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Population trends, threats, and conservation recommendations for waterbirds in China

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Abstract

Background: China is one of the countries with abundant waterbird diversity. Over the past decades, China's waterbirds have suffered increasing threats from direct and indirect human activities. It is important to clarify the population trends of and threats to waterbirds as well as to put forward conservation recommendations.

Methods: We collected data of population trends of a total of 260 waterbird species in China from Wetlands International database. We calculated the number of species with increasing, declining, stable, and unknown trends. We collected threatened levels of waterbirds from the *Red List of China's Vertebrates* (2016), which was compiled according to the IUCN criteria of threatened species. Based on literature review, we refined the major threats to the threatened waterbird species in China.

Results: Of the total 260 waterbird species in China, 84 species (32.3%) exhibited declining, 35 species (13.5%) kept stable, and 16 species (6.2%) showed increasing trends. Population trends were unknown for 125 species (48.1%). There was no significant difference in population trends between the migratory (32.4% decline) and resident (31.8% decline) species or among waterbirds distributed exclusively along coasts (28.6% decline), inland (36.6% decline), and both coasts and inland (32.5% decline). A total of 38 species (15.1% of the total) were listed as threatened species and 27 species (10.8% of the total) Near Threatened species. Habitat loss was the major threat to waterbirds, with 32 of the total 38 (84.2%) threatened species being affected. In addition, 73.7% (28 species), 71.1% (27 species), and 57.9% (22 species) of the threatened species were affected by human disturbance, environmental pollution, and illegal hunting, respectively.

Conclusions: We propose recommendations for waterbird conservation, including (1) strengthening conservation of nature wetlands and restoration of degraded wetlands, (2) enhancing public awareness on waterbird conservation, (3) improving the enforcement of Wildlife Protection Law and cracking down on illegal hunting, (4) carrying out long-term waterbird surveys to clarify population dynamics, (5) restoring populations of highly-threatened species through artificial intervention, and (6) promoting international and regional exchanges and cooperation to share information in waterbirds and their conservation.

Keywords: Conservation, Habitats, Population trend, Threatened species, Waterbirds, Wetlands, China

Background

Ecologically dependent upon wetlands, waterbirds are key biological indicators for assessing the quality and importance of wetlands. Due to impacts of habitat loss, pollution, over-hunting, biological invasions, and climate change, about 23% of global waterbird populations are declining, 19% of waterbirds have been listed as threatened species by the International Union for Conservation of Nature (IUCN), and some waterbirds with small populations have not been recorded in the field in recent years (Wetlands International 2012). In view of the serious

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situation of the rapid decrease of waterbird diversity, waterbird conservation has received increasing attention worldwide.

There are a total of 53.6 million hectares of wetlands in China, ranking the first among countries in Asia and the fourth in the world (The State Forestry Administration 2000). Wetland types are diverse in China, including many natural wetlands such as lakes, swamps, rivers, estuaries, and coastal wetlands, as well as artificial wetlands such as paddy fields, aquaculture ponds, salt pans, and reservoirs (The State Forestry Administration 2015). China's extensive wetlands support large numbers of waterbirds. For example, coastal wetlands in China provide critical stopover sites for millions of migratory shorebirds along the East Asian-Australasian flyway (Barter 2002; Bai et al. 2015); Lakes in the middle and lower reaches of the Yangtze River are the largest nonbreeding region for waterbirds in East Asia (Cao and Wong 2007; Wang et al. 2017). Swamps and lakes in northern China provide breeding sites for diverse waterbirds such as cranes, gulls, ducks, and geese (Chen and Ding 2008).

Over the past several decades, many measures have been implemented for waterbird conservation in China, such as establishing nature reserves with waterbirds and wetlands being the main conservation targets, designating key habitats for waterbirds as internationally important wetlands (Ramsar sites), conducting waterbird surveys to clarify population status, carrying out public education on waterbird and wetland conservation, and launching captive breeding to increase the population of threatened species (The State Forestry Administration 2015). All these efforts have played critical roles in waterbird conservation. Some waterbirds have gradually recovered from the edge of extinction. For example, only seven individuals were recorded when the Crested Ibis (*Nipponia nippon*) was discovered in Qinling Mountain in 1981. With effective conservation measures over the past more than 30 years, the number of the Crested Ibis is now over 2000, including more than 1000 individuals in the wild population (Wang et al. 2014). The population number of the Black-faced Spoonbill (*Platalea minor*) has increased from about 200 birds in the early 1990s to about 3000 birds in recent years (Sung et al. 2018). These achievements in waterbird conservation have become celebrated examples of global biodiversity conservation.

However, with the rapid economic development over the past 40 years, human activities have significantly increased in both range and intensity in China. Waterbird conservation suffered increasing pressure from many aspects. For example, wetland reclamation and exploitation in large scale and high intensity have caused dramatic habitat loss and degradation (Yang et al. 2011; Ma et al. 2014; Wang et al. 2017). Illegal hunting for waterbirds is not uncommon in both coastal and inland regions (Ma et al. 2012; Wang et al. 2017). Increasing toxic pollutants have persisted in wetlands and surrounding regions over a long period (Zhao et al. 2016). The spread of alien invasive species in wetlands has degraded habitat quality for waterbirds (Gan et al. 2009). In addition, climate changes not only alter habitats for waterbirds, but also affect ecological habits of waterbirds and the linkage between waterbirds and other organisms (Iwamura et al. 2013). All these issues have brought different degrees of direct or indirect impacts on waterbirds in China. As a consequence, clarifying population trends of waterbirds as well as identifying threats to waterbirds is fundamental to formulate strategies for waterbird conservation at both national and local levels.

