Moving forward: how best to use the results of waterbird monitoring and telemetry studies to safeguard the future of Far East Asian Anatidae species

LEI CAO[1,2,*], FANJUAN MENG[1], JUNJIAN ZHANG[1], XUEQIN DENG[1,2], YUSUKE SAWA[3] & ANTHONY D. FOX[4]

[1]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China.
[2]University of Chinese Academy of Sciences, Beijing 100049, China.
[3]Yamashina Institute for Ornithology, 115 Konoyama Abiko, Chiba 270-1145, Japan.
[4]Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, DK-8410 Rønde, Denmark.
*Correspondence author. E-mail: leicao@rcees.ac.cn

Abstract

This special issue of *Wildfowl* has summarised our knowledge of the biogeographical populations of ten key Anatidae species in East Asia, their current and recent estimated abundance and distributions, their migration routes and movements, and sites of importance to these populations at key stages of their annual cycles. The analysis was possible only through the active cooperation of the many biologists and site managers involved in studies of these species in different countries participating in a collaborative programme of monitoring, research and analysis. Development of new telemetry and bio-logging technology has played a key role in our ability to describe linkages between the breeding, moulting, staging and wintering areas used by individual waterbirds. Compilation of movement data recorded for tracked individuals of each species has provided initial information on flyway delineation and range definition, which forms the basis for future identification of biogeographical populations. Additionally, the tracking data have identified critical stopover and wintering sites for the different species which, when overlaid upon site protection boundaries, has enabled a preliminary appraisal of the effectiveness of current site safeguarded networks in providing adequate protection for waterbird populations along their flyways. Synthesis and analysis of new count data has permitted a description of recent population trends and a reassessment of their current size, together with recommendations for improving population monitoring into the future. High rates of utilisation of farmland habitats during staging periods within China, especially during spring migration, contrast with low levels of winter use, when most species are largely confined to natural habitats. We discuss the significance of these facets of habitat use and the need for improved study of feeding ecology throughout the non-breeding periods, to determine optimal land management and thus inform their conservation requirements at different times of year. Finally, we consider the way forward, with a view to maintaining and building on the impressive international collaboration established to date, in order to ensure that these long distance migratory waterbirds are safeguarded for future generations.

Key words: *Anser*, *Branta*, *Cygnus*, distribution range, geese, *Mareca falcata*, migration routes, swans.

Long-distance migratory waterbirds depend on the utilisation of a network of discrete and often widely separated wetland sites along their migration corridors, to fulfil their needs during the course of their annual cycle. Each site represents a link in a long chain of sites that provide crucial functions, such as safety from predators, a source of nutrients and energy for the next step in their annual migration, or places suitable for social activity, such as aggregation for courtship or colonial nesting. Developing effective conservation policies to ensure the survival of these long-distance travellers requires both a knowledge of the biogeographical population structure of each species, and an assessment of the relative importance of key sites to this population. In particular, it involves: 1) identification of groups of birds from a given species that consistently follow the same discrete migration routes (to assess changes in their abundance over time), and 2) knowledge of the relative importance of sites for these birds along the flyway, based on the relative numbers using them (relative to the population as a whole) and their role in the functioning of the annual cycle. This approach was initiated in the United States in the 1930s (Lincoln 1935) but not in Europe until the 1970s, when Atkinson-Willes (1976) began to assess the biogeographical populations of wintering ducks, swans and coots in order to relate their numerical distribution to the assessment of the importance of individual wetlands to their survival in winter. This process has continued, culminating with the mapping of western Palearctic waterbird distributions published in Scott & Rose (1996 for Anatidae), Madsen *et al.* (1999 for geese) and Delany *et al.* (2009 for waders), but inevitably is an on-going process as global change affects natural systems and our understanding develops and evolves.

