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Shifted to the South, Shifted to the North, but No Expansion: Potential Suitable Habitat Distribution Shift and Conservation Gap of the Critically Endangered Baer's Pochard (*Aythya baeri*)

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Abstract: There are many challenges in biodiversity conservation, especially for migratory waterbirds because their survival depends on the availability of a suite of interconnected sites at different stages of their annual cycle. Due to habitat loss and degradation, the population of Baer's Pochard (*Aythya baeri*), a migratory diving-duck, has declined to an extent that it has been listed as a critically endangered species by the IUCN Red List. To better understand the habitat requirements of this threatened waterbird for its effective conservation, we conducted seven years of field surveys within its historical distribution range in the East Asian–Australasian Flyway including China and neighbouring countries, covering 563 observation sites at 185 locations. Twelve new locations were identified as habitats for this species. By combining our surveys with literature and citizen science birding records, 171 Baer's Pochard's presence sites have classified as migratory stopovers, wintering grounds and breeding and potential breeding habitats. We then used Maxent model to estimate the potential distribution range and updated and refined the current IUCN distribution map. Finally, we identified the key conservation gaps by overlaying the distribution with a recent remotely acquired global landcover map. Our results show that: (1) The southernmost breeding site is about 1400 km south of its current IUCN breeding range; (2) the northern most wintering site is 800 km north of the IUCN wintering range; (3) Six newly discovered sites in Hebei, Henan, Shandong, Jiangxi and Hubei provinces, China are confirmed to be used all year round; (4) Most sites (81.8%) are not located in protected areas (PAs), and the majority of the suitable habitats (90%) are not protected by the current PA network. Our findings reveal that great changes have taken place in the distribution of Baer's Pochard and that there are many distribution overlaps throughout its annual migration circle (e.g., many historical stopover sites become breeding habitats). Moreover, the key habitats have retreated into eastern Asia, and most of the habitats overlap with urban developed areas and are outside of current PA network. Our study suggests that the existing PA network may be less effective for the conservation of this critically endangered species under predicted global climate change, and other effective area-based conservation measures should be part of the conservation strategy. More importantly, as the distribution of Baer's Pochard covers at least 15 countries, closely coordinated cross-border cooperation would be critical for its future survival.

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1. Introduction

Globally, migratory waterbirds are threatened by habitat loss, invasive species, pesticides, and climate change [1,2]. During their life cycle, migratory waterbirds need suitable habitats for breeding, feeding, resting, moulting and wintering. Habitat loss and degradation have been identified as the major threats along the East Asian–Australasian Flyway (hereinafter referred to as the Flyway), as this region contains over a third of the world's human population with the fastest-growing economies [1]. Waterbirds are responding to habitat loss and degradation by changing their distributions, creating debate about the effectiveness of existing networks of protected areas. Wetlands on this flyway have shrunk sharply in the past three decades [3]. However, few studies have estimated suitable habitat changes for endangered species according to a species' life cycle stages and evaluated the gap in the Flyway conservation network [4].

Species distribution modelling has become a practical conservation tool to predict a species' potential distribution range across landscapes based on species presence/absence data and environmental explanatory variables [5]. Field surveys could provide high quality data about the species' presences in a particular area. However, due to the high cost, they often cover a relatively small area and are usually not representative of the geographic range of a species. It is important to understand potential habitat distributions and changes in order to propose adequate and efficient conservation measures for endangered species [6,7]. Recently, at the flyway scale, species distribution models have been used to predict the vulnerability of species and their habitats to climate change [8], the impact of wetland loss on coastal waterbird suitable habitats [9] and identifying priority sites for conservation and classifying critical sites [10].

Baer's Pochard (*Aythya baeri*) is a migratory diving duck endemic in the Flyway that was formerly widespread in east and southeast Asia. Historically, Baer's Pochard was abundant throughout Asia, but the population has undergone a catastrophic decline since the 1980s on both its breeding and wintering grounds [11,12]. Its global population was estimated to be fewer than 700 mature individuals in the wild in 2019, and it was assessed as critically endangered (CR), on the verge of extinction in the wild [13]. The reasons for this decline were suggested as habitat loss and degradation in both its breeding and wintering ranges and the unsustainable harvesting of both adult birds and eggs [11,14,15].

The current distribution of Baer's Pochard used by the IUCN Red List was mapped by BirdLife International in 2019 (downloaded from http://datazone.birdlife.org/species/requestdis BirdLife International (2022) (accessed on 11 March 2022)). On this map, the species' breeding range is from the Amur and Ussuri basins in Russia southwards to north-eastern China. Its wintering range is from Central China and southern Japan to Southeast Asia [16]. However, during our observations between 2012 and 2014, we found evidence showing that both its breeding and wintering grounds have shifted. At that time, the southernmost breeding site was Hengshuihu National Nature Reserve in Hebei Province; it moved more than 4 latitude degrees to the south end of the mapped breeding range. In 2015, a new breeding site was reported in the central Yangtze region of China, formerly considered as its wintering ground [17]. The northernmost wintering ground was in Tianjin; it advanced more than 7 latitude degrees to the north end of the mapped wintering range. The shifts in distribution range, in particular the overlaps in breeding, stopover and wintering habitats, have important implications for formulating an effective conservation policy as different habitats require different management actions [1]. For example, while breeding habitats can be efficiently protected by nature reserves, it is not practical to establish a conservation area for all stopover sites and wintering grounds [18], and understanding how to optimise wildlife management in agricultural landscapes could be the key to successful conservation policy [19,20].

Given the perilous state of the wild population of Baer's Pochard, it is urgent to make a systematic flyway-scale habitat evaluation according to the current knowledge of the wintering, breeding and migration distribution and to identify conservation gaps. In this study, we conducted seven-year (2014–2021) field Baer's Pochard surveys at 563 sites at 185 locations within its distribution range in EAAF. Together with literature/birding records, we built geographic information system (GIS)–based species distribution models to update the current map by BirdLife International. Using the recent global land use land cover map derived from satellite imagery, we further quantified the conservation gaps to identify stresses for prioritizing conservation actions in the entire flyway. The specific objectives of the study are: (1) using a species distribution model to project potential range and suitable habitats according to Baer's Pochard's life cycle; (2) identify the conservation gap and (3) provide effective management suggestions.

2. Materials and Methods

2.1. Study Areas

As a critically endangered species whose population is rapidly declining, the existing distribution sites of Baer's Pochards are unclear. A review of the literature and database of bird-watching records revealed that many historical sites in the last century have had no observation for many years. In addition, it is difficult to confirm or obtain accurate location of records in some bird surveys due to the scarcity of numbers and the lack of photographic or video evidence. Therefore, we designed a special field survey dedicated to this species, covering (1) most wetlands in China with historical records of Baer's Pochards and its relative species; (2) suitable habitats in the historical distribution range but where no Baer's Pochard sighting has been reported and (3) some waterbird gathering places in neighbouring countries. The survey area is between 19–52° N and 86–145° E (Figure 1), and surveyed habitats included rivers, lakes, reservoirs and other types of wetlands such as marshes. Due to the size or shape of survey locations, multiple observation sites were set up. 563 observation sites at 185 locations were monitored between 2014 and 2021. Surveys are conducted in different seasons according to the life-circle of Baer's Pochard, and some regions have carried out continuous multi-season surveys for many years (Table S1 and Figure 1).