Many studies have discussed the population trends of, threats to, and conservation recommendations for waterbirds at global scales and in Europe and North America (e.g., Thomas et al. 2006; Gilroy et al. 2016; Amano et al. 2017). The population status of and threats to waterbirds in China is increasingly concerned due to China's importance for waterbird conservation along the flyways. For example, in recent years, many studies have indicated that loss of wetlands along China's coast is the most serious threat to migratory shorebirds along the flyway, causing dramatic declines in many populations (Melville et al. 2016; Piersma et al. 2016; Studds et al. 2017). Currently, only a few waterbird species (e.g., some cranes, storks, and spoonbills, ibises, geese) have been well studied in terms of their population dynamics (Liu et al. 2007; Zhang et al. 2010; Luo et al. 2012). There is still a lack of overall analysis on the population status of waterbirds in China. In recent years, along with emphasizing conservation of waterbirds and their wetland habitats by the central and local governments, public awareness in conservation has continuously increased (Ma et al. 2013). This provides opportunities to strengthen waterbird conservation. Meanwhile it is also necessary to understand the population trends of waterbirds in China, so as to provide the basis for formulating national and local policies for waterbird conservation.

Based on collecting data of waterbirds, we analyzed population trends of and threats to waterbirds in China. According to the major threats to waterbirds, we make recommendations for waterbird conservation.

Methods

According to the definition of waterbird by Wetlands International, there are a total of 871 waterbird species in 32 families and 8 orders in the world (Wetlands International 2012). We collected waterbird checklists in China according to the book of *A Checklist on the Classification and Distribution of the Birds of China* (Zheng 2017). A total of 260 waterbird species in China were

identified, belonging to 21 families and 9 orders (Phalacrocoracidae was listed under Pelecaniformes in Wetland International 2012 while under Suliformes in Zheng 2017). We used population trends of China's waterbirds from the waterbird database of Wetlands International (2012). Here population is defined as "a distinct assemblage of individuals that have not undergone a significant emigration or immigration, and interchange of individuals between populations remains at a low level" (Wetlands International 2012). Based on this definition and the distribution range of waterbird population (Wetlands International 2012), there are 293 populations for the 260 waterbird species in China. We collected population trends (increasing, stable, declining, and unknown) for each species. If a species has only one population in China, we used the trend of the population as the trend of the species. If a species has more than one population with different trends in China, we used the trend of the major population in China as the trend of the species.

The threatened levels of waterbirds in China referred to the *Red List of China's Vertebrates*, which was compiled according to the IUCN criteria (2012) of threatened species (Jiang et al. 2016). Because we aimed at waterbirds with natural distribution, six levels (Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, and Data Deficient) were involved while excluding other three levels (Extinction, Wild Extinction, and Regional Extinction) that species in the levels cannot be recorded in the field. Threatened species include those classified as Critically Endangered, Endangered, or Vulnerable. We identified the number of waterbird species at each level separately. We identified migratory and resident species as well as their distributional range (coastal, inland, and both coastal and inland). We classified waterbirds as migratory and resident species based on the latest version of *A Checklist on the Classification and Distribution of the Birds of China* (Zheng 2017). Partial migratory species were identified as migratory species. To avoid the effects of small sample size and unequal distribution of data among groups, Fisher's exact tests were used to check whether there was difference in the proportions of population declines between migratory and resident species as well as among groups with different distribution range.

To understand the major threats to the threatened waterbird species, we searched literature collected in the database of Web of Knowledge (http://apps.webofknowledge.com/) and literature published in Chinese in the database of China national knowledge internet (http://www.cnki.net/). We also searched the database of the IUCN Red Lists (http://www.iucnredlist.org/) and the Handbook of Birds of the World (https://www.hbw.com/). Based on literature review, we refined the major threats to the threatened waterbird species in China.

Population trends

Of the total 260 waterbird species in China, 84 (32.3%) species exhibited a declining trend, 35 species (13.5%) remained stable, and 16 species (6.2%) showed an increasing trend. Population trends were unknown for 125 species (48.1%). According to the classification of waterbirds, the proportion of declining species was the highest in Ciconiiformes (66.7%), followed by Anseriformes (38.9%) and Pelecaniformes (34.3%). In addition, there was less than 50% of species with known population trends in Gruiformes, Suliformes, and Podicipediformes (Table 1).

Most waterbirds in China are migratory birds (91.5%, 238 species). There was no significant difference in population trends between the migratory (32.4% decline) and the resident (31.8% decline) species (Fisher's exact test, $p = 0.58$) (Additional file 1: Table S1). There were 41 species distributed exclusively inland, 56 exclusively on the coasts, and 163 species found both inland and on coasts.

Table 1 Population trends of waterbirds in China in each order

Order	Declining	Stable	Increasing	Unknown	Number of species
Gaviiformes	0 (0.0%)	1 (25.0%)	1 (25.0%)	2 (50.0%)	4
Podicipediformes	1 (20.0%)	0 (0.0%)	0 (0.0%)	4 (80.0%)	5
Pelecaniformes	12 (34.3%)	8 (22.9%)	3 (8.6%)	12 (34.3%)	35
Suliformes	0 (0.0%)	1 (20.0%)	0 (0.0%)	4 (80.0%)	5
Ciconiiformes	4 (66.7%)	0 (0.0%)	0 (0.0%)	2 (33.3%)	6
Phoenicopteriformes	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)	1
Anseriformes	21 (38.9%)	4 (7.4%)	4 (7.4%)	25 (46.3%)	54
Gruiformes	5 (17.9%)	7 (25.0%)	0 (0.0%)	16 (57.1%)	28
Charadriiformes	41 (33.6%)	13 (10.7%)	8 (6.6%)	60 (49.2%)	122
Total	84 (32.3%)	35 (13.5%)	16 (6.1%)	125 (48.1%)	260

There was no significant difference in population trends among waterbirds distributed in various regions (Fisher's exact test, $p = 0.70$) (Additional file 1: Table S2).

