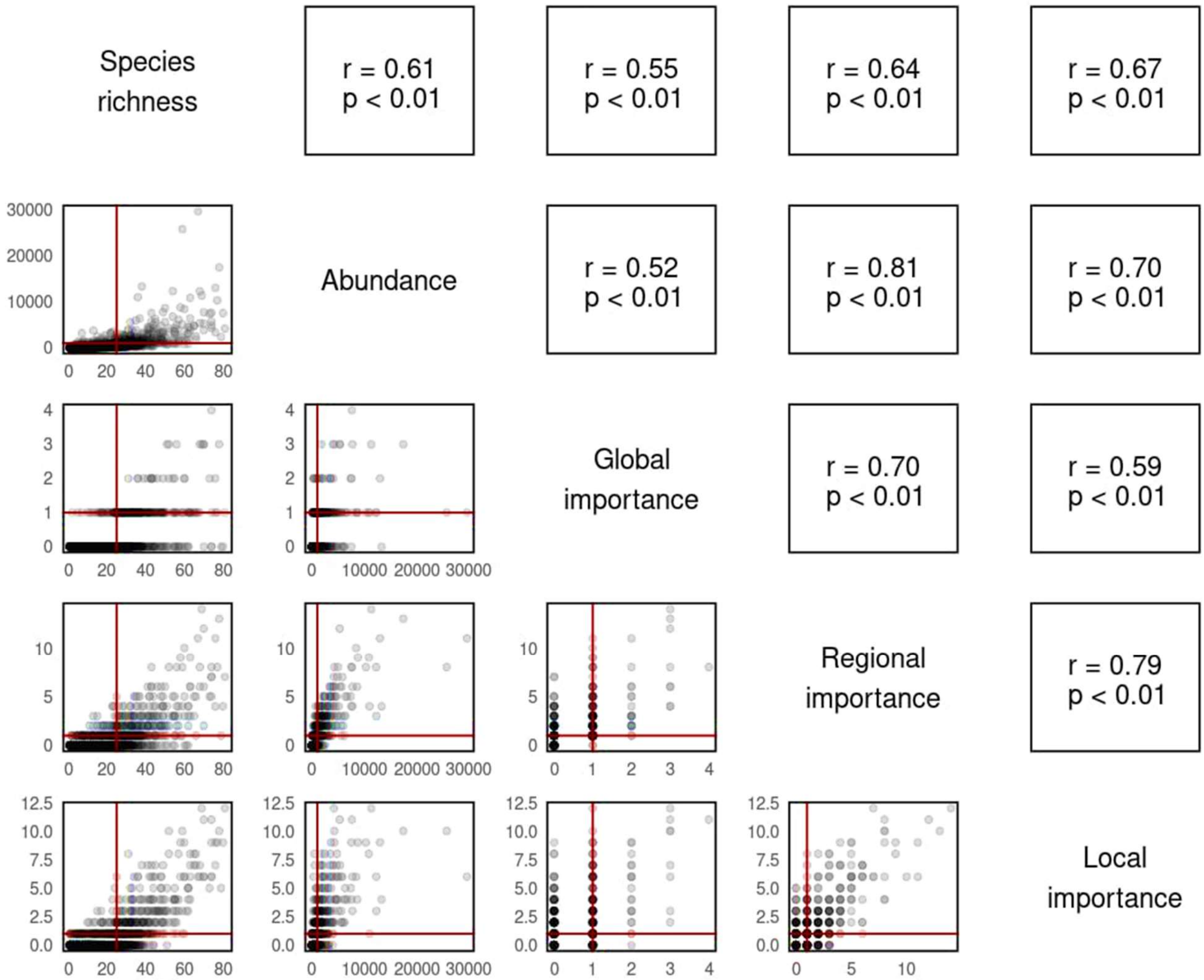

Fig. 2. Correlation between five criteria of winter waterbird hotspots: (1) Species richness, (2) Abundance, (3) Global importance, (4) Regional importance, (5) Local importance. Pearson correlation coefficients (r) and p-values (p) are shown. The red line is the threshold of each criterion.

The top three species were *Platalea minor* (320 grids), *Charadrius alexandrines* (160 grids), and *Pluvialis fulva* (100 grids).

In the local importance criterion, there were 603 grids covered 18 Taiwan threatened species, two NCR species *Aythya baeri* (20 grids) and *Saundersilarus saundersi* (126 grids), four NEN species *Calidris tenuirostris* (35 grids), *Ciconia boyciana* (47 grids), *Tringa guttifer* (eight grids), and *Numenius madagascariensis* (50 grids), 12 NVU species *Numenius arquata* (62 grids), *Anas crecca* (140 grids), *Calidris temminckii* (80 grids), *Hydrophasianus chirurgus* (52 grids), *Calidris ruficollis* (95 grids), *Calidris canutus* (30 grids), *Egretta eulophotes* (42 grids), *Limosa lapponica* (63 grids), *Limosa limosa* (100 grids), *Calidris alpina* (195 grids), *Aix galericulata* (21 grids), and *Mareca falcata* (130 grids) (Appendix 2).