Until recently, the conservation of Anatidae in Far East Asia has suffered somewhat, by comparison with Europe and North America, because of a hitherto lack of information for defining biogeographical populations, mainly due to a lack of metal ring marking of species which has been such a feature of European waterbird studies since the 1950s (Davidson *et al.* 1999). Our objective in this special issue of *Wildfowl* has been to summarise new data on the biogeographical populations of ten Anatidae species in East Asia, including on their current and recent estimated abundance and distributions, their migration routes and movements and the key sites that are of disproportionate importance to these populations throughout their annual cycles. This has been in no small measure due to the incredible cooperation made possible across the region, which has brought together the principal biologists and site managers studying these species in different East Asian countries, for a collaborative monitoring and research programme (see Supporting Materials Fig. S1, Table S1, Appendices S1 & S2). In addition, the development of new telemetry and bio-logging technology has played a key role in our ability to describe very rapidly the individual linkages between breeding, moulting, staging and wintering areas that individuals use during their annual cycle.

Towards biogeographical population delineation

One of our major objectives has been to bring together evidence to support the identification of meaningful biogeographical populations in Far East Asia for the ten species considered here (although movement data remain scarce particularly for the Mute Swan *Cygnus olor*, and regrettably we still lack much basic knowledge about the enigmatic East Asian Brent Goose *Branta bernicla nigricans* population), in a way that can support our ability to monitor the annual changes in their abundance (see Table 1). The deployment of devices that can track the positions of individual waterbirds in time and space throughout the year has been central to our ability to trace their precise migration corridors and link specific places used by different species at key points in their annual cycle. Rather than wait decades for the accumulation of small proportions of ringing recoveries, or using VHP radio techniques biased by human abilities to detect tagged birds, this technology has enabled us within a few years to show how birds from specific breeding and wintering areas disperse throughout the annual cycle and aggregate at important moulting, and staging areas. The results from highly precise and very frequent temporal and spatial location data have shown systematically how birds of different wintering provenance disperse on the summering areas and how this results, in some cases, in completely separate migration routes and staging areas. Such information enables us not only to justify monitoring these birds as separate entities and but also to identify specific sites of importance during the breeding, staging, moulting and wintering periods.

So, for example, tracking results from Greater White-fronted Geese *Anser albifrons* showed that the birds which wintered in China seemed to form a distinct entity (defined by its members that were tracked) from those that wintered in Japan and Korea, not merely in being separated on the winter quarters but seldom mixing at other stages in their annual cycle (Deng *et al.* 2020). This gives us some biological justification to continue to monitor their annual abundance separately in these three groups, as it has been politically expedient to do in the past, given that each country has its own waterbird monitoring programme. In addition, the generally low level of connectivity between these groups of Greater White-fronted Geese gives us the basis for considering these groups as discrete biogeographical populations, under

Table 1. Provisional recommendation for the establishment of 16 flyway populations of ten Far East Asia Anatidae species (in 27 winter management units) based on the species accounts published in this Special Issue of *Wildfowl*. This overview includes the IUCN Red List category for each species, the flyway definitions, current estimates of flyway population size, winter distribution ("management units"), the numbers wintering in each and their population trends.

Species (IUCN status)	East Asia population estimate	Flyway distribution	Winter distribution	Winter population estimate	Trends population estimate	Flyway
Mute Swan (LC)	1,000	Mongolian & N China–E China Flyway	China	400	Unknown	Unknown
Mute Swan (LC)		NE China–Korean Peninsula Flyway	North/South Korea	Unknown	Unknown	Unknown
Whooper Swan (LC)	57,690	East Asian Flyway	China	24,405	Increase	57,690
			South Korea	5,978	Increase	
			Japan	27,307	Increase	
Bewick's Swan (LC)	105,000	East Asian Continental Flyway	China	65,000	Decrease	65,000
Bewick's Swan (LC)		West Pacific Flyway	South Korea	10	Decrease	40,000
			Japan	40,000	Increase	
Swan Goose (VU)	54,420	Inland Flyway	Yangtze River China	54,000	Decrease	54,000
Swan Goose (VU)		Coastal Flyway	Minjiang Estuary China	368	Decrease	420
			South Korea	47	Decrease	