Waterbirds and their habitats along China's coasts have been highly concerned over the past decades (see review of Hua et al. 2015). Many studies have indicated that dramatic loss of coastal wetlands, which are critical habitats for many species, is the main reason for waterbird population decline (Melville et al. 2016; Studds et al. 2017). However, waterbirds distributed exclusively inland are relatively less concerned in China. This study indicated that the inland waterbirds exhibited similar proportion of population decline to that of waterbirds along the coasts, potentially highlighting a crisis for inland wetland ecosystems in China. Some studies have exhibited diverse threats to waterbirds inland. For example, damming along rivers have changed hydrological condition of both river and lakes, aquaculture in lakes have caused a decrease of vegetable food for waterbirds, and illegal hunting is not uncommon in lakes (see review of Wang et al. 2017). Moreover, the similar proportion of population decline between the migratory and resident species (both nearly one third population declined, higher than the global average of 23%) suggests that migratory birds suffered serious threats during their life history periods in China, as those resident birds that stay in China during their entire life history.

Threatened species

A total of 38 species (14.6% of the total) have been listed as threatened species, including 6 species (2.4%) being listed as Critically Endangered, 16 species (6.4%) Endangered, and 16 species Vulnerable (6.4%). Another 27 species (10.8%) were listed as Near Threatened (Table 2). In addition, 54 species (21.5%) were not assessed due to data deficiency or their marginal distribution in China. The threatened species were mainly in the Orders of Gruiformes (10 species), Charadriiformes (10 species), Anseriformes (8 species), and Pelecaniformes (8 species). The highest proportion of threatened species was in the Order of Ciconiiformes (40.0%) (Table 3). Although the percentage of threatened waterbird species in China (15.1% of the total) was slightly lower than that the global level (18.8%) (Wetland International 2012), the percentage of non-assessed species in China (21.5%) was much higher than that globally (0.4%).

Among the 38 threatened waterbirds, 21 species (55.3%) exhibited declining trends, 2 species (5.3%) (Crested Ibis and Black-faced Spoonbill) tended to increase, and 7 species (18.4%) remained stable. There were 8 species (21.1%) with unknown population trends (Fig. 1). Although some species did not exhibit population decline, they were assessed as threatened species because of their small population number or narrow distributional range. For example, the population of the Critically Endangered Chinese Crested Tern (*Thalasseus bernsteini*), with an unknown population trend, was estimated to be less than 50 birds (Chen et al. 2015). Although both the Endangered Crested Ibis and the Endangered Black-faced Spoonbill showed population increase in recent years, the population of Crested Ibis is still less than 2000 birds (Wang et al. 2014) and the population of Black-faced Spoonbill is less than 3000 birds (Sung et al. 2018). Moreover, the population of the Critically Endangered Siberian Crane (*Grus leucogeranus*) kept stable at around 3000–4000 birds in recent years, with 99% of the total population overwintering in Poyang Lake. Due to the plans of dam construction between Poyang Lake and the Yangtze River proposed by the local government, potentially dramatic changes of hydrology and vegetation in Poyang Lake would pose tremendous threats to the Siberian Crane (Wang et al. 2017).

Of the 38 threatened species in China, 33 species are migratory and 5 resident species. There was no significant difference in population trends between migratory and resident species (Fisher's exact test, $p = 0.40$) (Additional file 1: Table S3). Moreover, seven threatened species distribute exclusively inland, nine exclusively on the coasts, and 22 both inland and on coasts. There was no significant difference in population trends among their distributions (Fisher's exact test, $p = 0.90$) (Additional file 1: Table S4).

Table 2 Comparison on the threatened level of waterbirds in China and in the world

Category	In China		In the world	
	Number of species	Percentage (%)	Number of species	Percentage (%)
Critically Endangered	6	2.4	28	3.4
Endangered	16	6.4	52	6.3
Vulnerable	16	6.4	76	9.1
Near Threatened	27	10.8	71	8.5
Least Concern	132	52.6	602	72.4
Data Deficient	54	21.5	3	0.4
Total	251	100.0	832	100.0

Data are based on the IUCN criteria of threatened species. The threatened level in the world referred to the IUCN (2012). Among the total 260 waterbird species recorded in China, nine species were firstly recorded in China in recent years. They were listed in the checklists of Zheng (2017) while were not assessed in Jiang et al. (2016). These species include: *Ardeola grayii*, *Ciconia episcopus*, *Branta hutchinsii*, *Rallus aquaticus*, *Vanellus leucurus*, *Calidris fuscicollis*, *Ardeola speciose*, *Anser serrirostris*, and *Anas poecilorhyncha*

Table 3 Number of threatened waterbird species in China in each order

Order	CR	EN	VU	NT	LC	DD	Total
Gaviiformes	0	0	0	0	2	2	4
Podicipediformes	0	0	0	2	3	0	5
Pelecaniformes	1	6	1	3	15	7	33
Suliformes	0	0	0	1	3	1	5
Ciconiiformes	0	1	1	0	1	2	5
Phoenicopteriformes	0	0	0	0	0	1	1
Anseriformes	2	3	3	8	22	13	51
Gruiformes	1	3	6	2	12	3	27
Charadriiformes	2	3	5	11	74	25	120
Total	6	16	16	27	132	54	251

Nine species of new distribution records in China were not assessed in recent years

CR Critically Endangered, *EN* Endangered, *VU* Vulnerable, *NT* Near Threatened, *LC* Least Concern, *DD* Data Deficient

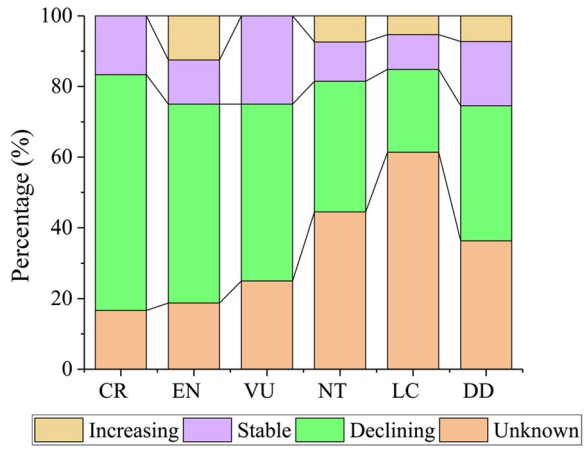

Fig. 1 Population trends and threatened levels of waterbirds in China. *CR* Critically Endangered, *EN* Endangered, *VU* Vulnerable, *NT* Near Threatened, *LC* Least Concern, *DD* Data Deficient. Nine species of new distributional records in China in recent years were not included

