Bird Conservation International (2017) 27:167–186. © BirdLife International, 2016
doi:10.1017/S0959270915000398

Wintering waterbirds in the middle and lower Yangtze River floodplain: changes in abundance and distribution

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Summary

The middle and lower Yangtze River floodplain is a globally important wintering area for waterbirds in the East Asian-Australasian Flyway. Ornithologists have reported on wintering waterbirds in the floodplain since the 1950s. However, an integrated analysis of the long-term changes in waterbird diversity is not available. Here, we synthesise existing information on changes in wintering waterbird abundance and distribution in the floodplain, summarise possible influencing factors and propose some priorities for further research. Waterbird richness and abundance have declined over the past 60 years. Declining trends have been observed in a number of areas and species. Nevertheless, a few areas and species showed different trends. In addition, waterbirds have become more concentrated in a few suitable areas such as Poyang Lake and Dongting Lake. Land reclamation, hunting, dam operation and extensive aquaculture are probably the four major threats to wintering waterbirds, while establishment of nature reserves is beneficial to waterbird conservation. Our study suggests that waterbirds in the floodplain are vulnerable, and that effective conservation measures are needed to protect and restore the waterbird diversity of this area.

Introduction

Freshwater ecosystems are among the most threatened ecosystems in the world, with declines in biodiversity that are greater than most affected terrestrial ecosystems (Sala *et al.* 2000, Dudgeon *et al.* 2006). The Yangtze River floodplain is globally important for its high biodiversity (Olson and Dinerstein 1998, Fu *et al.* 2003, Fang *et al.* 2006), especially for waterbirds (Barter *et al.* 2005, Cao *et al.* 2008). It has been designated by the World Wildlife Fund as one of the 'Global 200' priority ecoregions for conservation (Olson and Dinerstein 1998). However, the floodplain suffers great environmental stress (Chen *et al.* 1997, Cao and Fox 2009, Yang 2012). The floodplain covers about 1.8 million km^2, accounting for 19% of China' total area. Nevertheless, it is inhabited by about 400 million people, 29% of China's population, and contributes 42% of China's GDP.

The middle and lower Yangtze River (MLYR) floodplain (Figure 1) is an important wintering ground for migratory waterbirds of the East Asian-Australasian Flyway (Barter *et al.* 2005, Cao *et al.* 2009, 2010, Cui *et al.* 2014). Ornithologists have reported on wintering waterbirds in the floodplain since the 1950s. Related publications have increased since then, especially after 2000 (Figure 2a; see *Data sources* for details of the search strategy). However, most studies focused on limited areas (Figure 2b). The most frequently surveyed locations were Poyang Lake, Chongming Dongtan and Dongting Lake. In addition, most studies were short, covering only one or two years. An integrated analysis of the long-term status of waterbird dynamics in the MLYR floodplain is not available. Furthermore, most publications are in Chinese, making them unavailable to many potential readers. Because waterbird conservation depends upon efforts at both national

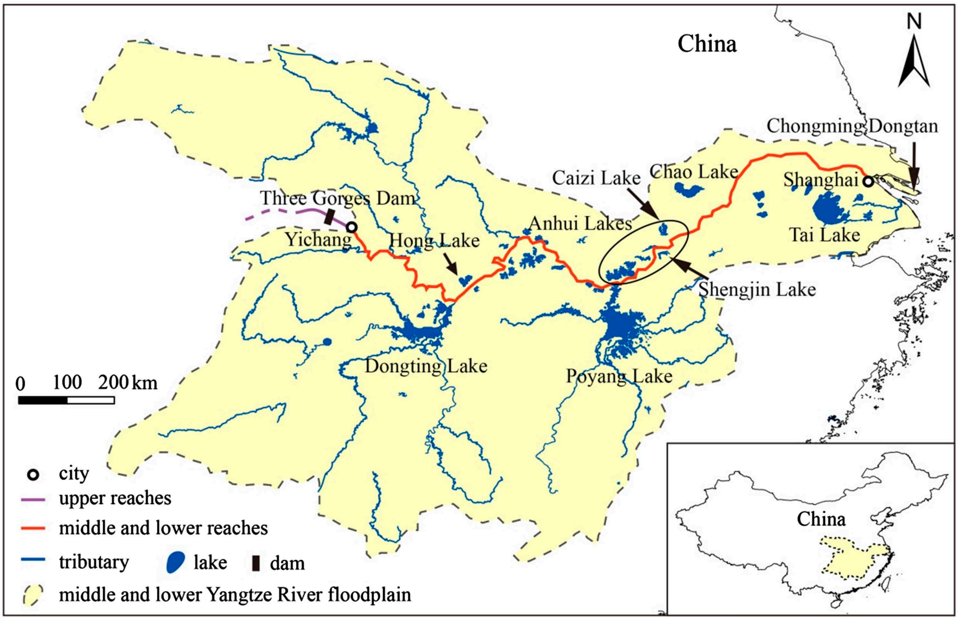

Figure 1. Map of the middle and lower Yangtze River floodplain.

and international levels, it would be ideal for information to be made available beyond China. Therefore, in this study, we attempt to integrate all available information on waterbird diversity in the floodplain. The aims of this study are to (1) review changes in wintering waterbird abundance and distribution in the past 60 years (1950s–2013/2014); (2) summarise possible influencing factors from the floodplain; and (3) propose some priorities for further research.

Materials and methods

Regional overview

The Yangtze River is the longest river in China and the third longest in the world. It originates on the Qinghai-Tibet Plateau and flows about 6,300 km eastward to the East China Sea. We refer to the section from Yichang (located near the Three Gorges Dam) to Shanghai as the MLYR (Figure 1).