Bean Goose (LC)	351,700	*serrirostris*				
		East Asian Flyway	E China	229,000	Increase	310,500
			South Korea	80,600	Increase	
			Japan	900	Increase	
Bean Goose (LC)		*middendorffii*				
		East Asian Continental Flyway	E China	24,100	Stable	31,800
			South Korea	7,700	Stable	
Bean Goose (LC)		*middendorffii*				
		West Pacific Flyway	Japan	9,400	Increase	9,400
Greylag Goose (LC)	30,000	Mongolia–China Flyway	China	30,000	Increase	30,000
Greater White-fronted Goose (LC)	375,500	East Asian Continental Flyway	China	48,000	Decrease	48,000
Greater White-fronted Goose (LC)		West Pacific Flyway	South Korea	123,500	Increase	327,500
			Japan	204,000	Increase	
Lesser White-fronted Goose (LC)	6,800	Eastern Palearctic Flyway	China	6,600	Decrease	6,800
			Japan	200	Increase	
Brent Goose (LC)	8,700	East Asian Flyway	China	Unknown	Unknown	8,700
			North/South Korea	Unknown	Decrease	
			Japan	2,500	Increase	
Falcated Duck (NT)	83,000	Eastern Palearctic Flyway	C & E Asia	83,000	Increase	83,000

the criteria recommended under the African Eurasian Waterbird Agreement (AEWA 2005) and as previously recognised by Wetlands International (2020) in their *Waterbird Population Estimates 5*. The telemetry evidence for distinguishing breeding and staging areas for Japanese- and Korean-wintering birds was far less conclusive. However, given the high winter site loyalty of this species globally (*e.g.* Wilson *et al.* 1991; Warren *et al.* 1992; Robertson & Cooke 1999), we support the continued recognition of these three units. This means that each population has its own population estimate based on wintering abundance, with its associated 1% criterion, used under Criterion 6 of the Ramsar Convention as the basis for recognising a wetland of international importance to instigate site protection (Ramsar Secretariat 2014).

Tracking showed a similar pattern for Bewick's Swan *Cygnus columbianus bewickii*, with location data from Japanese- and Chinese-wintering birds tagged to date demonstrating that birds from these two groups did not mix along their migration corridors, nor on the breeding grounds (Fang *et al.* 2020). However, this and other studies confirmed the remarkable dichotomy in breeding range of Chinese-wintering birds, with Bewick's Swans breeding in a westerly cluster as far west as the Yamal Peninsula, where the complicating factor is that they mix with breeding birds of European and southwest Asian wintering provenance (Vangeluwe *et al.* 2018; Rozenfeld *et al.* 2019).

The results from tracking of Whooper Swans *Cygnus cygnus* showed that the birds that wintered in Japan, Korea and China similarly seemed to be distinct entities, but our sample sizes of tracked individuals were rather small for a population with a very widespread breeding range. Furthermore, a historical recovery of a Whooper Swan ringed in Japan recovered in the Yamalo-Nenets Autonomous Okrug suggests that there is far more mixing of East Asian Whooper Swans than our results may suggest (Ao *et al.* 2020a). In this case, we feel justified in applying prudence and considering this population as a single entity until such time that we can gather more data to amend this finding.

The gathering evidence for the Swan Goose *Anser cygnoides*, endemic to East Asia, shows the existence of at least two flyways for the species. The first is an Inland Flyway, which links continental breeding areas extending across Mongolia, Inner Mongolia, and the Songnen Plain to Xilin Gol and Kangba Noel (China) and Khanka Lake (Russia) with Chinese wintering areas in the Yangtze River floodplain (Damba *et al.* 2020). The other Coastal Flyway consists of birds summering in northern parts of Sakhalin and at Udyl Lake which are thought to migrate via South Korea (where some small numbers occur) to overwinter there and on the Minjiang Estuary, Fujian Province (China). However, this species breeds across 30 degrees of longitude in Mongolia alone, and the results of telemetry tracking shows the species migrating on a relatively dispersed broad front (Damba *et al.* 2020). This contrasts, for instance, with the relatively narrow corridors taken by Bewick's Swans and Greater White-fronted Geese to their arctic breeding areas (Fang *et al.* 2020; Deng *et al.* 2020). For this reason, we might expect that staging areas for birds breeding in the extreme east and extreme west of the breeding areas are unlikely to overlap along their respective migration routes, which could potentially lead to segregation and non-random pairing in this population (see Zhu *et al.* 2020). However, for the time being and until we have the benefit of more genetic analysis and further results of telemetry studies, it seems prudent to base decisions on population delineations on the major dichotomy.