To accurately predict all possible suitable habitats for this species under current environmental conditions, we selected an area between 0–66° N and 70–155° E (Figure 1) as our modelling area. This area covers the known historical and present distribution of Baer's Pochard, as well as most inland areas of the Flyway in the northern hemisphere.

2.2. Baer's Pochard Occurrence

Occurrence data of Baer's Pochard for modelling were derived from: (1) our own field survey between 2014 and 2021, covering 88 presence sites of 563 observation sites; (2) locally and internationally peer-reviewed articles, published reports and nature reserve surveys between 2000 and 2021, covering 33 presence sites [21–27]; (3) birding records from eBird and Birdreport.cn with photos between 2000 and 2021, covering 60 presence sites.

We classified those data according to four different life stages (Figure 1). Breeding: where nests, eggs or ducklings could be found during June to August (breeding season). Potential breeding: adults in pairs or adult females have been observed continuously during the breeding season but no nests, eggs or ducklings were found. Wintering: records between mid-January and February. Migratory stopovers: records at other seasons.

A total of 107 migration stopover records, 74 wintering records, 21 breeding records and 33 potential breeding records were obtained, with some sites having records in multiple categories.

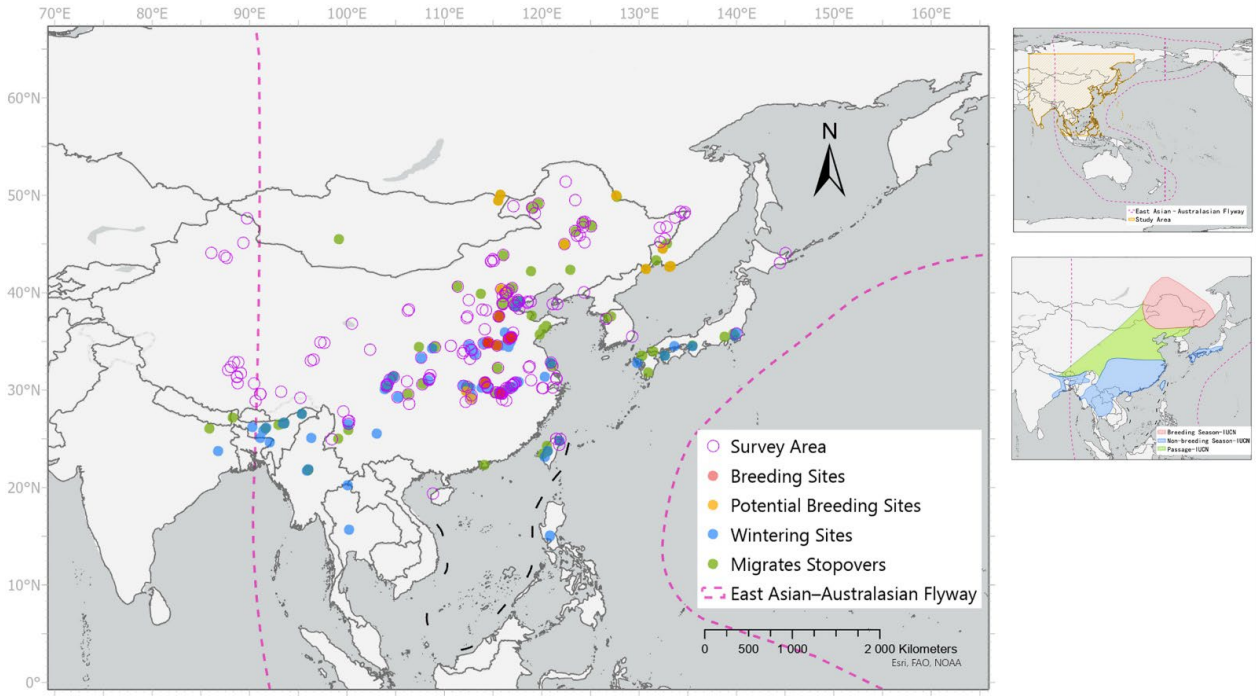

Figure 1. Baer's Pochard survey sites and historical presence sites for modelling. The study area within the East Asian–Australasian Flyway is shown in inset upper right, and inset lower right is the current distribution map by IUCN.

2.3. Environment Data

Bioclimate data were extracted from the WorldClim Global Climate Data (V2.1) (http://www.worldclim.org (accessed on 1 July 2021)) with an original data resolution of 30 s. Strong collinearity between the bioclimate variables may cause misinterpretation of the SDMs to the high level of correlation among variables [28,29], therefore, the correlations among all 19 bioclimatic variables were evaluated using SDM Tools in ArcGIS Pro (Version 2.6.0 Copyright © 1995–2020 Esri. Published in the United States of America.). The layers with high Pearson correlation coefficients ($r \geq 0.80$ or $r \leq -0.80$) were removed (Table S2). The variables from a set of highly correlated variables which were biologically more relevant to Baer's Pochard were selected, resulting in nine predictors being kept for model building (Table 1). Elevation was derived from ASTER Global Digital Elevation Model Version 003 with a resolution of 1 arc second (https://doi.org/10.5067/ASTER/ASTGTM.003, accessed on 26 March 2021). All environmental variable data were interpolated to 1 km spatial resolution for subsequent model prediction and grid analysis.

Table 1. Environmental variables used for modelling the suitability habitat of Baer's Pochard in the Flyway.

Variables	Unit
Mean diurnal range (bio2)	°C
Isothermality (bio3)	Unitless
Max temperature for warmest month (bio5)	°C
Min temperature for coldest month (bio6)	°C
Annual precipitation (bio12)	mm
Precipitation of wettest month (bio13)	mm
Precipitation of driest month (bio14)	mm
Precipitation of warmest quarter (bio18)	mm
Precipitation of coldest quarter (bio19)	mm
Elevation	m

2.4. Species Distribution Modeling and Evaluation

We used MaxEnt (Version 3.4.4) to predict Baer's Pochard's potential suitable habitat. In the process of modelling, 75% of the observation data of Baer's Pochard were randomly selected as the training data, and 25% of the samples were used as the testing data. The model replicates were set as 10 runs [30].

Model performances were evaluated based on the area under the curve (AUC) of the receiver operating characteristic curve. An AUC value between 0.9 and 1.0 indicates excellent model performance, 0.8–0.9 = good, 0.7–0.8 = average, 0.6–0.7 = poor and 0.5–0.6 = insufficient [31].