Table 4 Threats to the threatened waterbirds (38 species totally) in China

Threats	Number of threatened species	Percentage (%)
Habitat loss	32	84.2
Human disturbance	28	73.7
Hunting	27	71.1
Pollution	22	57.9
Biological invasion	9	23.7
Disease	7	18.4
Natural disaster	6	15.8
Climate change	5	13.2
Genetic diversity loss	4	10.5
Unknown	3	7.9

Threats to waterbirds

Waterbirds in China face various threats from both direct and indirect human activities, such as habitat loss, human disturbance, pollution, and illegal hunting (Table 4). Most waterbird species suffer multiple types of threats (Table 5). Habitat loss is the most common threat to waterbirds, affecting 32 of the 38 threatened species (84.2%) (Table 4). Many studies have indicated that the area of wetlands in China has dramatically decreased over the past half a century due to large-scale reclamation of both coastal and inland wetlands. It is estimated that China's wetlands have decreased by a total of 9.9 million hectares (21.6%) during the second half of the twentieth century (An et al. 2007). According to the national surveys on wetland resources, the total area of wetlands in China decreased by 3.4 million hectares (8.8% of the total) in 2003–2013. Coastal wetlands suffered more loss than inland wetlands, with 1.36 million hectares (22.9% of the total) of coastal wetlands being lost in the decade (The State Forestry Administration 2015). Coastal wetlands in the Yellow Sea suffered the most serious loss: More than half of the coastal wetlands have been lost over the past 50 years (Murray and Fuller 2015). Many studies have indicated that dramatic loss of wetland habitats in the Yellow Sea is the major cause for the rapid population decline of migratory shorebirds along the East Asian-Australasian flyway, which rely on the Yellow Sea coasts as critial stopover habitats (Melville et al. 2016; Piersma et al. 2017; Studds et al. 2017).

Human disturbance is another major threat to waterbirds in China, affecting 73.7% of the threatened species (27 of 38, Table 4). Human activities have strong interactions with waterbirds. In the nonbreeding and migration season, many herbivorous birds, such as cranes, geese, and ducks, forage for crops in farmland. Some piscivorous and benthivorous birds, such as herons, storks,

Table 5 The threatened and near threatened waterbirds in China

English name	Scientific name	Population trend	Level at the national key protected wildlife	Threatened level in China	Threatened level of the world	Threats	Distribution region	Residence
Red-necked Grebe	*Podiceps grisegena*	Unk	II	NT	LC	Unk	Both	Migrant
Horned Grebe	*Podiceps auritus*	Unk	II	NT	LC	2, 4, 8, 7	Both	Migrant
Great White Pelican	*Pelecanus onocrotalus*	Unk	II	EN	LC	1, 2, 4, 6	Inland	Migrant
Spot-billed Pelican	*Pelecanus philippensis*	Dec	II	EN	NT	1, 2, 3, 4, 5	Both	Migrant
Dalmatian Pelican	*Pelecanus crispus*	Dec	II	EN	VU	2, 3, 4	Both	Migrant
Pelagic Cormorant	*Phalacrocorax pelagicus*	Sta	II	NT	LC	Unk	Coast	Migrant
Chinese Egret	*Egretta eulophotes*	Sta	II	VU	VU	1, 2, 3, 4	Coast	Migrant
White-eared Night Heron	*Gorsachius magnificus*	Dec	II	EN	EN	1, 2, 3, 5	Both	Resident
Malaysian Night Heron	*Gorsachius melanolophus*	Unk		NT	LC	Unk	Both	Resident
Little Bittern	*Ixobrychus minutus*	Unk	II	NT	LC	Unk	Inland	Migrant
Black Stork	*Ciconia nigra*	Unk	I	VU	LC	1, 2, 4	Both	Migrant
Oriental Stork	*Ciconia boyciana*	Dec	I	EN	EN	1, 2, 3, 4	Both	Migrant
Black-headed Ibis	*Threskiornis melanocephalus*	Dec	II	CR	NT	2, 3, 4	Both	Migrant
Crested Ibis	*Nipponia nippon*	Inc	I	EN	EN	1, 2, 3, 4, 9	Inland	Resident
White Spoonbill	*Platalea leucorodia*	Dec	II	NT	LC	1, 2, 4, 6	Both	Migrant
Black-faced Spoonbill	*Platalea minor*	Inc	II	EN	EN	1, 2, 3, 4, 6	Coast	Migrant
Lesser Whistling Duck	*Dendrocygna javanica*	Dec		VU	LC	Unk	Both	Migrant
Mute Swan	*Cygnus olor*	Unk	II	NT	LC	2, 3, 4, 6, 7	Both	Migrant
Whooper Swan	*Cygnus cygnus*	Unk	II	NT	LC	1, 2, 3, 4, 6, 7	Both	Migrant
Tundra Swan	*Cygnus columbianus*	Unk	II	NT	LC	1, 2, 4, 6	Both	Migrant
Swan Goose	*Anser cygnoid*	Dec		VU	VU	1, 2, 3, 6, 7	Both	Migrant
Lesser White-fronted Goose	*Anser erythropus*	Sta		VU	VU	1, 3	Both	Migrant
Cotton Pygmy-goose	*Nettapus coromandelianus*	Unk		EN	LC	Unk	Both	Migrant
Mandarin Duck	*Aix galericulata*	Dec	II	NT	LC	1	Both	Migrant
Falcated Duck	*Mareca falcata*	Dec		NT	NT	3	Both	Migrant
Baikal Teal	*Sibirionetta formosa*	Inc		NT	LC	1, 3, 4, 6	Both	Migrant
Baer's Pochard	*Aythya baeri*	Dec		CR	CR	1, 2, 3	Both	Migrant
Ferruginous Duck	*Aythya nyroca*	Dec		NT	NT	1, 3, 4, 8	Inland	Migrant
Long-tailed Duck	*Clangula hyemalis*	Unk		EN	VU	1, 3, 4, 6	Both	Migrant
Velvet Scoter	*Melanitta fusca*	Unk		NT	LC	2, 3, 4	Both	Migrant
Scaly-sided Merganser	*Mergus squamatus*	Dec	I	EN	EN	1, 2, 3, 4, 9	Both	Migrant