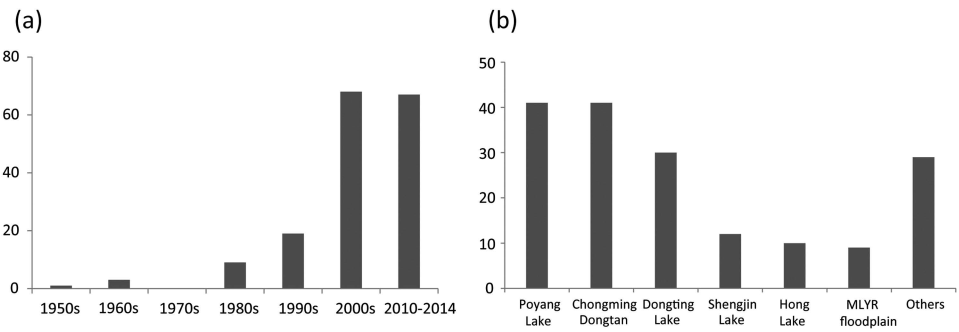

Figure 2. Number of publications focusing on wintering waterbird diversity in the middle and lower Yangtze River (MLYR) floodplain since the 1950s by publication time (a) and target locations (b).

https://doi.org/10.1017/S0959270915000398 Published online by Cambridge University Press

The length of the MLYR is about 1,880 km, and it drains about 800,000 km^2 (Tong and Han 1982). The MLYR floodplain is a complex river-lake ecosystem, including the Yangtze River and many lakes and their tributaries (Huang and Chen 2010). Lakes interact hydrologically with the Yangtze River and its tributaries. Normally, water runoff from tributaries goes through lakes to the river. Water flow also can reverse, running from the river to lakes during the peak wet season in the upper reaches of the river from July to September (Guo *et al.* 2012). The MLYR floodplain has more lakes than most other places in China and includes four of China's five largest freshwater lakes: Poyang Lake, Dongting Lake, Tai Lake and Chao Lake (Ma *et al.* 2011).

Water levels in the floodplain lakes vary widely across wet (April–September) and dry (October–March) seasons (Chu *et al.* 2008, Feng *et al.* 2012). Flood pulses during the wet season bring nutrients and organic matter to floodplain lakes, and water recession during the dry season exposes rich feeding areas for numerous waterbirds. In addition to seasonal variation, floodplain lakes also show significant inter-annual variation (Ding and Li 2011, Feng *et al.* 2012). Precipitation varies widely across years, making the floodplain one of the most frequently flooded and drought-stricken areas in China (Zhang *et al.* 2006, Gemmer *et al.* 2008). This hydrological variation, both within and among years, renders the floodplain unique in its ability to produce abundant plant and animal food for numerous waterbirds (Barzen 2012).

Wintering waterbird diversity

More than 900,000 wintering waterbirds belonging to 104 species, eight orders, 13 families and 30 genera have been recorded in the MLYR floodplain (Lei *et al.* 2011). About 80% of the total count of eastern China's Anatidae and 99% of the total count of eastern China's inland shorebirds inhabit the floodplain (Cao *et al.* 2008, 2009). Ducks, geese and swans were most abundant, comprising 66% of the total individuals, followed by shorebirds (16%), gulls (7%) and herons/egrets (5%; Barter *et al.* 2004, 2006, Lei *et al.* 2011).

The MLYR floodplain is home to 19 species listed at some level of conservation concern by IUCN (Lei *et al.* 2011). It supports a high proportion of the global numbers of seven threatened species: Siberian Crane *Grus leucogeranus* ('Critically Endangered', almost 100% of the estimated global population), White-naped Crane *G. vipio* ('Vulnerable', about 20% of the estimated global population), Hooded Crane *G. monacha* ('Vulnerable', about 10% of the estimated global population), Oriental White Stork *Ciconia boyciana* ('Endangered', about 57% of the estimated global population), Swan Goose *Anser cygnoides* ('Vulnerable', almost 100% of the estimated global population), Lesser White-fronted Goose *A. erythropus* ('Vulnerable', about 65% of the estimated global population) and Falcated Duck *Anas falcata* ('Near Threatened', about 89% of the estimated global population) (Barter *et al.* 2005, 2006, Cao *et al.* 2008, Lei *et al.* 2011, BirdLife International 2015). While these species are rare globally, some of them are commonly seen in the floodplain (Ji *et al.* 2007).

About 24 lakes contain at least one waterbird species with internationally important numbers (i.e. ≥ 1% of the total flyway population; Barter *et al.* 2004, 2006, Lei *et al.* 2011). Poyang Lake, Dongting Lake and Shengjin Lake are three extremely important lakes for abundant waterbirds including species of conservation concern (Barter *et al.* 2004, 2006, Ji *et al.* 2007, Lei *et al.* 2011).

Data sources

In order to understand the change in numbers of publications focusing on wintering waterbird diversity in the MLYR floodplain, we searched for Chinese articles through the China National Knowledge Infrastructure (CNKI) database and articles in English through Google Scholar. Relevant studies identified in the search were retrieved. Books and reports also were searched. The search terms included 'waterbird diversity', 'Yangtze River' and individual lake names such as 'Poyang Lake', 'Dongting Lake' and 'Shengjin Lake'. We collected data on waterbird numbers