We refined our prediction of the Baer's Pochard spatial distribution range by classifying results with predictions greater than 95%; observation data are included in each life stage group as suitable areas in ArcGIS Pro (Version 2.6.0).

2.5. Species Distribution Shifting and Conservation Gap Analysis

Potential suitable habitat shift and conservation gap analysis were conducted in three steps (Figure 2).

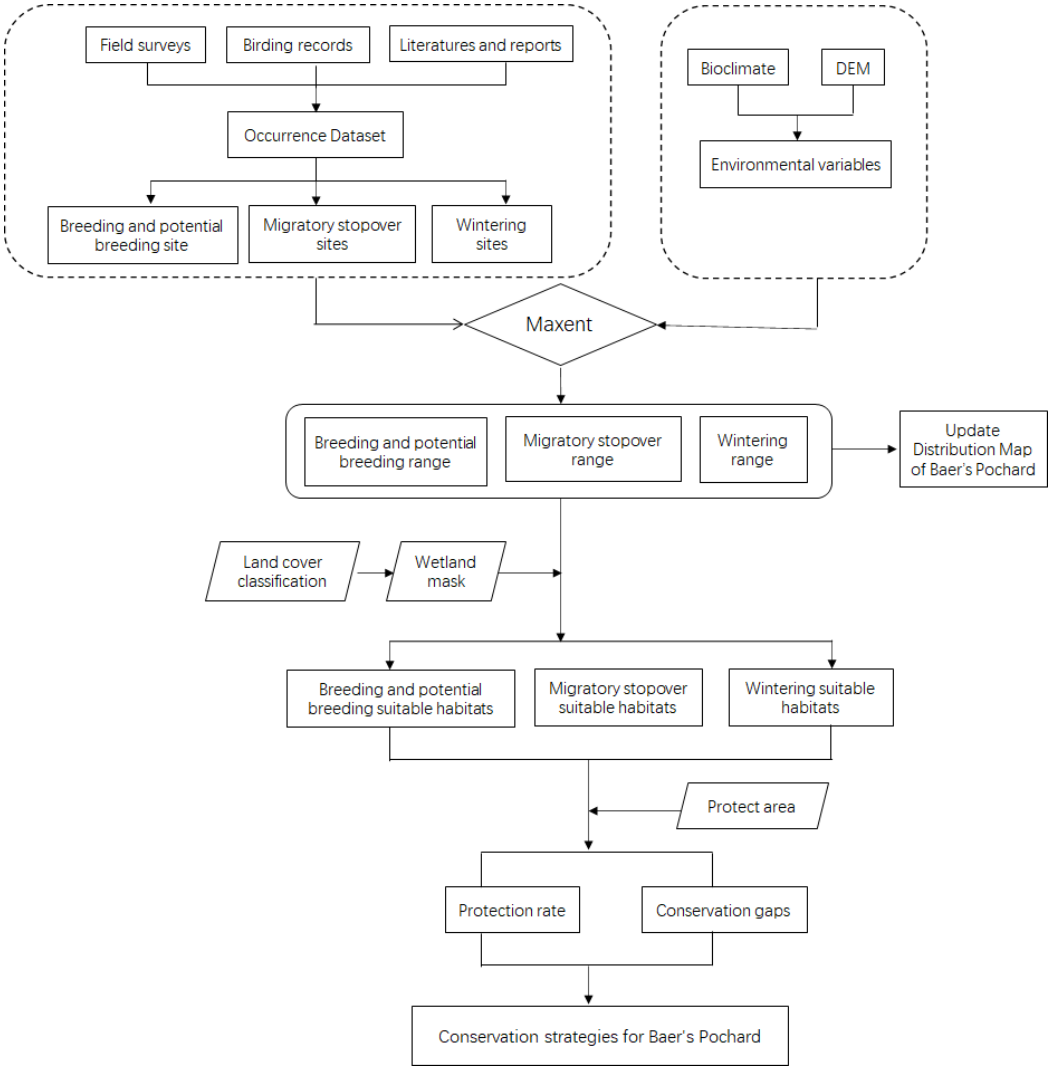

Figure 2. Flowchart showing the steps proposed for formatting effective Baer's Pochard conservation policy.

First, Baer's Pochard suitable habitats range shifting was estimated by comparing predicted Baer's Pochard present records with a historical Baer's Pochard distribution map

(downloaded from http://datazone.birdlife.org/species/requestdis BirdLife International (2022) (accessed on 11 March 2022)). The northernmost and southernmost distribution range shifts were compared. Central breeding and potential breeding, migratory stopovers and wintering grounds were estimated using the directional distribution (standard deviation ellipse) function in ArcGIS Pro 2.6.

Second, the predicted Baer's Pochard habitat probability raster was masked by clipping to the water bodies and wetland category using 2020 GlobeLand30 data (http://www.globallandcover.com/ (accessed on 5 December 2021)). A buffer zone of 1 km was added to water bodies and wetland polygons because Baer's Pochard is considered to use habitats in and near wetlands [13]. The area of pixels was summed up to the total area of habitat suitable for Baer's Pochard at each life stage.

Finally, conservation gaps were analysed by overlaying the Baer's Pochard suitable habitats with the current nature conservation area (data downloaded from UNEP-WCMC (2017). The Protected Area Profile for Asia & Pacific from the World Database of Protected Areas, January 2017, is available at: www.protectedplanet.net (accessed on 25 January 2017)). The Urban Area data uses a 1 km global consensus land-cover dataset from EarthEnv produced in 2014 (available at: https://www.earthenv.org/landcover (accessed on 13 November 2018)).

3. Results

3.1. Distribution Range of Baer's Pochard Improved

A total of 12 new locations were discovered from this study, including two new breeding sites, five migration stopover or potential breeding sites and five wintering sites. Some of these locations recorded Baer's Pochard all year round. These data are spatially spread out, giving new insights into the distribution and possible migration patterns of this species and providing more detail to update the current IUCN distribution map.

3.1.1. All Six Confirmed Breeding Sites Are Outside the Current IUCN Map, the Farthest One Being about 1400 km to the South

Baer's Pochard breeds around lakes and other freshwater habitats with rich aquatic vegetation including artificial habitats such as fishponds and parks. The species' traditional breeding range was from the Amur and Ussuri basins in Russia southwards to north-eastern China. However, according to our survey and data collection, all six confirmed breeding sites since 2000 are in central-east China (Figure 3), far away from the "Breeding Season" range in the original IUCN distribution map. The major breeding populations are between the lower Yellow River and mid-lower Yangtze River. The southernmost one was about 1400 km from its original breeding range. Some locations in the Ussuri basin in Russia, north-eastern China and eastern Mongolia also have records of adults during the breeding season and could be breeding sites.