Table 5 continued

English name	Scientific name	Population trend	Level at the national key protected wildlife	Threatened level in China	Threatened level of the world	Threats	Distribution region	Residence
White-headed Duck	*Oxyura leucocephala*	Dec		CR	EN	1, 2, 3	Inland	Migrant
Siberian Crane	*Leucogeranus leucogeranus*	Sta	I	CR	CR	1, 2, 3, 8	Both	Migrant
White-naped Crane	*Antigone vipio*	Sta	II	EN	VU	1, 2, 3, 4, 7	Both	Migrant
Common Crane	*Grus grus*	Dec	II	NT	LC	1, 3, 4	Both	Migrant
Hooded Crane	*Grus monacha*	Sta	I	EN	VU	1, 2, 3, 4, 5, 9	Both	Migrant
Black-necked Crane	*Grus nigricollis*	Sta	I	VU	VU	1, 2, 3, 4, 7, 8	Inland	Migrant
Red-crowned Crane	*Grus japonensis*	Dec	I	EN	EN	1, 2, 3, 4, 6, 9	Both	Migrant
Swinhoe's Rail	*Coturnicops exquisitus*	Dec	II	VU	VU	1, 2, 3, 4	Both	Migrant
Slaty-legged Crake	*Rallina eurizonoides*	Unk		VU	LC	Unk	Coast	Resident
Corncrake	*Crex crex*	Sta	II	VU	LC	1, 2	Inland	Migrant
Ruddy-breasted Crake	*Zapornia fusca*	Unk		NT	LC	Unk	Both	Resident
Band-bellied Crake	*Zapornia paykullii*	Unk		VU	NT	1	Both	Migrant
Purple Swamphen	*Porphyrio porphyrio*	Unk		VU	LC	1, 4, 5, 6	Both	Resident
Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	Dec		NT	LC	Unk	Both	Migrant
Ibisbill	*Ibidorhyncha struthersii*	Inc		NT	LC	2, 4, 8	Both	Resident
River Lapwing	*Vanellus duvaucelii*	Unk		NT	NT	Unk	Both	Resident
Long-billed Ringed Plover	*Charadrius placidus*	Dec		NT	LC	Unk	Both	Migrant
Wood Snipe	*Gallinago nemoricola*	Dec		VU	VU	1, 2, 3	Inland	Migrant
Asian Dowitcher	*Limnodromus semipalmatus*	Dec		NT	NT	1, 2, 3, 4	Both	Migrant
Bar-tailed Godwit	*Limosa lapponica*	Dec		NT	LC	1	Coast	Migrant
Little Curlew	*Numenius minutus*	Unk	II	NT	LC	1, 2, 4	Both	Migrant
Eurasian Curlew	*Numenius arquata*	Unk		NT	NT	1, 3, 4, 6	Both	Migrant
Far Eastern Curlew	*Numenius madagascariensis*	Dec		VU	VU	1	Both	Migrant
Nordmann's Greenshank	*Tringa guttifer*	Dec	II	EN	EN	1, 2, 3, 4, 5	Coast	Migrant
Great Knot	*Calidris tenuirostris*	Dec		VU	VU	1, 2, 4, 5	Coast	Migrant
Red Knot	*Calidris canutus*	Dec		VU	LC	1, 2, 3, 5, 6, 8	Coast	Migrant
Spoon-billed Sandpiper	*Calidris pygmaea*	Dec		CR	CR	1, 5, 8	Coast	Migrant
Saunders's Gull	*Saundersilarus saundersi*	Dec		VU	VU	1, 2, 3, 4, 5, 7	Coast	Migrant
Relict Gull	*Larus relictus*	Dec	I	EN	VU	1, 2, 3, 4, 7, 8	Both	Migrant

Table 5 continued

English name	Scientific name	Population trend	Level at the national key protected wildlife	Threatened level in China	Threatened level of the world	Threats	Distribution region	Residence
Little Gull	*Hydrocoloeus minutus*	Sta	II	NT	LC	2, 4	Both	Migrant
Chinese Crested Tern	*Thalasseus bernsteini*	Unk		CR	CR	2, 3, 4, 7	Coast	Migrant
Greater Crested Tern	*Thalasseus bergii*	Sta		NT	LC	2, 3, 4	Coast	Migrant
River Tern	*Sterna aurantia*	Dec	II	NT	NT	2	Inland	Resident
Black-bellied Tern	*Sterna acuticauda*	Dec		EN	EN	1, 3	Inland	Resident

Population trends include: declining (Dec), increasing (Inc), stable (Sta), and unknown (Unk). The National key protected wildlife include two levels, the first (I) and the second (II) level. Threats to waterbirds include: (1) habitat loss; (2) human disturbance; (3) hunting; (4) pollution; (5) biology invasion; (6) disease; (7) natural disaster; (8) climate change; (9) genetic diversity loss. Distribution regions were classified as exclusively coastal, exclusively inland, and both inland and coastal region. Residence was classified as migrant and resident

The threatened level in the world referred to the IUCN (2012) to match the threatened level in China (Jiang et al. 2016). *CR* Critically Endangered, *EN* Endangered, *VU* Vulnerable, *NT* Near Threatened, *LC* Least Concern

spoonbills, and shorebirds, forage for aquatic products in aquaculture areas. These waterbirds might affect economic income of local people and thus are frequently driven off (Yu et al. 2017). In the coastal region, fishnets on the mudflats not only impacted on feeding activities of waterbirds, but also cause some waterbirds mortality through drowning during high tide due to entanglement in the nets (Crighton 2016).