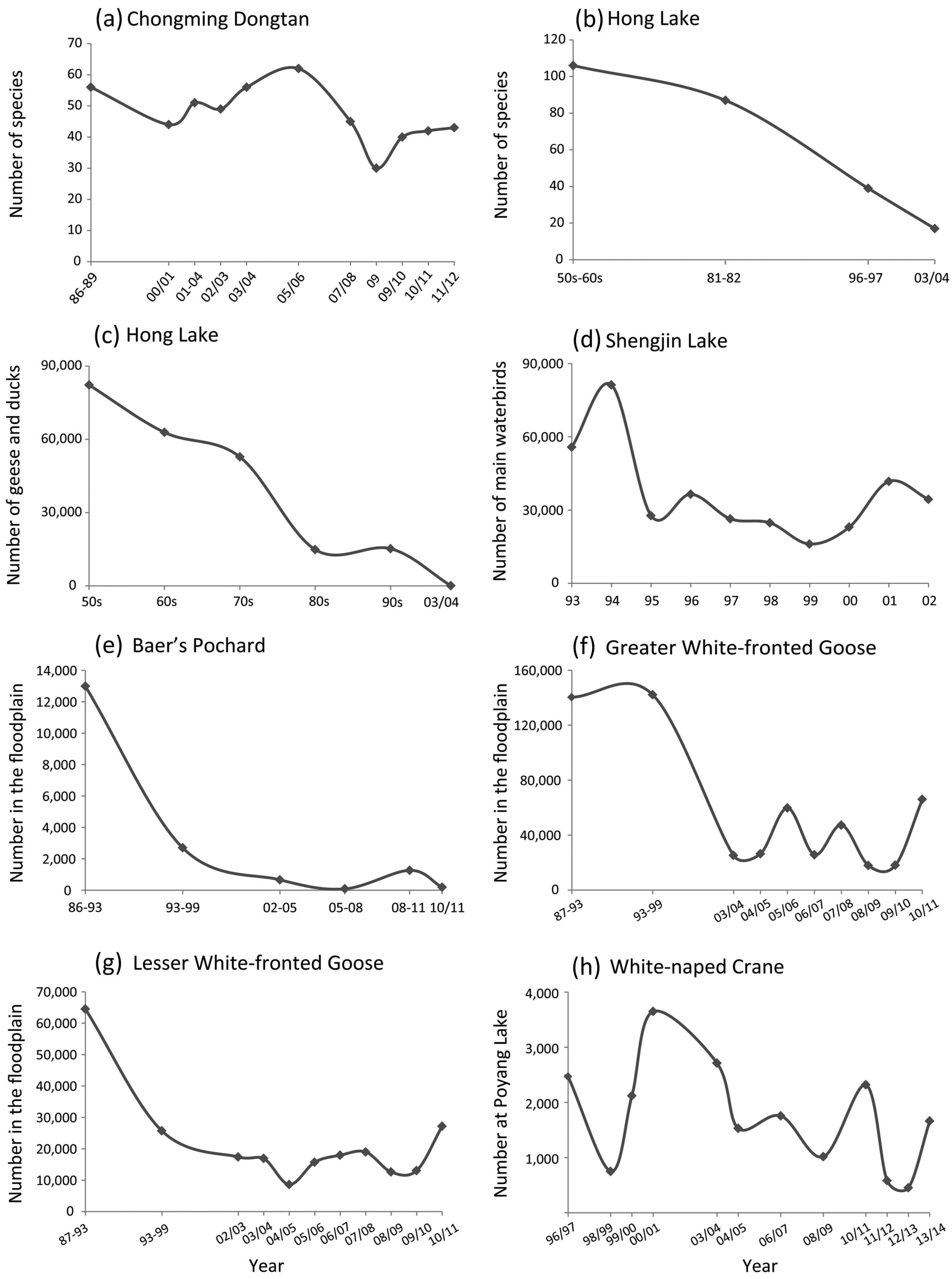

Figure 3. Lakes showing declines in waterbird richness/abundance and waterbirds showing declines in abundance. (a) Number of species at Chongming Dongtan. (b) Number of species at Hong Lake. (c) Number of geese and ducks at Hong Lake. (d) Number of individuals of main wintering waterbirds at Shengjin Lake. Main species are Hooded Crane, Siberian Crane, Common Crane (*Grus grus*), White-naped Crane, Oriental White Stork, Black Stork (*Ciconia nigra*), Eurasian Spoonbill (*Platalea leucorodia*), Tundra Swan, Great Bustard (*Otis tarda*), Swan Goose, Bean Goose (*Anser fabalis*), Greater White-fronted Goose and Anatidae. Counts of Baer's Pochard (e), Greater

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from the literature, and used the average number when several estimates were available in the same winters (See Table S1 in the online supplementary material for details). Excel was used to analyse data.

Changes in wintering waterbird abundance and distribution

Wintering waterbird richness and abundance have declined in the past 60 years. The declining trend has been observed in a number of areas, including Chongming Dongtan, Hong Lake, Longgan Lake, Dong Lake, Cheng Lake, Shengjin Lake, Shijiu Lake and Tai Lake (Qian and Zhu 1980, Wang *et al.* 1983, Xu 1999, Yang *et al.* 1999, Hu and Kang 2004, Hu *et al.* 2005, Liu 2014). For example, at Chongming Dongtan, the average numbers of wintering waterbird species declined from 53 (± 6 SD) in 1986–2005/2006 to 42 (± 2) in 2009/2010–2011/2012 (Figure 3a). Thirty-one out of 60 species declined substantially between the 1980s and the 2000s (Ma *et al.* 2009). At Hong Lake, the number of species declined from 106 in the 1950s–1960s to 17 in 2003/2004 (Figure 3b). Thirty-five out of 39 species declined greatly between the 1960s and the 1990s (Fang *et al.* 1997). Geese and ducks declined from 82,231 individuals in the 1950s to 78 individuals in 2003/2004 (Figure 3c). At Shengjin Lake, numbers of main wintering waterbirds declined from 68,484 (± 18,001) in 1993–1994 to 28,839 (± 8,245) in 1995–2002 (Figure 3d). In addition, numerous species have declined substantially in the floodplain. For instance, counts of Eurasian Coot *Fulica atra* declined by 93%, from about 140,000 in the 1990s to less than 10,000 in the 2000s (Hashimoto and Sugawa 2013); counts of Baer's Pochard *Aythya baeri* declined by 99%, from 12,995 in 1986–1993 to 194 in 2010/2011 (Figure 3e); counts of Greater White-fronted Goose *Anser albifrons* declined by 53%, from 140,365 in 1987–1993 to 66,015 in 2010/2011 (Figure 3f); and counts of Lesser White-fronted Goose declined by 58%, from 64,494 in 1987–1993 to 27,182 in 2010/2011 (Figure 3g). Most of these declines occurred between the 1980s and the 1990s. Counts of White-naped Crane at Poyang Lake, where almost 100% of the Yangtze population winters (Barter *et al.* 2004, 2006, Lei *et al.* 2011), fluctuated between 1996/1997 and 2000/2001, and then declined greatly over the past 15 years (Figure 3h). Consistent with the waterbird decline in the floodplain, waterbirds in the breeding grounds of the Russian Far East also have shown significant declines. The present waterfowl numbers are approximately one tenth to one eighth of those 100 years ago (Syroechkovski and Rogacheva 1995). All goose populations have declined by more than 80% (E. Syroechkovski Jr. *in litt.*). Ten out of 13 migratory populations of dabbling ducks and six out of 14 populations of diving ducks have also decreased (E. Syroechkovski Jr. *in litt.*).