3.1.2. 23 Wintering Sites Have Been Found Outside the Current IUCN Map, with the Farthest One about 800 km to the North

In winter, Baer's Pochard prefers freshwater lakes and reservoirs, but it can be found in any rivers, fishponds and parks that do not freeze. In the last 10 years, some wetlands in northern China no longer freeze in winter. Five new wintering sites have been found in Beijing, Tianjin and Hebei by our survey, as well as 18 sites from citizen science and other studies which are out of the current "Non-breeding Season/Winter" category of the IUCN map. The northernmost wintering site is 800 km north from that (Figure 3).

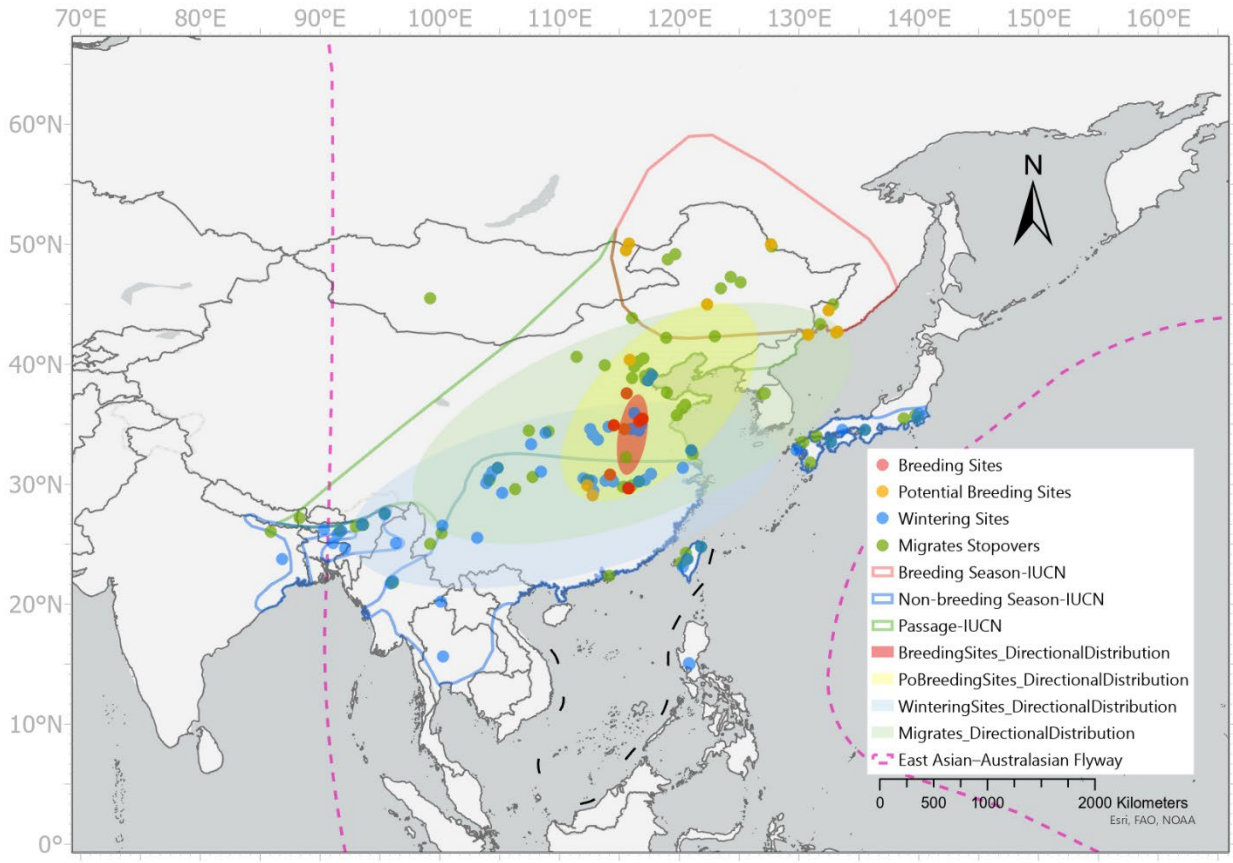

Figure 3. The central breeding range of Baer's Pochard has shifted to central-east China, and the wintering ground has expanded northward in comparison with the current distribution map by IUCN. In addition, there is a large geographical overlap among the three life stages (breeding, stopover and wintering).

3.1.3. Large Overlap among Its Breeding, Migrating Stopovers and Wintering Ground

For migratory birds, we normally describe their distribution range as breeding range, migration stopovers and wintering ground. However, our current survey observed Baer's Pochard's breeding, stopover and wintering populations at the same places during different seasons. For example, in Hengshuihu National Nature Reserve, Hebei province of China, the maximum spring migration population was 308 in March, the maximum breeding population was 4 adults with 17 ducklings in June and the maximum wintering population was 48 in January. In Jiujiang, Jiangxi province of China, the maximum spring migration population was 265 in March, the maximum breeding population was 12 adults with 4 ducklings in June and the maximum wintering population was 189 in mid-January. Similar changes in population patterns have occurred in Henan, Shandong and Hubei provinces. This shows that in these overlap regions, habitats may be used by small populations all year round with heavily reliance in particular seasons by other populations (Figure 3). Similar characteristics have been found in other Genus "*Aythya*" birds.

3.2. Details of Habitat Suitability Spatially Revealed within Baer's Pochard Distribution Range

The species distribution models show good performance with high accuracy. The AUC of the breeding, potential breeding, migration and winter distribution range models were 0.99, 0.99, 0.96 and 0.98, respectively. The variable jack-knife tests showed that Bio6 (min temperature for coldest month) and Elevation in Breeding, Elevation, Bio6 and Bio18 (precipitation of warmest quarter) in potential breeding; Elevation, Bio5 (max temperature for warmest month) and Bio6 in migration and Bio6, Elevation and Bio18 in wintering made the biggest contributions to model performance.

3.2.1. 78.1% of the Predicted Breeding and Potential Breeding Distribution Range Are out of the Current IUCN Map

To prevent bias due to the lack of investigation in the Amur and Ussuri basins of Russia, we used confirmed breeding sites (in red) and potential breeding sites (in yellow) to estimate its current breeding range. The new distribution range estimate covered an area of 1,420,388 km^2 (18.94413–59.90612° N, 71.34401–154.99583° E, Figure 4A) in China, Russia, Japan, the Democratic People's Republic of Korea and the Republic of Korea. This shows that the breeding hotspot could have shifted southward, and wetlands in central-east China are important breeding habitats for this endangered species, covering Beijing, Tianjin, Hebei, Shandong, Henan, Hebei and Jiangxi (Figure 4A-1). The Southern part of northeast China, the west coastal area of the Korean Peninsula (Figure 4A-2) and the east most part of China with Ussuri basins of Russia (Figure 4A-3) are also very important in the breeding season. In addition, the modelling result shows that suitable breeding habitats might occur in the coastal areas of Japan.