In recent years, with the continuous expansion of land exploitation, human activities in some regions (including highways, channels, ports, industrial parks, and tourist areas) are close to natural habitats of waterbirds. Waterbirds are disturbed in various ways, such as reduction of foraging time, increase of vigilance behavior, and frequently being flushed (Wang et al. 2011). In addition, the number of wildlife photographers rapidly increased in China over the past decades. To get better view of birds, some photographers approach too close to birds and even interfere with nests. As a consequence, waterbirds that are susceptible to human disturbance are forced to abandon original habitats. Some breeding waterbirds abandon their nests, resulting in breeding failure (Luo et al. 2012; Li et al. 2017).

More than 60% of threatened waterbirds are affected by environmental pollution. Discharge of pollutants is the major environmental issue in China. Wetlands receive pollutants from diverse industrial and agricultural production activities (Hu et al. 2005; Sun et al. 2007; Zhi et al. 2015). Diverse heavy metal and persistent organic pollutants enter the body of waterbirds through direct contact and food chains. Pollutants accumulate in the body and adversely affect the condition of waterbirds, such as producing eggs with thin shells, decline of nest hatching success, and deformity of chicks (Xi et al. 2009). Moreover, heavy use of agrichemicals and pesticides causes decline of both invertebrates and small vertebrates, resulting in food shortage for insectivorous and carnivorous birds (Hallmann et al. 2014). However, it is still lack of quantitative study on the impacts of pollutants on waterbirds in China.

Traditionally, bird hunting has been a method of getting food and economic income by people in underdeveloped regions. It is estimated that in the late 1980s, about 50% of wintering ducks and geese were killed each year in the middle and lower reaches of the Yangtze River (Wang et al. 2017). Since the 1990s, with the implementation of the *Wild Animal Protection Law*, bird hunting became illegal in China. However, poaching still frequently occurs. For example, in the lakes in the middle and lower reaches of the Yangtze River, poaching geese and ducks using poisoned baits often occurs in winter. This may be the main cause for the population decline of the critically endangered Baer's Pochard (*Aythya baeri*) and the vulnerable Lesser White-fronted Goose (*Anser erythropus*) (Ma et al. 2012). In November 2012, a total of 21 endangered Oriental Storks (*Ciconia boyciana*) died from eating poisoned baits spread by poachers in Tianjin (Zeng 2012). In the coastal regions, some poachers sell eggs of gulls and terns in the market during breeding season, which is probably the major cause for the near extinction of the critically endangered Chinese Crested Tern (Chen et al. 2015).

Waterbirds are also affected by biological invasion. Invasive alien species have serious impacts on native species, such as predation of birds and eggs, alternation of habitat structure, decline of habitat quality and food availability (Gan et al. 2007). All these have direct or indirect impacts on waterbirds. Since the 1990s, alien

Smooth Cordgrass (*Spartina alterniflora*) has spread rapidly in coastal wetlands in China through artificial plantation and natural expansion. The Smooth Cordgrass has out-competed native plants, occupied saltmarsh and mudflat, and altered the structure and composition of biological communities in the invaded region. This has resulted in a significant decrease in waterbird diversity (Gan et al. 2009). The exotic Red Swamp Crawfish (*Procambarus clarkii*) was cultivated as an economic aquatic product in many regions in China. Currently it is common in many inland wetlands. The crawfish is omnivorous and has a high reproduction rate. The spread of crawfish has largely reduced local benthic diversity and decreased food for waterbirds (Jiang et al. 2007). Although many invasive species in wetlands have been reported, the impacts of most exotic species on waterbirds remain largely unknown.

Like anywhere else in the world, climate change has also affected waterbirds in China. On the one hand, sea-level rise caused by global warming decreased the area of coastal wetlands, which provides critical habitats for many waterbirds, especially providing refueling habitats for millions of migratory shorebirds along the East Asian-Australasian flyway. It is estimated that that sea-level rise would reduce 23–40% of intertidal habitat, causing population decline of 72% among ten long-distance migratory shorebirds (Iwamura et al. 2013). On the other hand, because different biological groups have various responses to climate change, climate change would affect the temporal and spatial linkage between waterbirds and their biological and abiotic environments, such as mismatches between breeding period and the peak of food (Both and Visser 2001), causing fitness decline. Climate change can also increase the frequency of extreme weather events such as droughts and floods, which adversely affect waterbird populations (Galbraith et al. 2002; Zhang et al. 2011).

Natural disasters has threatened some waterbird populations. For example, summer typhoons in the coastal areas often cause breeding failure of the Chinese Crested Terns (Chen et al. 2015). In 1998, flooding in the middle and lower reaches of the Yangtze River raised water levels in Dongting and Poyang Lake. It is difficult for some waterbirds to access their food of submerged plants in deep water, causing decrease of waterbird diversity in the region (Wang et al. 2017). Since 2006, long-term drought in Taolimiao-Alashan Nur of Inner Mongolia has largely reduced the area of nest sites for Relict Gull (*Larus relictus*), causing decline of breeding success (He and Ren 2011). Drought at Dalai Lake in Inner Mongolia, a breeding site for waterbirds, led to a dramatic population decline of the Red-crowned Crane (*Grus japonensis*), the White-naped Crane (*Antigone vipio*), and the Mute Swan (*Cygnus olor*) (Tian et al. 2016). In 2001, fire at Zhalong Nature Reserve destroyed 18% of the total area of breeding sites for the red-crowned cranes, causing decrease of breeding success (Tian et al. 2004). Although habitats can be gradually restored after natural disasters, the impact of natural disasters on bird populations might last for long periods. If combined with other adverse effects, natural disasters may cause more serious consequences, such as extinction of small populations.