Nevertheless, waterbird richness and abundance at some lakes changed little or increased. At Poyang Lake, the number of species changed little between 2003/2004 and 2013/2014 (Figure 4a). Though annual fluctuations were large, the numbers of individuals showed significant linear increases between 1996/1997 and 2013/2014 (Figure 4b; $R^2 = 0.49$, $P = 0.004$; See "*Other negative factors*" for reasons for the low number in 1998/1999). At East Dongting Lake, the number of species increased slightly between 2005/2006 and 2010–2012, and the numbers of individuals increased from 33,000 in 2005/2006 to 111,605 in 2010–2012 (Figure 4c and 4d; See "*Other*

Figure 3. (Continued)

White-fronted Goose (f) and Lesser White-fronted Goose (g) in the middle and lower Yangtze River floodplain. (h) Counts of White-naped Crane at Poyang Lake. Data are from Zhang and Yuan (1989), Huang *et al.* (1993), Fang *et al.* (1997), Liu and Jia (2000), Wu and Ji (2002), Zhao *et al.* (2003a), Barter *et al.* (2004), Fu (2004), Hu and Kang (2004), Ma *et al.* (2004), Hu *et al.* (2005), Barter *et al.* (2006), Wang *et al.* (2007a), Wang *et al.* (2007b), Jin *et al.* (2008), Ma *et al.* (2009), Wu *et al.* (2010b), Lei *et al.* (2011), Qin *et al.* (2011), Wu *et al.* (2011), Li *et al.* (2012a), Li *et al.* (2012b), Liu *et al.* (2012), Wang *et al.* (2012a), Wang *et al.* (2012b), Zhao *et al.* (2012), Liu *et al.* (2013a), Wu *et al.* (2013a), Wu *et al.* (2013b), Liao *et al.* (2014) and Liu *et al.* (2014).

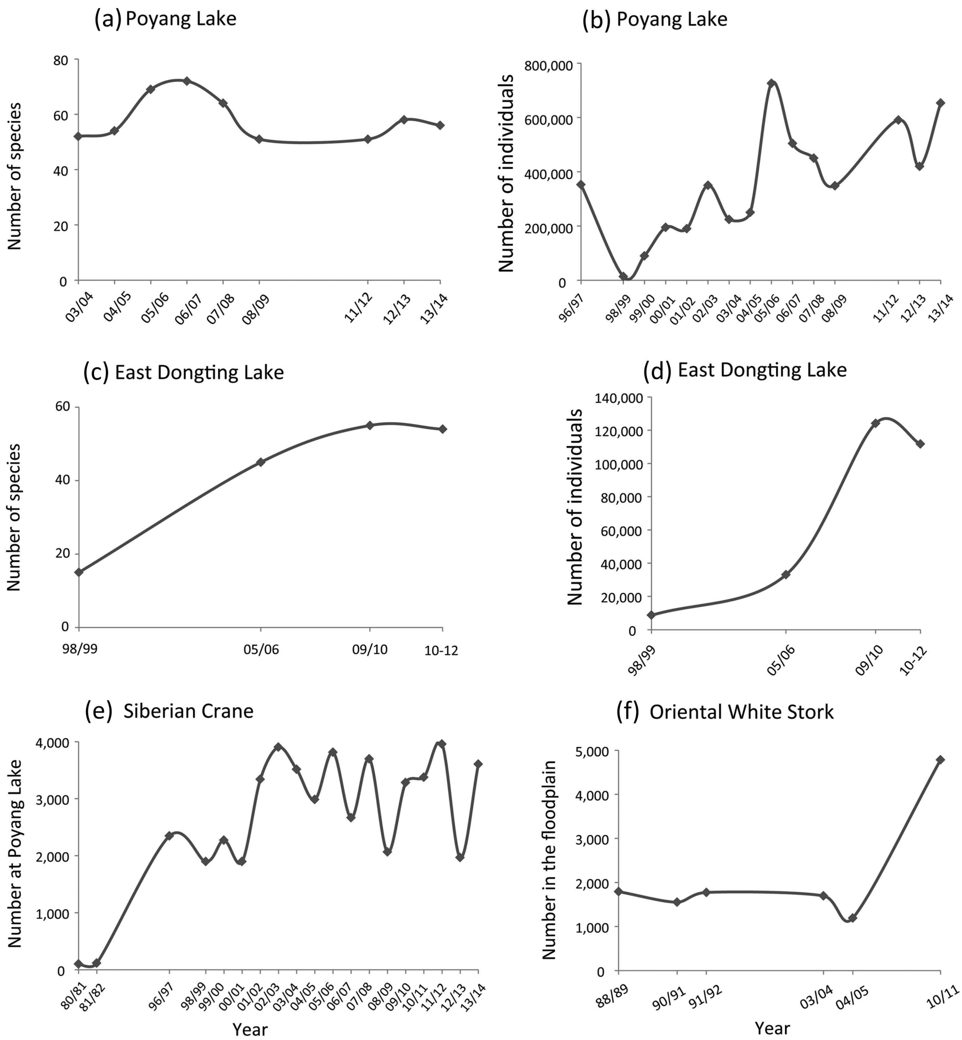

Figure 4. Lakes where waterbird richness/abundance changed little or increased and waterbirds showing abundance increases. Number of species (a) and number of individuals (b) at Poyang Lake. Number of species (c) and number of individuals (d) at East Dongting Lake. Counts of Siberian Crane at Poyang Lake (e). Counts of Oriental White Stork in the middle and lower Yangtze River floodplain (f). Data are from Zhou and Ding (1982), Wang and Yang (1995), Liu and Jia (2000), Deng *et al.* (2001), Wu and Ji (2002), Qian (2003), Barter *et al.* (2004), Li *et al.* (2005), Barter *et al.* (2006), Li *et al.* (2007), Li *et al.* (2010), Wu *et al.* (2010a), Lei *et al.* (2011), Lü (2011), Qian *et al.* (2011), Li *et al.* (2012b), Liu *et al.* (2012), Shan *et al.* (2012), Zhu *et al.* (2012), Liu *et al.* (2013a), Yuan *et al.* (2013), Liao *et al.* (2014) and Liu *et al.* (2014).

negative factors" for reasons for the low numbers in 1998/1999). In addition, a few species increased in recent decades. For example, counts of Siberian Crane at Poyang Lake, where almost 100% of the global population winters, increased from about 100 in 1980/1981 to 3,902 in 2002/2003, and then fluctuated moderately after 2002/2003 (Figure 4e). Counts of Oriental White Stork in the floodplain increased from an average of 1,602 in 1988/1989–2004/2005 to 4,784 in 2010/2011 (Figure 4f).