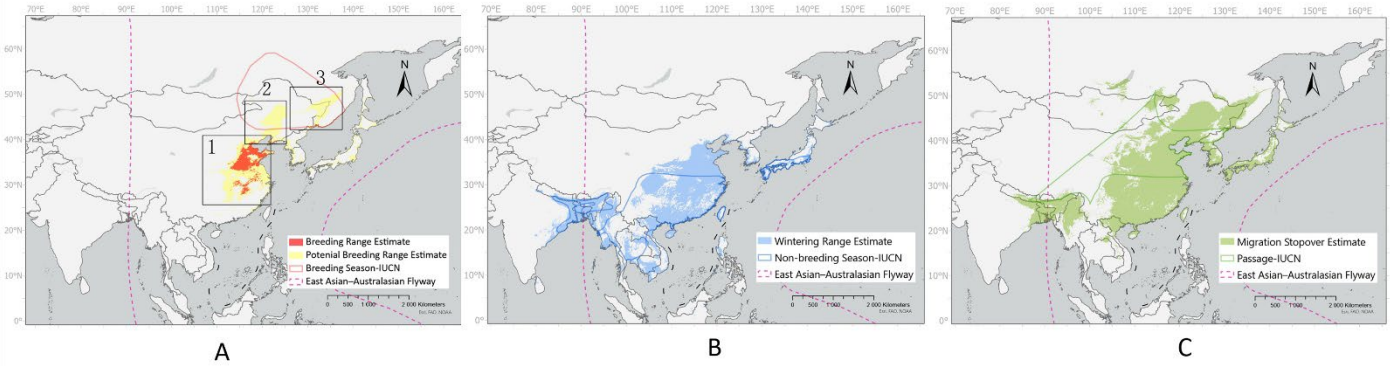

Figure 4. Maps showing the breeding distribution range of Baer's Pochard in the recent two decades is in central-east China (**A**); the wintering ground has been shifting north and expended (**B**); and migratory stopovers overlaps with both breed and wintering distribution (**C**).

3.2.2. 43.9% of the Predicted Wintering Distribution Range Are Outside of the Current IUCN Map

The new wintering distribution range estimate covers a total area of 3,744,443 km^2 (0.27929–60.10612° N, 73.68961–154.89898° E, Figure 4B), ranging from northeast India, Nepal, Bangladesh, Thailand, Myanmar, Vietnam, Cambodia and the northern Philippines to southeast and central China, South Japan and the southwest of the Korean Peninsula.

3.2.3. Changes to the IUCN Seasonal Category Map

Our current distribution estimate of Baer's Pochard shows that its breeding range, migration stopovers and wintering ground have large overlap in central-east China, the Democratic People's Republic of Korea, the Republic of Korea and southern Japan. The new migration stopover range estimate has a total area of 5,394,532 km^2 (13.51788–59.81588° N, 80.12734–154.4375° E, Figure 4C). The overlap covers an area of 277,703 km^2 (27.0264–41.00807° N, 112.17734–124.38246° E), and is mainly located in the North China Plain and the Mid-Lower Yangtze River (Figure S1).

The current IUCN distribution map of Baer's Pochard is divided to three categories: Breeding Season (Code 2), Non-breeding Season/Wintering (Code 3) and Passage (Code 4) (Figure 1) [32]. However, our results suggest that the life-stage and habitat use of this species are more complicated than what is known previously. There are 12 species of genus *Aythya* in the world. Three of the *Aythya* are sedentary and do not migrate at all; the other nine have a relatively complex life history. The distributions of six *Aythya* species have been divided into four seasonal categories based on extensive studies and data on species distribution.

We suggest dividing the distribution range of Baer's Pochard into four seasonal categories as its sister species and updating the distribution map of this species according to our detail distribution data (Figure 5). In this map, "resident" habitats can be used by Baer's Pochard all year round, including possible small non-migrate populations and big populations with different migration strategies.

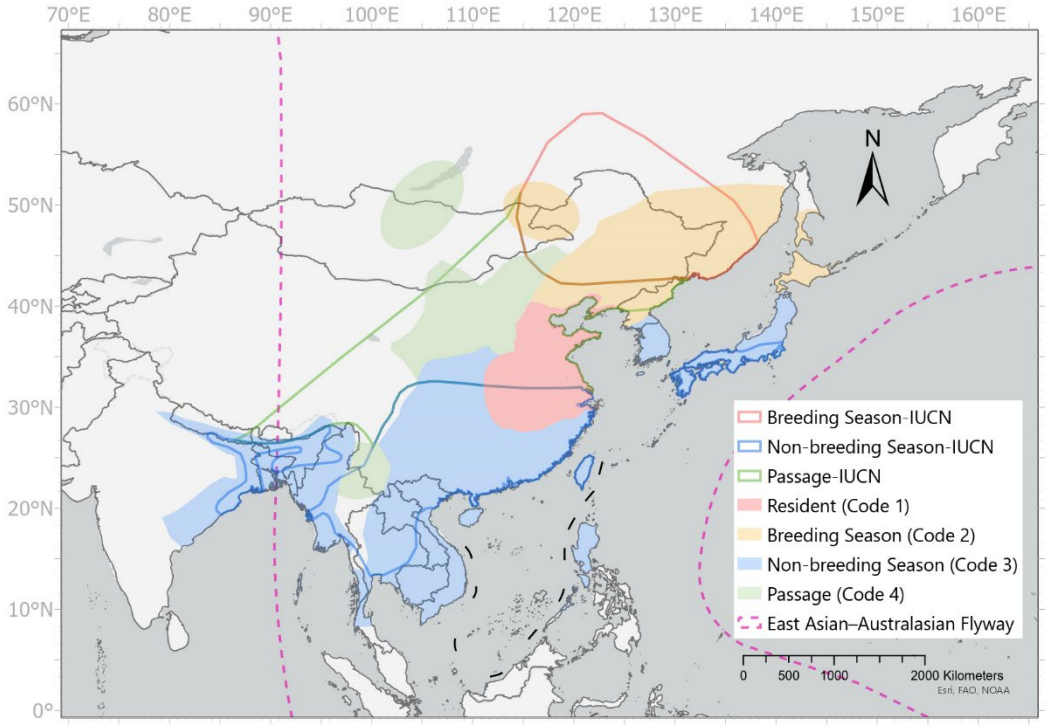

Figure 5. Updated Distribution Map of Baer's Pochard based on the results of this study.

3.3. Refined Suitable Habitat Distribution Map

In order to calculate the accurate area and range of suitable habitats for Baer's Pochard in each life stage, we clipped the estimate distribution range with the buffered map of shallow water bodies and wetlands because this species depends entirely on wetlands in its whole life stage.

Suitable breeding and potential breeding habitats are 567,464 km^2, mainly located in (a) the Heilongjiang River of China and Amur River of Russia (Figure 6A-1); (b) the northeast plain of the Songhua River and the lower reaches of the Nenjiang River of Northeast China (Figure 6A-2); (c) the inland wetlands of Bohai Bay (Figure 6A-3) and (d) the tributaries and lakes of the middle and lower reaches of the Yangtze River and the Yangtze River Delta area (Figure 6A-4). There are also possibilities along the west coastal area of Democratic People's Republic of Korea and the Republic of Korea (Figure 6A).