For the remaining species featured in this Special Issue, the tracking data are insufficiently substantive to enable us to define flyway structures that represent major changes from the prevailing definitions of biogeographical populations (*e.g.* those defined by Wetlands International 2020). We still know very little about the flyway structure of the Falcated Duck *Mareca falcata*, which is endemic to East Asia, but telemetry results suggest no major differentiation to justify continuing to consider that the population constitutes anything other than a single entity (Zhang *et al.* 2020). The Lesser White-fronted Goose *Anser erythropus* is likely to have only one flyway (Ao *et al.* 2020b), especially because the results of Lei *et al.* (2019) show that birds caught on the wintering grounds at East Dongting Lake fanned out on spring migration towards summering areas spread across most of the known breeding range for the species. There remains a question mark, however, about the summering origins of the small but regular and increasing wintering population in Japan. The Mute Swan remains widespread and relatively scarce and scattered in East Asia (Meng *et al.* 2020) and, from the little we know about the species, it seems prudent to consider at least three potential flyway units. Telemetry data confirmed that Mute Swans wintering along the coast of eastern China coasts summered along the Selenga River (Russia), central Mongolia and in Inner Mongolia (China). Mute Swans wintering in South Korea apparently originate from summering areas in Inner Mongolia and the Amur Region (straddling Russia and China). Finally, the sedentary introduced Mute Swan population in Japan appears to be isolated from those elsewhere. However, there is evidently much overlap on the summering areas for the two migratory Mute Swan groups, so this is a species for which we require far more information about its summer and wintering distributions and the relationships between them.

The East Asian Brent Goose population remains one of the world's least known populations of Brent Geese *Branta bernicla* as we still have very little information to link specific summering and wintering areas (Sawa *et al.* 2020), or even to identify all the wintering areas used by the population (Syroechkovskiy 2006). Despite enormous gains in knowledge since Fox & Leafloor (2018), there also remain considerable challenges associated with identifying the flyways of the Greylag Goose *Anser anser* in East Asia. For the first time, Yan *et al.* (2020) were able to clarify the relationships between Mongolian breeding areas and wintering sites in China. The telemetry data seem to imply two discrete corridors connecting the eastern Mongolian/Daurian Russian and Inner Mongolian (China) breeding areas with the Yangtze River floodplain and the Yellow River in winter. However, this dichotomy may simply result from the distribution of catch effort when tagging geese, as this distribution broadly reflects eastern and western extremes of the Swan Goose (Damba *et al.* 2020). Finally, our knowledge of Eastern Tundra Bean Goose *Anser fabalis serrirostris* linkages between the breeding areas in Russia and the Chinese- and Korean-wintering areas has received a major boost from the telemetry studies (Li *et al.* 2020). However, we still lack similar data from birds wintering in Japan, needed to provide a full understanding of how geese disperse from this wintering area along the flyway and on the breeding grounds. Likewise, we remain lamentably ignorant about the precise numbers and distribution of Eastern Taiga Bean Goose *Anser fabalis middendorffii*, both at its breeding and wintering sites. Hence, it remains difficult to determine discrete flyways definitively, beyond being able to separate the Japanese-wintering birds that originate from Kamchatka from those wintering in China, which originate from the Russian taiga zone further to the west (Li *et al.* 2020).

Despite leaving many more unresolved questions, there is no doubt that the results of the telemetry studies have advanced our understanding of the connectivity between the breeding and wintering areas for nine of the species. For the tenth, the Brent Geese of the region, we await further deployment of telemetry devices to enlighten us to the precise flyways of this species which is poorly known in East Asia. While there is a limit to how much more we can learn from bio-logging technologies and we must always carefully weigh the potential behavioural and energetic impacts of attaching tracking devices to birds against the benefits to gaining further knowledge, there is no doubt that all the species subject to treatment here would benefit greatly from further telemetry studies to extend our knowledge. In particular, we remain ignorant of the migration corridors of Eastern Taiga Bean Geese and especially the geographical relationships between Korean- and Chinese-wintering birds (particularly those wintering away from East Dongting Lake) and their respective breeding ranges. For the Greylag Goose as well, tracking birds marked away from breeding areas in Mongolia and at Chinese wintering areas away from the Yangtze River floodplain would provide more information on the migration routes followed by the species. Mute Swan, Lesser White-fronted Goose and Falcated Duck would also benefit from a greater sample size of data from tagged individuals, better distributed from across their natural ranges, to provide much needed insight into the annual movements of birds away from sites where the small numbers have already been marked.