In contrast to surveys focused on individual lakes, three coordinated wintering waterbird surveys were conducted in the floodplain in 2003/2004, 2004/2005 and 2010/2011 (Barter *et al.* 2004, 2006, Lei *et al.* 2011). These survey results showed an increase from 83 species and 515,896 individuals in 2003/2004 to 104 species and 914,088 individuals in 2010/2011 (Figure 5). However, the increasing trend should be treated with caution as the number of survey sites and amount of wetland coverage also increased. The increase might also be affected by habitat contraction in other wintering grounds, such as Huai River floodplain, which formerly supported high numbers of waterbirds, but only small proportion are left at present (Cao *et al.* 2010).

Waterbird distribution has also changed greatly. Waterbirds have increasingly been confined to limited suitable areas, such as Poyang Lake and Dongting Lake. For example, Baer's Pochard formerly wintered throughout eastern and southern China, but now is concentrated in three lakes of the MLYR floodplain (Wang *et al.* 2012a). Likewise, Swan Goose, Tundra Swan *Cygnus columbianus* and Greater White-fronted Goose once wintered throughout the MLYR floodplain, but now up to 95% of these species are found at Poyang Lake and Anhui Lakes (Cong *et al.* 2011, Zhang *et al.* 2011, 2012). Lesser White-fronted Goose also wintered throughout the floodplain, but now 69% of the population is confined to Dongting Lake and 29% to Poyang Lake (Wang *et al.* 2012b). These concentrations might have contributed to the increase in waterbird abundance at Poyang Lake and Dongting Lake in the past 10 years (Figure 4).

Possible influencing factors from the floodplain

Waterbird abundance may be influenced by factors acting throughout the annual cycle. Wintering waterbirds in the MLYR floodplain mainly migrate through central China and breed in northern China, Mongolia and central and eastern Siberia (Higuchi *et al.* 2004, Takekawa *et al.* 2010). Due to low human population densities in Siberia, it is likely that waterbird declines in the flyway resulted from factors in other places (Syroechkovski and Rogacheva 1995, Tomkovich *et al.* 2002). In other breeding and staging grounds apart from Siberia, threat include habitat degradation (Amano *et al.* 2010, Yang *et al.* 2010), land reclamation (MacKinnon *et al.* 2012, Ma *et al.* 2014), drought (Liu *et al.* 2006, Goroshko 2012), hunting (MaMing *et al.* 2012) and so on. The high human density in the MLYR floodplain also has significantly impacted waterbird abundance and distribution. Here we focus on factors from the MLYR floodplain.

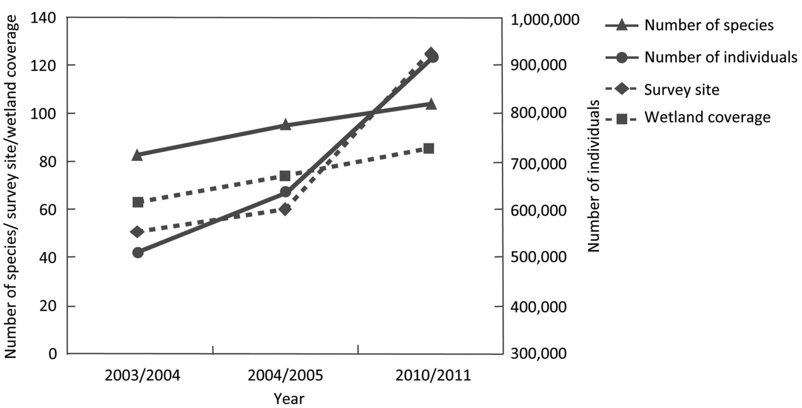

Figure 5. Trends in numbers of wintering waterbird species, numbers of individuals, survey sites and wetland coverage in the coordinated surveys in 2003/2004, 2004/2005 and 2010/2011. Data are from Barter *et al.* (2004, 2006) and Lei *et al.* (2011).

https://doi.org/10.1017/S0959270915000398 Published online by Cambridge University Press

Land reclamation

Land reclamation which directly reduces the area of suitable habitat, is considered an important driver of waterbird declines (Zhao *et al.* 2005, Fang *et al.* 2006). To meet the requirement of a growing Chinese population, which increased rapidly from 0.55 billion in 1950 to 0.99 billion in 1980 (National Bureau of Statistics of the People's Republic of China), more than one third of the MLYR floodplain's lakes have been converted to cropland (Shi 1989, Yin and Li 2001, An *et al.* 2007). For example, at Poyang Lake, the water surface area decreased by 26%, from 5,200 km^2 in 1949 to 3,840 km^2 in 1983 (Peng 1996). At Dongting Lake, the water surface area decreased by 38%, from 4,350 km^2 in 1949 to 2,691 km^2 in 1984 (Peng 1996), and the mean patch size of water body decreased by 39%, from 33 km^2 in the 1950s to 2.0 km^2 in 1978 (Zhao *et al.* 2005). In the Jianghan Plain, the number of lakes decreased by 40%, from 414 to 250, and the total area of lakes decreased by 53%, from 3,885.4 km^2 to 1,839.1 km^2, between the 1950s and 1978 (Fang *et al.* 2005). In contrast, cropland increased sharply (Bian and Gong 1985). At Dongting Lake, the cropland area increased by about 14%, from about 13,000 km^2 in the 1950s to about 14,800 km^2 in 1978 (Zhao and Fang 2004).