We observed that species richness showed a moderate correlation with the other criteria, while abundance, regional importance, and local importance demonstrated high correlation. Additionally, there was a strong relationship between abundance and regional importance. Moreover, the relationship between regional importance and local importance was high (Fig. 2).

Only 35.11% (349 grids) winter waterbird hotspots were located in protected areas, and 64.89% hotspots were unprotected, 60.41% species richness hotspots, 54.21% abundance hotspots, 48.55% global importance hotspots, 57.34% regional importance hotspots, and 60.36% local importance hotspots were unprotected (Table 1); Several winter waterbird hotspot areas (45.98 %, 457 grids) were located in IBAs and significantly overlapped with human activity near the coastal area (61.97 %, 616 grids). The land-use types of these hotspot grids included wetlands (26.66%), aquaculture (22.15%), agriculture (22.11%), paved surfaces and buildings (17.04%), tidal flats (7.54%), and forests (4.50%). In each criterion of winter waterbird hotspots, the major land use types were wetland, aquaculture, and agriculture (Table 2).

Table 2. The percentage of land-use types for each hotspot criterion.

Land-used type (%)	1. Species richness	2. Abundance	3. Global importance	4. Regional importance	5. Local importance	All hotspots
agriculture	18.73	15.14	8.28	16.52	21.48	22.11
aquaculture	27.21	26.14	32.87	26.40	20.36	22.15
paved surfaces and buildings	15.26	13.63	12.67	15.31	15.89	17.04
forests	3.40	3.19	2.95	3.54	5.46	4.50
wetlands	29.06	32.02	34.46	28.90	27.96	26.66
tidal flats	6.36	9.88	8.77	9.32	8.86	7.54

DISCUSSION

In this study, we systematically identified winter waterbird hotspots in Taiwan by considering species richness, abundance, and the presence of threatened species. This study fills a crucial spatial knowledge gap necessary for maintaining populations of migrant waterbirds in the EAAF during the non-breeding season. These waterbird hotspots can serve as valuable tools for environmental impact assessments and conservation initiatives. Furthermore, their potential extends to various spatial planning applications for future policy implementation. Our results also contribute to achieving the goals of the Kunming-Montreal Global Biodiversity Framework. This global framework for biodiversity conservation prioritizes actions based on the concepts of irreplaceability and vulnerability, and offers a range of spatial conservation options (CBD, 2022).

However, spatial conservation planning faces several challenges, and imperfect data represent a significant limitation. This imperfection manifests in two key aspects: spatial gaps in data coverage and variability in monitoring efforts (Clemens *et al*., 2012). The presence of spatial gaps hinders a comprehensive assessment of conservation needs and priorities, as certain areas may lack sufficient data for informed decision-making. We applied data from eBird, the world's largest biodiversity-related citizen science database, to efficiently fill the spatial gap of species occurrence, and eBird Taiwan is also one of the most active regional portals of eBird (eBird, 2023). This eBird dataset provides vast quantities of data and extensive coverage of Taiwan, particularly the coastal regions. To ensure the reliability of our data analysis, we controlled for data quality to identify credible winter waterbird hotspots in Taiwan (Lewandowski and Specht, 2015).

Taiwan is a known waterbird hotspot on the EAAF (Li *et al*., 2019). However, similar to global trends, winter waterbird populations in Taiwan have been steadily declining (Lin *et al*., 2023). Furthermore, the most recent release of the IBAs list dates back nearly a decade. The high-resolution winter waterbird hotspot map we generated for Taiwan at the national scale aligns with the present-day management needs.

Winter waterbird hotspots indicate the target areas for management to protect high-biodiversity areas. In our study, species richness showed a weak correlation with the other criteria, indicating that focusing solely on species richness in biodiversity may ignore hotspots where single species aggregate in large numbers. Therefore, abundance is a necessary criterion. Additionally, the low correlation between global and local importance indicated the importance of considering local conservation needs when addressing globally threatened species. Our research results provide a comprehensive assessment of winter waterbird hotspots at the global, regional, and local levels of species richness and abundance, and provide information on the threatened species. We identified 2.5% of the area (994/39,780) covering winter waterbird biodiversity hotspots, which occupy relatively small areas in Taiwan. However, a comparison of hotspots identified and protected areas indicated that 64.89% of winter waterbird hotspots lie outside reserves. Our results suggest that these migratory waterbirds need more diverse management policies compared to the traditional designation of protected areas, such as targeting agriculture and aquaculture planning to fill the protection gaps (Runge *et al*., 2015).