The outbreak of diseases can cause rapid decline of waterbird population. For example, in 2002, a total of 73 Black-faced Spoonbills overwintering in Taiwan died of *Clostridium botulinum* (Yu and Swennen 2004). In 2005, the break of H5N1 influenza virus caused 10% of the total Bar-headed Goose (*Anser indicus*) to die at Qinghai Lake (Liu et al. 2005). Many waterbirds concentrate in large flocks or in colonies in breeding, migration stopover, and nonbreeding period, further increasing the probability of disease transmission and outbreak (Chen et al. 2006; Zhang et al. 2011).

Most threatened birds have a small population with relatively low genetic diversity. On the one hand, the probability of inbreeding is high in such small populations, which decreases the viability of nestlings and increases the probability of breeding failure (Chen and He 2011). For example, the records of thinning egg shells, chick malformations, and mortality rates was relatively high in the Crested Ibis, which might be because the Crested Ibises originated from a small population with low genetic diversity (Xi et al. 2009). On the other hand, low genetic diversity may decrease the adaptability of birds to environmental changes and thus increase the risk of extinction in a changing environment (Zhang et al. 2004; Zhang and Zhou 2012).

Besides these threats to waterbirds and their habitats listed above, the management policy also affects population dynamics of waterbirds. On the aspect of habitat management, although wetlands provide essential ecological services for human being, they have been considered as unused lands, and thus wetland exploitation has been encouraged, for long term in China. Many hydraulic engineering projects, such as damming construction along rivers and seawall construction along coasts, have been implemented over the past several decades, with taking little account of the integrated values of natural wetlands, nor the ecosystem services they provide. To meet the target of no-net-loss of arable land, large area of wetlands has been enclosed and changed to farmland to compensate their loss along with rapid economic development. Moreover, wetlands are under the jurisdictions of different agencies, with often conflicting mandates symbolizes the difficulties for conservation. All these have caused dramatic loss of wetlands, in both

quality and area, which adversely affected waterbirds that depend on wetland habitats (An et al. 2007; Ma et al. 2014).

In recent years, with increasing understanding of the importance of wetlands, wetland conservation has obtained increasing attention. Many legislations, regulations, and guidance emphasize wetland conservation. For example, the *Law of Land Administration* that revised in 2004 has changed the articles from encouraging wetland exploitation in the earlier version to that "it is forbidden to reclaiming farmland from lakes and to occupy river beach". The *Regulations for the Conservation and Management of Wetlands* issued in 2013 proposed that "Prohibit reclamation, landfill, or draining of wetlands". In February 2018, the draft of *Measures for Protection and Management of Coastal Wetlands* was announced by the State Oceanic Administration, announcing that commercial development of coastal wetlands will be prohibited (Stokstad 2018). All these suggest changes in the management of wetland habitats for waterbirds. However, it generally takes a long stage for the recovery of waterbird populations, the effectiveness of such changes on waterbird conservation remains to be seen.

Recommendations for waterbird conservation

Multiple threats have caused waterbirds in China to be one of the most threatened wildlife groups. Because nearly half of the populations were still unknown for their trends, the population declines of waterbirds in China might be more serious than we have known. We propose comprehensive measures for waterbird conservation as follows:

Strengthen wetland conservation and restoration of degraded wetlands to provide high quality habitats for waterbirds

Habitat conservation is the basis of species conservation. In view of the severe situation of rapid wetland loss and degradation in China, wetland conservation is the priority for waterbird conservation. Because wetland reclamation is the main cause of wetland loss, we suggest that all the wetland reclamation projects should be strictly assessed for their impacts on waterbirds and their habitats. Wetland reclamation should be forbidden in key habitats for waterbirds. Meanwhile key habitats for waterbirds should be designated as nature reserves, Ramsar sites, or other types of protected areas. At present, local governments in China are designing the "ecological red-line" for conservation (Zhang et al. 2017). This will improve the conservation of natural wetlands and provide suitable habitats for waterbirds. In January 2017, the newly revised *Wild Animal Protection Law* came into effect. Compared with the previous version, the revision put the conservation of habitats for wildlife into an important position (Ma 2017). However, although some regulations for wetland conservation have been issued at both national and local levels, it is still lack of special law for wetland management. Formulation of wetland management law will provide further legal support for protection and sustainable use of wetlands.

For degraded wetlands, targeted measures are required to restore their function, such as controlling the discharge of pollutants, eradicating invasive and regaining native species, and improving the long-term hydrological condition of wetlands. In 2012, constructing "beautiful China" and "ecological civilization" was proposed as national strategies at the Eighteenth National Congress of the Communist Party of China. In 2017, the 19th National Congress of the Communist Party of China further proposed to enhance ecosystem conservation, including to strengthen wetland restoration (Xi 2017). This provides policy support for restoration of degraded wetlands. In recent years, both the central and local governments provide special funding to support wetland restoration (The State Forestry Administration 2015). Wetland restoration has been conducted in many regions, such as the projects of "returning farmland to lake" in the middle reaches of the Yangtze River (Sun et al. 2015), the project in the Yellow River Delta to establish hydrological linkage among various wetland components (Li et al. 2011), and the project of eradicating invasive Smooth Cordgrass using engineering or non-toxic herbicide measures in the Yangtze and Minjiang estuary (Xu 2010; Ma 2017). All these projects have improved wetland quality and increased waterbird diversity. Currently, there is still a lack of integrated technical support in wetland restoration. Development of guidelines for wetland restoration, which should be associated with specific wetland types, can be helpful for sharing experience of successful practice. A successful wetland management will raise wetland quality and improve their supports for waterbirds.