Land reclamation has resulted in significant negative environmental consequences, such as increased flooding, a decline in biodiversity and extinction of some endemic species (Yin and Li 2001, Zhao *et al.* 2005, Fang *et al.* 2006). These impacts made the Chinese government and local residents realise the importance of wetlands. At the same time, with the increases in cropland area and productivity, China was able to supply enough food for its population by the early 1980s (Rozelle *et al.* 1997). Therefore, land reclamation was forbidden along the central Yangtze River floodplain in the early 1980s. After the highest flood in the MLYR floodplain in recorded history in 1998, the Chinese government implemented a wetland restoration policy in the central Yangtze River floodplain. Lake restoration resulted in an increase in the area of water bodies (Zhao *et al.* 2003b, Ding and Li 2011). For example, the water surface area of the Jianghan Plain increased by 17%, from 1,839.1 km^2 in 1978 to 2,144.4 km^2 in 1998 (Fang *et al.* 2005). Simultaneously, waterbird diversity recovered somewhat (Li *et al.* 2012c).

However, due to a national policy of increasing forest cover and large demand for paper and synthetic fibre board, some lake shorelines have been recently reclaimed to grow Italian poplar *Populus euramericana* (Zhao and Fang 2004, Kang 2005). At West Dongting Lake, the area used for poplar plantations increased nine times from 1996 to 2013 (Liu *et al.* 2013b). Planting poplar is becoming an important driver of wetland degradation and waterbird declines in the floodplain (Hu and Kang 2004, Liu *et al.* 2013b).

Hunting

Hunting is another important factor driving waterbird declines in the MLYR floodplain (Lu 1993, Fang *et al.* 1997, Cao *et al.* 2010). A study of hunting pressure in the floodplain estimated that approximately 50% of the total wintering waterfowl were killed in 1987–1992 (BirdLife International 2003). Geese and ducks, which are prized for food, suffered the greatest hunting pressure (Lu 1993, Fang *et al.* 1997, Cao *et al.* 2010). For example, in 1960–1961, 350,000 kg of geese and ducks were harvested at Hong Lake (Fang *et al.* 1997), and 40,382 kg of ducks were taken at Tai Lake (Qian and Zhu 1980). Hunting is thought to be a major reason for the decline of Baer's Pochard in China (Wang *et al.* 2012a), the decline of Lesser White-fronted Goose in the MLYR floodplain (Wang *et al.* 2013a) and the disappearance of Oriental White Stork at Shijiu Lake (Wang and Yang 1995) and Cheng Lake (Kang 2005). Waterbirds were mostly hunted using guns before 2000. In order to protect wildlife, the Wildlife Protection Law was launched in 1988, and the Gun Control Law in 1996. After that, waterbird hunting has been partly controlled. However, hunting still occurs frequently in the floodplain using less conspicuous methods such as poison baits and nets (MaMing *et al.* 2012).

Dam operation

China has been particularly active in dam construction, building about half of the world's large dams (Lu 2004). The Yangtze River floodplain has more than 45,700 dams with a total storage capacity of 220 billion m^3 of water (Yang *et al.* 2009). The Three Gorges Dam (TGD), located at the upper reaches of the Yangtze River, is the world's largest hydropower project. The TGD operation has affected water and sediment discharge, as well as terrestrial and aquatic biodiversity in the MLYR floodplain (Fu *et al.* 2003, Wu *et al.* 2004, Wang *et al.* 2005, Guo *et al.* 2012). Water discharge increases from May to June to create capacity for flood control, and decreases from October to November to recharge the reservoir (Wu 2007). Water impoundment in October decreases the water level of downstream lakes, and results in earlier exposure of recessional grasslands (Wu 2007, Guo *et al.* 2012, Sun *et al.* 2012). Earlier exposure of grasslands further advances the period of grass growth (Wu 2007), resulting in *Carex* too high for geese to exploit when they arrive (Zhao *et al.* 2012). This decline in habitat suitability was suggested as a link to the decline of Greater White-fronted Goose (Zhao *et al.* 2012). Recessional grasses of *Eleocharis* and *Alopecurus*, the major food of Lesser White-fronted Goose, are also sensitive to the timing of substrate exposure (Deil 2005, Wang *et al.* 2013a). Thus, the TGD operation might also have negative impacts on Lesser White-fronted Goose (Wang *et al.* 2012b, 2013a). In contrast to these disadvantages, some researchers have suggested that the TGD operation might assist waterbirds. For example, Wu *et al.* (2009) suggested that water release from May to June raises water levels of downstream lakes, which is likely to increase water clarity and productivity of *Vallisneria*, thus increasing the food supply for tuber-feeding waterbirds.

In addition to large dams, many small sluices were built at the outlet of almost all shallow lakes in the MLYR floodplain (Fang *et al.* 2006). Poyang Lake and Dongting Lake are the only two lakes remaining that are freely connected with the Yangtze River. Sluice operation reduces variation in lake water levels, both within and among years (Chu *et al.* 2008). Hydrological variability is essential for waterbird communities (Barzen *et al.* 2009). Reducing hydrological variability may reduce waterbird abundance and density (Kingsford *et al.* 2004). Sluice operation also can lead to a decline in water quality (Yang 2012). Water quality at Poyang Lake and Dongting Lake is better than most other lakes in the MLYR floodplain (Yang *et al.* 2010), though they are also facing degradation problems (Lu *et al.* 2003, Deng *et al.* 2011). The superior environment at Poyang Lake and Dongting Lake might contribute to the waterbird concentrations there. However, a dam has been proposed by the Jiangxi Government at the outlet of Poyang Lake. Although the proposal immediately provoked strong opposition at home and abroad (Li 2009), it has not been vetoed. If the dam is constructed, it is likely to have negative impacts on waterbirds (Barzen *et al.* 2009, Xia *et al.* 2010).