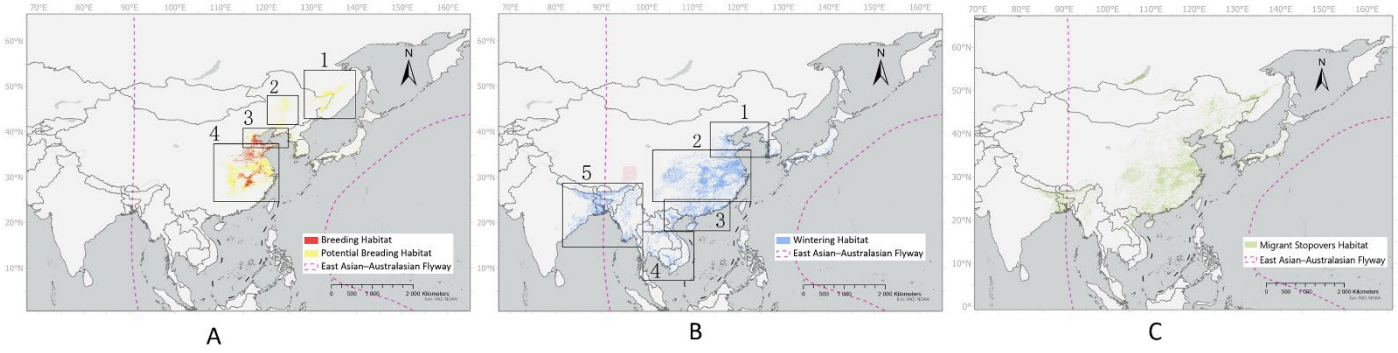

Figure 6. Suitable Habitat of Bear's Pochard during its three life stages. (**A**) Breeding, (**B**) Wintering, and (**C**) Migratory stopover.

The wintering habitat is 1,276,815 km^2, mainly distributed in (a) the inland wetlands of Bohai Bay (Figure 6B-1); (b) the Middle and Lower Yellow River, the Middle and Lower Yangtze River and the tributaries of those rivers and lakes in China (Figure 6B-2); (c) the Pearl River Delta in China and the Lower Red River, as well as its its tributaries in Vietnam (Figure 6B-3); (d) downstream of the Ganges River and the Brahmaputra River with wetlands around in India, Nepal and Bangladesh (Figure 6B-4) and (e) the Irrawaddy River and its tributaries in Myanmar (Figure 6B-5), Tonle Sap Lake and the Lower Mekong River in Cambodia. There are also possibilities along the coastal area of Japan, Luzon Island in the Philippines and the western part of Taiwan. (Figure 6B).

The migration stopovers habitat is 1,420,596 km^2, mainly overlapping with the breeding and wintering ground besides the southern part of Myanmar, Vietnam, the Philippines and Cambodia. But in the northern part, it covers a large area in Shanxi, Shaanxi, Inner-Mongolia of China, eastern Mongolia and Amur in Russia (Figure 6C).

3.4. Conservation Gaps

Habitat protection is the key to the conservation of Critically Endangered species. However, our result shows that 81.8% of Baer's Pochard sites in the past two decades are not covered by PAs of any kind. Only two current breeding sites are protected:Hengshuihu National Nature Reserve and the Ancient Yellow River National Wetland Park, both in China. For their potential breeding sites, Torey Lakes, Lake Khanka in Russia, Xianghai, Yeyahu Wetland Park and East Dongtinghu National Nature Reserve in China are protected (Figure S2, Table 2).

We also mapped and calculated the refined suitable habitats of Baer's Pochard in PAs. Only 35,314 km^2 of its breeding habitat, 67,718 km^2 of its wintering habitat and 82,133 km^2 of its migration stopover habitat are protected. This means that more than 90% of its suitable habitat is outside of the current PA network (93.8% in breeding, 94.2% in migration, 94.7% in wintering, (Figure S3).

In particular, we calculated the conservation situation in the "resident" area, which could have the most important habitat for supporting the whole life-stage of Bear's Pochard. Only 4.6% of the 389,172 km^2 of suitable habitat in this category is covered by current PAs. Furthermore, 9.4% of the suitable "resident" habitat overlaps with urban areas, including 11 big cities in China such as Beijing, Tianjin, Shanghai and Wuhan (Figure 7).

Table 2. Current Baer's Pochard present sites in Protect Area.

Country	Protected Area (PA)	Type of PA	Life Stage of BP *
Russia	Torey Lakes	Ramsar Site	1 + 2
	Lake Khanka	Ramsar Site	1 + 2
	Zeya-Bureya Plains	Ramsar Site	2
Japan	Quasi National Park	National Protect Area	2
	Prefectural Wildlife Protection Area	National Protect Area	2
	Kirishima kinkowan	National Park	2
	Fujisan kita	Prefectural Wildlife Protection Area	2
	Tokyowan	Prefectural Wildlife Protection Area	2
China	Xianghai National Nature Reserve	Ramsar Site; National Protect Area	1 + 2
	Xingkai Lake National Nature Reserve	Ramsar Site; National Protect Area	2
	Xilin Gol Natural Steppe Protected Area	National Protect Area	2
	Yeyahu Wetland Park	Wetland Park	1 + 2
	Hengshuihu National Nature Reserve	Ramsar Site; National Protect Area	1 + 2 + 3
	Ancient Yellow River National Wetland Park	Wetland Park	1 + 2 + 3
	Nansihu Nature Reserve	State Protect Area	2 + 3
	Dong Dongtinghu National Nature Reserve	Ramsar Site; National Protect Area	1 + 2 + 3
	Shengjinhu National Nature Reserve	Ramsar Site; National Protect Area	3
	Yancheng National Nature Reserve	Ramsar Site; National Protect Area	3
	Chenhu Nature Reserve	Ramsar Site; State Protect Area	3
	Longganhu National Nature Reserve	National Protect Area	2
	Jinyunshan National Nature Reserve	National Protect Area	2
	Cangshan-Erhai National Nature Reserve	National Protect Area	2
	Caomei Wetlands Wildlife Refuge (Taiwan)	Wildlife Refuge	2
Myamar	Indawgyi Lake and Indawgyi Wildlife Sanctuary	Ramsar Site	3
India	Kaziranga	National Park	2 + 3

* BP = Baer's Pochard. 1 Breeding and Potential Breeding; 2 Stopover; 3 Wintering.