The results of our comparison between the winter waterbird hotspots we identified and IBAs revealed that many of the identified hotspots were not within the IBAs; only 45.98% of the winter waterbird hotspot areas have been indicated as IBAs. This suggests that we discovered new locations that were previously not known, or that there may have been changes in the distribution of waterbirds.

Winter waterbird hotspots were primarily located along the coastline and overlapped significantly with human activities. Unfortunately, these critical habitats have been threatened by human-induced land type changes since the last century, causing the loss of tidal flat areas due to development, which is a major threat to shorebirds (Sutherland *et al*., 2012; Chen *et al*., 2024). This issue is not unique to Taiwan but extends to other coastal regions along the EAAF, where natural wetlands have been transformed into agricultural, aquacultural, residential, and commercial development (Murray *et al*., 2014; Moores *et al*., 2016; Choi *et al*., 2018).

To address these challenges, conservation efforts must consider both natural and artificial wetlands (Ma *et al*., 2004). Although natural wetlands hold greater significance for waterbirds, the ongoing decline in natural habitats underscores the increasing importance of artificial wetlands for waterbird conservation. This highlights the need to enhance or preserve the quality of both natural and artificial wetlands for waterbird conservation (Ma *et al*., 2004; Li *et al*., 2013; Sebastián-González and Green, 2016; Jackson *et al*., 2020). Artificial habitats, such as aquaculture ponds and salt pans, provide vital roosting areas and supplementary foraging grounds during high tides, while granting access to nearby flats during low tides. Shorebirds favor landscapes with abundant aquaculture ponds, minimal arable fields, and less wasteland (Bai *et al*., 2018, Jackson *et al*., 2019). After harvest, drained aquaculture ponds resemble mudflats and attract many foraging shorebirds. Flooded farms also mimic mudflats and act as attractive foraging grounds for shorebirds. In Taiwan, when ponds are drained, such as milkfish and hard clam ponds, they create a mudflat environment that provides an ideal feeding and resting habitat for waterbirds (Huang and Hsueh, 2014). Artificial wetlands, such as rice fields, flooded shallot fields or irrigation ponds designed for food production, provide additional value to birds, potentially playing a critical role in maintaining population viability (Sebastián-González *et al*., 2010; Kasahara *et al*., 2020; Huang, 2021).

Establishing and maintaining stable, high-quality roosting sites within these artificial habitats is crucial to bolster the resilience of regional habitats for shorebirds. Concurrently, preserving foraging habitats, including abundant aquaculture ponds, minimal arable fields, and wastelands is critical for supporting shorebird populations in modified coastal landscapes (Green *et al*., 2015; Bai *et al*., 2018; Jackson *et al*., 2021). The "hottest" hotspots are concentrated in the southwestern and northeast coastal areas, which are largely occupied by aquaculture and agriculture activities. Therefore, it is recommended to maintain the existing aquaculture ponds and fields in this area and promote environmentally friendly aquaculture and agriculture practices to provide stable habitats for wintering waterbirds. These findings highlight the importance of an integrated approach that considers both natural and artificial wetlands in waterbird conservation efforts in Taiwan.

Recently, the threats to the waterbird hotspots are the commercial, residential and energy development leading to changes in wetlands, aquaculture, and agricultural landscapes. Nevertheless, energy development poses a new threat to these artificial wetlands, particularly in western Taiwan, a major waterbird hotspot. Numerous wind turbines and solar panels have already been erected along the coastline and there are plans for further expansion. The Changhua coastline is one of the significant hotspot areas in Taiwan, and Bai *et al*. (2018) have highlighted the significance of areas dominated by aquaculture ponds for migratory shorebirds. Coastal artificial wetlands in Changhua are potentially affected by development plans. In Taiwan's densely developed coastal regions, the extensive use of artificial habitats by significant waterbird assemblages during high tides underscores the need for enhanced coordination in management efforts in terms of pragmatic strategies for facilitating the persistence of birds. Strategies to mitigate habitat threats to migratory waterbirds can be improved through economic policies and effective land use planning (Kirby *et al*., 2008).

Utilizing decision support tools at the regional, national, and local levels can enhance restoration planning and implementation, effectively addressing the unique socioecological contexts of each area. These benefits are most pronounced with ambitious goals to preserve natural ecosystems using comprehensive landscape approaches that integrate conservation, restoration, and sustainable agricultural practices (Strassburg *et al*., 2020). Policymakers in densely populated regions face the complex task of reconciling ecological and economic considerations to balance the preservation of biodiversity as well as fulfilling human development needs (Green *et al*., 2015). Our study, based on crowdsourced scientific data, provides up-to-date information for fostering biodiversity management in such sites.

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