Extensive aquaculture

The MLYR floodplain is a centre of freshwater aquaculture in China, accounting for more than 45% of production in the country. Aquaculture production in the floodplain has increased rapidly in recent decades, from 0.40 billion kg in 1979 to 12.03 billion kg in 2011 (Fishery Bureau, Ministry of Agriculture, China 1980, 2012). There are three major aquaculture methods in the floodplain. The first is Lake Aquaculture, characterised by the culture of commercial fish and crabs throughout individual lakes. The second is Enclosure Aquaculture, characterised by enclosing parts of lakes for aquaculture using netting. Both Lake Aquaculture and Enclosure Aquaculture are intensive, because stocking fry leads to high density of fish. The third and less intensive method is named Lake Enclosed in Autumn and is characterised by managing water levels of sub-lakes without stocking fry.

Intensive aquaculture may greatly influence water quality and the density of submerged vegetation, with the influence of Lake Aquaculture greater than Enclosure Aquaculture (Ban *et al.* 2010, Xiao *et al.* 2010). Short periods of intensive aquaculture may cause great damage to vegetation,

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and long periods of aquaculture may lead to collapse in all submerged macrophytes (Chen *et al.* 2011). At Meixi Lake, a sub-lake of Poyang Lake, *Vallisneria* plant density and tuber density were 74.2 (± 41.3) individuals/m² and 9.8 (± 4.1) individuals/m², respectively, during non-fishing years, while reduced to 0.0 (± 0.0) individuals/m² and 1.0 (± 1.4) individuals/m² during fishing years (Wu *et al.* 2012a, 2012b). The *Vallisneria* tuber is an important food for tuber-feeding waterbirds. Declines in food abundance may drive declines in waterbirds. At Meixi Lake, the mean number of tuber-feeding waterbirds was 451.7 (± 474.9) during non-fishing years, while reduced to 18.0 (± 22.6) during fishing years (Zeng *et al.* 2012). In addition, intensive aquaculture may affect waterbird species in different ways. For example, at Caizi Lake and Shengjin Lake, the density of fish-eating waterbirds (mainly Ardeidae) showed little difference between natural fishery areas and intensive aquaculture areas, whereas non-fish eating waterbirds (Gruiformes, Anseriformes and Charadriiformes) occurred at higher densities in natural fishery areas (Chen *et al.* 2011). This is detrimental to waterbird conservation as most threatened species in the floodplain belong to Gruiformes and Anseriformes.

Lake Enclosed in Autumn is a unique and commonly used fishing method in the floodplain, especially at Poyang Lake. Local fishermen utilise seasonal variation in water levels to raise and catch fish. During the wet season, floods overflow the banks of sub-lakes and bring fish and nutrients, then during the dry season, the banks trap fish and water in sub-lakes, facilitating fishing. Local fishermen release water when they want to catch fish. Before water release, the water level is too high for many waterbirds. Suitable habitat appears when the water is released gradually. Generally, fishermen release water around January, the time of the Chinese Spring Festival, when the price of fish is high. Releasing water at the same period in multiple sub-lakes leads to limited habitat availability in other periods. In addition, to catch as many fish as possible, fishermen normally remove all water from lakes, directly reducing habitat for waterbirds. According to nearly 10 years of surveys of Nanjishan Wetland National Nature Reserve, a reserve located at Poyang Lake, waterbird abundance would be reduced by about 77% if all lakes were drained simultaneously (Hu and Wan 2014). Therefore, Lake Enclosed in Autumn may greatly influence sub-lake hydrology and waterbird diversity (Guo *et al.* 2014). The impacts depend upon when and how water is released. We suggest that some effective measures should be taken to encourage fishermen to stagger water release and stop draining lakes dry, in order to protect waterbirds.

Other negative factors

Pollution, extreme weather, sand dredging, invasion of alien species and buffalo grazing also affect waterbirds in the floodplain. Pollution is a prominent threat to the environment and biodiversity of the floodplain (Yang 2012). About 23.4% of lakes in the floodplain are highly eutrophic, 64.9% are eutrophic, and only 11.7% are not eutrophic (Yang 2012). Eutrophication is one of the major reasons for the decline and disappearance of submerged macrophytes (Fox *et al.* 2013). Eutrophication induced a *Vallisneria* collapse at Shengjin Lake, which was followed by a decline in tuber-feeding waterbirds, including Hooded Crane, Swan Goose and Tundra Swan (Fox *et al.* 2011, Zhang *et al.* 2011, Luo 2012). Moreover, Swan Goose and Hooded Crane have been forced to move off the traditionally used shallow water and mudflat areas and have started to forage on grasslands and paddyfields (Zhou *et al.* 2009, Zhang *et al.* 2011, Luo 2012).

The MLYR floodplain is one of the most frequently flooded and drought-stricken areas in China (Zhang *et al.* 2006, Gemmer *et al.* 2008), and the occurrence of flood and drought is expected to increase due to climate change (Ye *et al.* 2011, Field 2012) and anthropogenic activities (Sun *et al.* 2012, Zhang *et al.* 2012). Low dry-season water levels may negatively affect waterbirds by directly reducing areas of suitable habitats (Xia *et al.* 2010, Wang *et al.* 2013b, Chen *et al.* 2014). High wet-season water levels have also negatively affected waterbirds. For example, the 1998 flood led to obvious declines in the number of species at East Dongting Lake and numbers of individuals at Poyang Lake and East Dongting Lake, compared with adjacent years (Figure 4). High water levels in 2010 forced Siberian Cranes to switch diet and forging habitat (Jia *et al.* 2013), and led to a decline in breeding success in the next year (James Burnham unpubl. data).

Sand dredging caused an increase in water turbidity, and decreased light availability and productivity of *Vallisneria*, which reduced the food supply for tuber-feeding waterbirds (Wu *et al.* 2007). Sand dredging also widened and deepened lake outflow channels, increasing water discharge from lakes into the Yangtze River (Lai *et al.* 2014). The increased discharge further led to abnormally low water levels in the dry season and reduced waterbird habitat (Lai *et al.* 2014). Invasion of alien plants is widespread in the floodplain (Ge *et al.* 2010, Hou *et al.* 2011). Invasion of smooth cordgrass *Spartina alterniflora* greatly affected species composition and structure of bird communities at the Yangtze estuary (Ma *et al.* 2009). Buffalo grazing negatively affected the growth and availability of grass, which may further affect grass-feeding waterbirds (Kang 2005, Wang *et al.* 2014). Nevertheless, some researchers suggested that buffalo grazing can assist in maintaining suitable grass heights for waterbirds (Zhao *et al.* 2012).