Enhance public awareness to improve waterbird conservation

Since the late 1990s, many locally-based non-government organizations focusing on birdwatching have been established in China. This promoted the increase of public awareness in bird conservation. Moreover, some birdwatching societies have exerted their influence to promote the decision making of governments in conservation (Ma et al. 2013). However, the modern concept of natural conservation has only a short history in China. There is still a lot of room for improvement of public awareness. As a consequence, public education should be further strengthened, especially targeted at decision-makers, young people, and people in underdeveloped

regions. Through increased advocacy, direct actions, effective campaigns, pressure on governments, and targeted public-government partnerships on bird conservation, the increased public awareness will largely improve conservation.

Improve the enforcement of wildlife protection law and crack down on illegal bird hunting

The *Wild Animal Protection Law* provides the legal basis for punishing illegal hunting, with emphasizing protection of national key protected animals. However, the checklist of the national key protected animals was formulated in 1989 and has not been updated (except for slight adjustments in 1993 and 2003) since then. Many threatened waterbirds, such as the critically endangered Spoon-billed Sandpiper (*Calidris pygmaea*) and Baer's Pochard, are not included in the checklist due to lack of data when the law was formulated (Table 5). We recommend that the checklist of the national key protected animals should be updated regularly (e.g., every five years) based on the population dynamics, so these threatened birds can be protected by law. Moreover, the enforcement of the *Wildlife Protection Law* should be strengthened to make sure that illegal acts receive due punishment.

Conduct long-term waterbird surveys to clarify population dynamics

The population trends collected in the paper come from the database of Wetlands International (2012), in which most data were in the 2000s. Due to the rapid changes of waterbirds and their habitats in China, the population trends in the 2000s might be different from that in recent years for some species. For example, the population trend of Oriental Stork (*Ciconia boyciana*) was designated to "decline" according to the data between 1995 and 2005 (Wetland International 2012). However, with expanding breeding region and increasing breeding numbers, the population of Oriental Stork might have increased in recent years (Duan et al. 2015). Moreover, most waterbird species lack long-term surveys, some even lack of basis ecological data, making it difficult to assess population trends in China.

In recent years, the Ministry of Environmental Protection, the State Administration of Forestry, and many local wildlife management agencies have organized regional waterbird surveys (The State Forestry Administration 2015). The public also is active in waterbird surveys. Since 2005, birdwatchers in the coastal regions have launched the *China Coastal Waterbird Census*. By monthly waterbird surveys, these surveys have provided information about the distribution, population status, and key habitats of waterbirds, promoting waterbird conservation in coastal region (Bai et al. 2015). We suggest that systematic and long-term waterbird surveys should be conducted to fill knowledge gaps, with close cooperation between government agencies and the public. With increasing numbers of birdwatchers, the public will play more and more important role in bird surveys in China. Those third party data from "citizen science" contribute not only to clarifying population dynamics of waterbirds, but also to providing references in environmental impact assessment and making of regulations (Ma et al. 2013; Zeng et al. 2018). Furthermore, an integrated waterbird database including both waterbirds and habitat information, which should be shared by everyone in a transparent way, is required to provide basic data for analyzing waterbird population trends and for supporting the formulation of conservation measures.

Restore populations of highly-threatened species through artificial intervention to reduce extinction risk

For some Critically Endangered and Endangered species with small populations, it is crucial to increase their populations by artificial interventions. The population restoration of Crested Ibis is a representative case. One the one hand, by controlling natural enemies during the breeding period, reproductive success of the Ibises was largely increased. On the other hand, based on successful captive breeding, captive populations have been reintroduced into the field, augmenting the wild population and increasing genetic diversity (Li et al. 2018). After more than 30 years of efforts, the threatened level of Ibises has been down listed from Critically Endangered to Endangered (Wang et al. 2014). In recent years, artificial intervention measures have also been conducted for population restoration of the Spoon-billed Sandpiper and the Chinese Crested Tern (Chen et al. 2014; Peng et al. 2017). Some threatened waterbirds, such as cranes and storks, have successfully bred in many zoos with large captive populations, which can provide the basis for increasing natural population by reintroduction provided suitable habitat still exits. It should be emphasized that on the background of dramatic habitat loss in China over the past several decades, habitat conservation is the priority in species conservation. Especially for nature reserves, habitat conservation is always the first task, captive breeding cannot be used as an excuse.

Promote international and regional exchange and cooperation to share information and experience about waterbird conservation

Most waterbirds in China are migrants. Three of the nine global flyways, namely the East Asian-Australasian Flyway, Central Pacific Flyway, and the Central Asian Flyway, pass through China. Therefore, waterbird conservation in China is closely related to waterbird conservation along

the flyways. The Chinese government has joined several international and regional waterbird conservation treaties, such as the Ramsar Convention and the East Asian-Australasian Flyway Partnership. Some international conservation organizations, such as the World Wide Fund for Nature (WWF), Wetland International, Paulson Institute, and the International Crane Foundation (ICF), have set up their offices in China and launched many waterbird conservation programs. BirdLife International, the Royal Society for the Protection of Birds (RSPB), and many other organizations are also active in supporting China's waterbird conservation. In the future, enhancing international and regional exchange and cooperation, sharing information of and experience in waterbirds conservation among countries and organizations will promote waterbird conservation in China. In view of the critical role of China in supporting diverse waterbirds, recognizing international obligations under the treaties and agreements to address population decline of waterbirds will contribute to waterbird conservation along the flyways.

Additional file

Additional file 1: Table S1. Population trends of migratory and resident waterbird species in China. **Table S2.** Population trends of waterbird species distributed exclusively on coast, inland, and both in China. **Table S3.** Population trends of threatened waterbird species in China. Data were classified according to residence. **Table S4.** Population trends of threatened waterbird species distributed exclusively on coast, inland, and both in China.

Authors' contributions
ZM and XW designed the study, XW collected and analyzed the data, XW and ZM wrote the paper with contribution from FK and KT. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
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