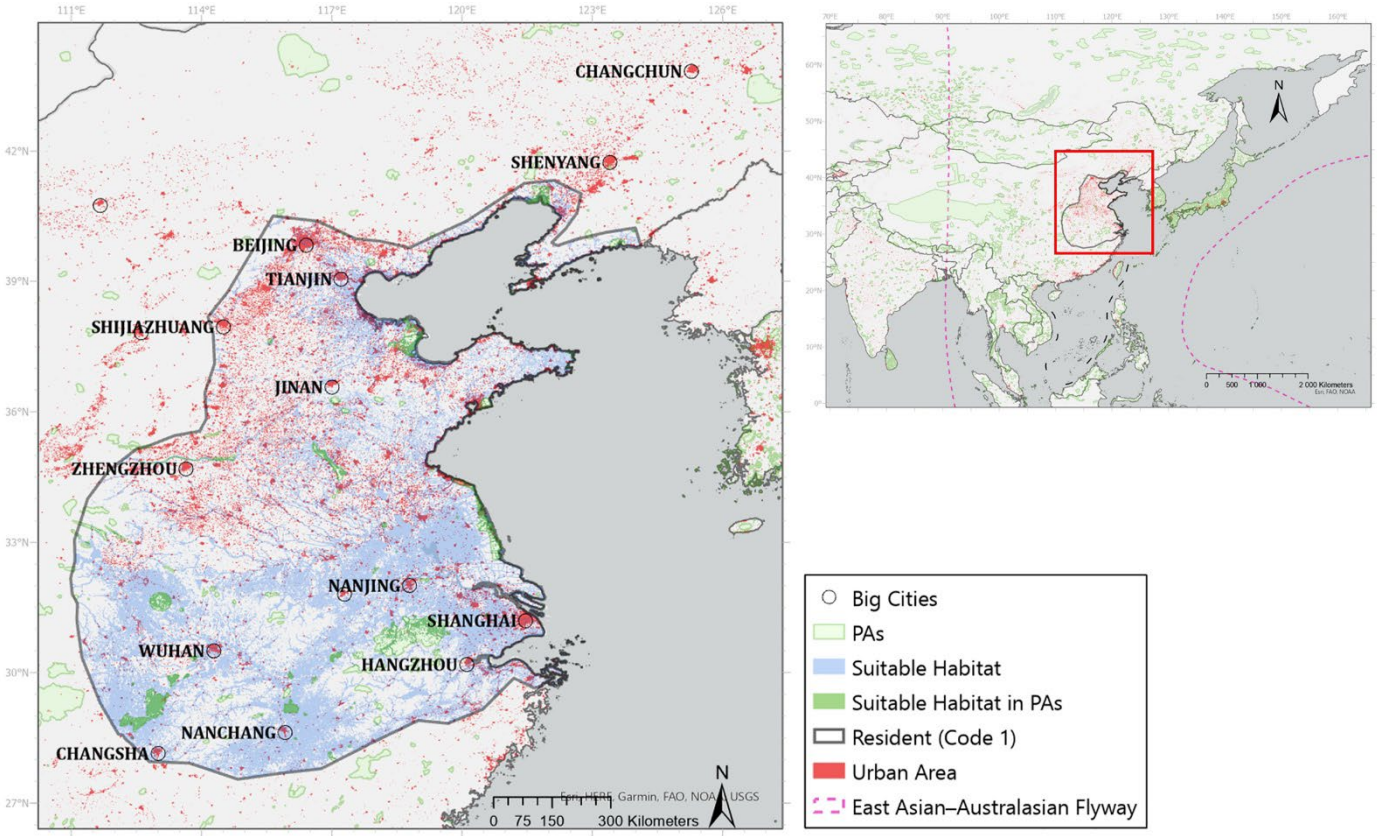

Figure 7. The most important habitat of BP has overlap with large cities.

4. Discussion

4.1. Distribution Expanded Northward and Southward, but Total suitable Habitat Area Shrank

The population of Baer's Pochard has rapidly declined in the past 20 years and, as a result, it was assessed by IUCN as Vulnerable (VU) in 1994, Endangered (EN) in 2008 and Critically Endangered (CR) in 2012 [13]. There are few studies about Baer's Pochard at its breeding sites. One case study in the 1990s showed that Baer's Pochard prefers freshwater wetlands with rich aquatic vegetation, especially reed marshes in Jilin, China. Their nest site selection was similar to other sympatric pochards, and nest parasitism occurred [33]. However, there has been no confirmed breeding of this endangered diving duck in its historical breeding area (northeast China and eastern Russia) since the 1990s (Table 3) [34].

Table 3. Historical breeding sites of Baer's Pochard.

Country	Location	Latest Breeding Records
Russia	Barun-Torey lake	1987
	Amkan river mouth	1974
	lower Pompeyevka river	1992
	Smidovichskiy district	1988
	lower Iman river	1965
	Khanka lake	1975
	Gnilye lakes	1975
	Lebedinoye lake	1975
	Tumen river mouth	1975
China	Zhalong National Nature Reserve	1990
	Tailai county	Undated, before 1992
	Shangzhi county	Undated, before 1992
	Momoge Nature Reserve	1992
	Xianghai National Nature Reserve	1989
	Barga steppe	1956
	Horqin Nature Reserve	1988

At the same time, more and more records of Baer's Pochard during the breeding season have been reported outside the traditional breeding range. Some were confirmed by our surveys or other researchers as breeding sites. These newly discovered breeding sites cover various types of wetlands and are quite different from the large reed marsh wetlands in the historical breeding sites. The habitats in the new locations include rivers, reservoirs, fishponds, abandoned mines and parks, some of which are small and fragmented. The only thing they have in common is a low level of human activity and a sufficient abundance of emergent vegetation and riparian plants.

It is not considered that the historical breeding range of Bear's Pochard is no longer suitable for this species, but due to the rapid population decline, it is difficult to observe and monitor nests or ducklings in the vast and relatively inaccessible swampy wetlands of northeast China and the Russian Far East. The lack of recent breeding evidence may be due to inadequate investigation efforts. Therefore, we believe that the "potential breeding habitat" and the "breeding habitat" are both available for this species in our modelling results. The habitat in these areas is very important for the conservation of Baer's Pochard.

In winter, Baer's Pochard prefers freshwater lakes and reservoirs, but it can be found in any rivers, fishponds and parks that do not freeze. It used to have a large wintering population (>200) in the Lower Yangtze River of China, Myanmar, the lowlands of north-east Bangladesh and Thailand [34]. However, in most of these locations there are now only small numbers of Baer's Pochard in winter, even though there have been continuous surveys in the last 20 years [11,12,14,26,35–38]. There are relatively large wintering populations in Shandong, Anhui and Henan according to our surveys, and the northernmost wintering sites are in Beijing.

One possible reason for this change in distribution is that in some parts of Southeast Asia, the historical wintering habitat of Baer's Pochard is decreasing due to human activities. For example, the lowlands of north-east Bangladesh formerly provided wetlands with shallow open waters, seasonally flooded grasslands and swamp forest, but these habitats have now been converted to agricultural use [14]. On the other hand, due to climate change, rivers and lakes in some parts of East Asia no longer freeze completely in winter, while in some areas human activities (such as the discharge of cooling water from power stations or reclaimed water) have increased the water temperature of wetlands in winter. Changes in the availability of food resources due to climate change may affect the migration behaviour and survival strategies of this species.