Establishment of nature reserves

In contrast to the factors above, establishment of nature reserves has benefitted waterbird populations. With a growing awareness of the importance of wetlands, a series of wetland nature reserves was established in the MLYR floodplain, mostly within the past 30 years (Fang *et al.* 2006, Huang and Chen 2010). By the end of 2008, 89 wetland nature reserves had been established, protecting a total area of 16,282 km^2, about 2% of the floodplain (Huang and Chen 2010). Among them, 21 reserves are aimed specifically at protecting waterbirds (Huang Xinyi *in litt.*).

While increases in waterbird diversity at Poyang Lake and Dongting Lake might have resulted from wetland degradation in other lakes, it might also have been promoted by the establishment of nature reserves and by conservation practices within those reserves (Fang *et al.* 2006). The increases in Siberian Crane and Oriental White Stork might also have been promoted by the establishment of nature reserves. Siberian Crane decreased significantly in China before the 1950s. In 1953, only two specimens in Anhui Province were recorded (Zhou *et al.* 1981). No other record existed until Zhou *et al.* (1981) found about 100 individuals at Poyang Lake in the winter of 1980. In order to protect this species, the Poyang Lake Nature Reserve was established in 1983. Due to protection, the average number of Siberian Cranes increased from 120 before the establishment of the reserve to 3,298 (± 642) afterwards (Figure 4e). In order to protect the Oriental White Stork, a number of nature reserves were established at breeding, staging and wintering grounds (Ma *et al.* 2006). Several nature reserves in the north-east of China, a key breeding area for Oriental White Stork, built artificial nests to attract breeders (Zhu *et al.* 2008, Lian 2011). This method has proved to be effective. For example, 112 breeding pairs were successfully attracted, and 455 chicks hatched, in 1993–1999 at the Honghe Nature Reserve (Zhu *et al.* 2000).

Limitations of the study

Our inferences about the changes in waterbird diversity and distribution in the MLYR floodplain were necessarily based on a variety of surveys that were not designed for this kind of longitudinal study. Surveys varied in methods, dates, areas, observer experience and environmental conditions. In addition, most surveys were conducted within nature reserves, where environments may be more hospitable to waterbirds than elsewhere. Thus, our results might be biased. Nevertheless, we believe the most parsimonious conclusion is that the abundance and distribution of waterbirds in the MLYR floodplain have contracted in recent decades.

Future perspectives

China continues to grow, demographically and economically. Thus, demand for food, water and other natural resources in the MLYR floodplain will continue to increase, creating additional pressures on waterbirds and their habitats. Effective waterbird conservation depends on clear objectives and sound science. To provide a scientific underpinning for such a conservation effort, we suggest the following research priorities.

Increase and improve waterbird monitoring in the floodplain. Until now, only three comprehensive and simultaneous surveys have been conducted in the floodplain; this is not enough to fully understand changes in waterbird diversity. Moreover, standardised methods should be developed and used throughout the floodplain to improve data comparability across years and sites.

Further assess the influence of the TGD and sluices on waterbirds and their environments. To date, many studies have focused on the influences of the TGD operation on the Yangtze River, primarily on water and sediment discharges (Wu 2007, Guo *et al.* 2012, Sun *et al.* 2012). However, few studies have focused on the interactions among the TGD, the Yangtze River and lakes or on the effects of sluices on wetland environments. Exploring these issues is particularly important for understanding the influence of water management on waterbird habitats. It is also important to investigate the best ways to manage dam and sluice controlled wetlands to provide adequate food and habitat for waterbirds.

Study the interactions between aquaculture operations and waterbird populations and seek methods that optimise fish management while enhancing waterbird conservation. Aquaculture is economically important for residents of the MLYR floodplain. Thus, we must find ways to optimise aquaculture and fishing methods in ways that minimise negative impacts on waterbirds, and where possible, enhance waterbird populations. Furthermore, in order to encourage fishermen to protect waterbirds, we should enhance their awareness of waterbird conservation, and also explore programmes to compensate fishermen when waterbird protection reduces profits from fishing, such as promoting ecotourism and paying for environmental management.

Identify conservation priority areas and accelerate the establishment of nature reserves. The decline and concentration of waterbirds make them vulnerable to external factors such as human disturbance and wetland degradation. Thus, it is critically important to protect the limited remaining suitable areas such as Poyang Lake and Dongting Lake. It also is important to restore habitats in other lakes to buffer the negative influence of these factors. Although nature reserves play an important role in waterbird protection in the MLYR floodplain, reserve coverage is not large enough, and some key areas are unprotected (Zhao 2005, Cao *et al.* 2010). In addition, no single nature reserve can include the entire wetland ecosystem upon which waterbirds depend. External threats to ecosystem integrity are therefore not completely mitigated by the establishment of nature reserves (Harris and Hao 2010). A priority for future efforts should be to develop whole-lake management plans for wetland systems that are larger than the conservation areas within them.

Given the complexity of waterbird conservation, collaborations among ornithologists, hydrologists, policy makers and local residents are required to minimise negative impacts of human activity, maximise the effectiveness of nature reserves, and protect waterbird diversity in the floodplain.

Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0959270915000398

Acknowledgements

This is part of Wenjuan Wang's postdoctoral work at Fudan University. We thank Zhijun Ma, Fengshan Li, Jeb Barzen, Haiming Qin, Binsong Jin and Jun Rong for valuable comments. We also thank the International Crane Foundation and Jiangxi Poyang Lake National Nature Reserve for their support. This study is funded by the National Natural Science Foundation of China (grant number 31401969) to WW, the "Gan-Po Talent 555" Project of Jiangxi Province to JDF and State Forestry Administration of China-United Nations Development Program/Global Environment Facility (83911NP-2014-007) to JC.

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Received 7 March 2015; revision accepted 25 November 2015;
Published online 16 May 2016