Range definition

While it is naïve to expect that we could ever realistically define the precise edges of the vast areas of terrain that constitute the summer areas of many Anatidae species, we have taken the opportunity to use the telemetry data and the engagement of species experts from along the flyways to redraw the mapped boundaries of the summer and wintering distributions of each of the species featured here. Almost without exception, this has resulted in some contractions in breeding range because of new knowledge, but especially in reductions in the extent of wintering areas. This does not automatically mean that all or indeed any of the species have physically contracted their ranges, since many distribution maps featured in avian publications seek to generalise the distribution for a range of reasons, not least because these may change between years and because the actual fine-grained distribution may be poorly known or patchy rather than continuous as expediently depicted. On the summering areas, several arctic-nesting species were previously shown as having ranges distributed well south of the coastal region, which our telemetry studies suggest do not in reality constitute such importance to the birds during the breeding and moulting seasons as previously implied. It may well be that the birds do use these areas, but given the adherence of the majority of the tagged birds to arctic coastal Russia, we feel it better to highlight the restricted nature of their distribution until such time as more information to the contrary is forthcoming, in order to draw attention of these areas known to be important for different species. Based on the combination of telemetry results, expert opinion and the results of waterbird counts from China, we are more confident now that especially the winter distribution within China of most of these species is highly restricted to the Yangtze and Yellow River floodplains and to the coastal fringe. As a result, the actual winter distribution within China is far more restrictive than suggested by the solid, rather broad-brush patterns shown in previous distribution maps, underlining the truly extraordinary importance of particularly the Yangtze River floodplain, which draws waterbirds from half of the arctic tundra, taiga and steppe biomes of Eurasia during winter.

This massive concentration of waterbird biomass from throughout the biomes of a vast continent underlines how critical these Chinese river systems were and continue to be for wintering Anatidae and how we must work to understand their wetland ecosystem structure and function to best fulfil the needs of the birds that are dependent upon them. Most species have shown some signs of contraction of range within the Yangtze River floodplain in the last 10–15 years, while the same is not true for the same species of favourable conservation status wintering in Japan and Korea. This pattern of range contraction within the most important part of the winter quarters is especially troubling because it is also occurring on provincial and national nature reserves, which generally enjoy excellent protection under China's nature conservation laws. The problems are often associated with factors affecting the quality of the nature reserves operating outside of their boundaries (*e.g.* concerning water quality and quantity issues imposed upstream of the reserve). The suspected causes of many of these declines are many, varied and most likely interacting, and are mostly described in detail in the species accounts of this special issue and elsewhere. However, factors affecting the extent and quality of the available wetland habitats for wintering waterfowl include: physical habitat loss (*e.g.* Jia *et al.* 2018), enhanced water table drawdown (*e.g.* Zou *et al.* 2017), excessive flooding (Aharon-Rotman *et al.* 2017), extreme vegetation change (*e.g.* Jia *et al.* 2017), human disturbance (*e.g.* Zhang *et al.* 2019), loss of submerged macrophytes (Fox *et al.* 2011) and isolation (through dam construction) from the hydrology of the floodplain (*e.g.* Xia *et al.* 2017). The scale and extent of the problems underline the need for catchment management scale solutions, as well as tackling issues at the local, basin level to restore biodiversity and wetland function, both of which require integrated research to establish the ultimate causes and identify solutions (Cao & Fox 2009).

Critical stopover sites

Although not a major output of these species accounts, the use of telemetry has highlighted the importance of critical stopover sites used by a suite of species in their annual migrations between winter quarters and breeding areas. Although such areas may be used for relatively restricted periods of the annual cycle (a few weeks compared to several months spent on the winter quarters), their intensive use as a source of energy, nutrients and minerals at crucial points in the annual cycle make them of disproportional importance for staging waterbirds. Further assessment of the cumulative use of staging areas, by multiple numbers of individuals of the same and different species, would highlight the great importance and value of these sites for a range of waterbirds in their annual cycle. We propose to undertake a more detailed, sophisticated and in-depth analysis of these data in the near future.