Although the current records and our species distribution model predicted that the breeding grounds of Baer's Pochard would expand southward and the wintering grounds would expand northward, the overall distribution area has not expanded. Compared with the last century, the distribution area has retreated significantly towards the east coast of Asia. It has not been recorded in Lake Baikal in Russia, Xinjiang, Qinghai and Tibet in China, northern India or Pakistan for more than 30 years. The retreat of the distribution may be caused by climate change, the loss of a suitable habitat in central Asia or the disappearance of marginal populations due to a sharp population decline (Figure S4).

It was difficult to check all the wetlands in suitable range by field surveys—the Maxent model gave us a full picture of that by its estimation. With this range and the landcover information, we could find its possible suitable habitat, focus on the conservation gaps and try to check these places in the future for better conservation strategies. That is the most important reason for this research—to protect this critically endangered species. Our study was not designed to investigate the habitat preference of Baer's Pochard; therefore, we did not conduct detailed analysis of the environmental suitability of the Maxent output.

4.2. Challenges and Conservation Strategies for Bear's Pochard

Before the 1990s, Baer's Pochard, like other pochards, had a very large population and was widely distributed in many countries in Asia. It bred in eastern Russia, north-east China and possibly in Mongolia and the Democratic People's Republic of Korea, and occurred on passage or in winter in Mongolia, Japan, the Democratic People's Republic of Korea, the Republic of Korea, mainland China, Hong Kong, Taiwan, Pakistan, India, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, Vietnam and the Philippines. The main wintering areas were in eastern and southern China, northeast India, Bangladesh, Thailand and Myanmar [34]. It was once a common game bird in many places [39].

In the past two decades, despite the increasing number of birdwatchers and researchers and the increase in accessibility of recording methods such as photography and video, many areas where Baer's Pochard was once distributed have not seen records for a long time, such as Mongolia and many locations in Far East Russia, Xinjiang, Qinghai, Xizang and Guangzhou in China. In eastern Asia, although our study shows that the range of breeding and wintering grounds for this species may be expanding, the available habitat may be shrinking. Our surveys and other studies have shown that a suitable habitat for Baer's Pochards covers almost all types of freshwater wetlands [15,17,25,39,40]. They can also use a much wider range of water depth than previously thought [41]. Therefore, all kinds of wetland protection may have a positive effect on the maintenance of its population.

There are 37,356 protected areas of different types, covering 11.7% of land in our study area. However, these are more likely to be found in the Russian Arctic, western Mongolia, western China, the Himalayas and southern East Asia. The concentrated distribution area of Baer's Pochard, especially the overlap of its breeding range, migration stopovers and wintering ground in central-east China, the Democratic People's Republic of Korea, the Republic of Korea and southern Japan has a high human population and includes few or no protected areas. If we overlay the land use data in this area, we can see that these areas are also urban concentrated areas (Figure 7). Besides Baer's Pochard, these areas are also important for other threatened waterbirds [42–45]. This means that the conservation

challenges for this species are enormous. Another Effective area-based Conservation Measure, first mentioned in Aichi Biodiversity Target 11 in 2012 (UNEP/CBD, 2012), is a designation for areas that are achieving effective in situ conservation of biodiversity outside of protected areas (CBD, 2018). Other effective area-based conservation measures could have a positive protective effect on species such as Baer's Pochard, which uses a variety of suitable habitats, can survive and reproduce in small wetlands, is mainly distributed outside the existing PAs and is highly overlapped with urban distribution. It is also important to promote cooperation among various stakeholders and to balance biodiversity conservation and human welfare rather than view them as in conflict.

As a migratory bird, some populations of Baer's Pochard may migrate over long distances. Studies have shown that only 9% of 1451 migratory birds in the world are adequately covered by protected areas across all stages of their life cycle, in comparison with 45% of nonmigratory birds [46]. The distribution of Baer's Pochard is associated with many countries and regions. On its major flyway, the EAAF, 18 of 22 countries have been partners to the East Asian-Australasian Flyway Partnership (EAAFP), which aims to protect migratory waterbirds, their habitats and the livelihoods of people dependent upon them. The Baer's Pochard Task Force was established in 2015 to produce, coordinate and catalyse the implementation of the International Single Species Action Plan, stimulate and support Range States in its implementation and monitor and report on the implementation and its effectiveness. It could promote international cooperation and cross-border protection in its distribution range.

In 2022, China is hosting the 15th Conference of the Parties to the United Nations Convention on Biological Diversity (COP15). This is the point at which more than 190 governments are due to agree on a new Global Biodiversity Framework. To help bend the curve of species extinction, China is advancing its conservation efforts to cover more species. Baer's Pochard is one of more than ten bird species that have their own single species action plans as part of the "National Action Plan for Rare and Endangered Birds (2022–2035)", which is being developed by the National Forestry and Grassland Administration of China. In the UN negotiations, one key element of the agreement is the target to protect 30% of land for nature [47]. However, as we previously described, protected areas are not enough for species such as Baer's Pochard, as these protected zones are generally distributed in areas of low human population and do not intersect with the species' range. If the goals of the new biodiversity agreement are to be met, it is vital that biodiversity—and particularly the needs of endangered species—are integrated across the full range of spatial planning, including in urban areas. With consideration, urban parks, wetland parks and other man-made green spaces could be made suitable for a wider range of biodiversity, including Baer's Pochard.

5. Conclusions

With the help of species distribution models and remote sensing technology, we estimate the potential distribution range of Baer's Pochard and refine the current IUCN distribution map by collecting presence data from the past two decades. Our study shows large overlap between breeding, migrating stopovers and wintering grounds. We suggest to divide the distribution range of Baer's Pochard into four seasonal categories, and update the distribution map of this species according to our detailed distribution data. Baer's Pochard distribution has expanded northward and southward but the total area of suitable habitat has shrunk compared with the last century. Furthermore, more than 90% of suitable habitat is not covered by PAs of any kind and much of the most important habitat of this Critically Endangered species overlaps with large cities. We suggest that OECMs (other effective area-based conservation measures) should be part of the conservation strategy for this species. As a migratory bird covering at least 15 countries, cross-border cooperation will be critical for its survival.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/rs14092171/s1, Figure S1: Current distribution range estimate of Baer's Pochard and their overlap; Figure S2: Only a few present sites are in the PAs which may provide protected habitat for this species; Figure S3: Suitable habitat covered by protect area; Figure S4: The range of Bear's Pochard recedes into eastern Asia; Table S1: Field survey sites for Baer's Pochard during 2014–2021; Table S2: Environmental variables used for modeling the suitability habitat of Baer's Pochard in East Asian–Australasian Flyway.

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