However, in the meantime, the results that have come through from the data we present here shows that the four long-distance migratory species of East Asian waterbirds that breed in the arctic use seven discrete migratory corridors and therefore seem to constitute separate biogeographical populations. These are two populations of Bewick's Swan, two of Eastern Tundra Bean Goose, two of Greater White-fronted Goose and a single Lesser White-fronted Goose population. Their breeding distributions range from the Yamal Peninsula in the west to Chukotka in the east. All of these species have their main wintering sites in the Yangtze River floodplain and the middle and lower reaches of the Yellow River in China, in South Korea and along the east and west coasts of Japan. Six of these migratory populations (excepting the Eastern Tundra Bean Goose on its West Pacific Flyway) mainly stage in northeast China, in areas which include the Songnen and Sanjiang Plains. This congruence of staging areas highlights the importance of this part of northeast China as a vital source of energy and nutrients for these birds, especially as they head north in spring. Future analysis will also provide more detailed information across the different species on the habitat types, safe roosting areas and precise core foraging areas used by these birds, the degree to which these are situated within currently protected sites and the precise duration of their staging phenology, which will provide the spatial and temporal basis for providing more effective protection in these critical areas.

Six species within East Asia undertake relatively short migrations between the breeding and wintering grounds and, on the basis of work presented here, it appears that these comprise nine discrete migratory biogeographical populations (two of Mute Swans, one of Whooper Swans, two of Swan Geese, at least one of Greylag Geese, two Eastern Taiga Bean Geese populations and a single Falcated Duck population). These species breed across the Mongolian steppe, in northeastern China and to different degrees throughout the Russian taiga zone, as well as the Ulbansky Bay region and northern Sakhalin Peninsula. They winter mainly in the Yangtze River floodplain, the middle and lower reaches of the Yellow River and on the Minjiang River estuary in China (in the case of the Swan Goose), Bohai Bay in the Yellow Sea in China, in South Korea and on the east and west coasts of Japan. These populations mainly staged in China and North Korea, including on the Inner Mongolia wetlands (Bayannaoer and the Hetao Plain), along coastal areas of the Yellow Sea (Bohai Bay and Yalu River estuary), the Hei River in Gansu Province, and (as in the case of the longer distance migrants) in the Songnen and Sanjiang Plains in northeast China. Among these, it is important to stress that the staging sites in Inner Mongolia and Heihe in Gansu are situated in extremely arid areas, where the wetlands are usually small and the extent of open water area varies greatly within and between years. These factors mean that there is a more urgent need to maintain these crucial but often ephemeral elements of the wetland network (which are so sensitive to climate change), to support the birds through different seasons and in different years. In addition, coastal wetlands as well as wetlands further inland in northeast China have been lost and severely degraded in recent years (Xu *et al.* 2019). We therefore need to continue the work of identifying the most important features of these areas, and to protect and improve the few remaining wetlands as best we can, so that these birds can continue to migrate successfully between their breeding and wintering areas as they do now. However, just as important is to attempt to restore yet more degraded wetlands, in order to buffer against the potential further loss of existing sites as a result of climate and other environmental change.

It is striking, on comparing results across the different species, how many tagged waterbirds used areas of cultivated land and agricultural grassland on the spring and autumn staging areas (*e.g.* Lesser White-fronted Geese; Ao *et al.* 2020b). This is made all the more interesting by many of the same species assiduously avoiding using such farmland in winter, despite the apparent abundance of suitable available farmland, and its profitability as a food resource for the birds on the winter quarters in China (*e.g.* Yu *et al.* 2017; Zhao *et al.* 2018). Given the importance of crops as energetic and nutritional resources for migrating geese along the spring migration corridor and their potential effects on reproductive output, we would stress the importance of ecological studies on these spring staging waterbirds for elucidating how we might enhance their ability to acquire nutrient and energy stores at stopover sites. We should be wary of encouraging Far East Asian staging waterbirds to abandon natural wetlands in favour of sustaining higher rates of nutrient acquisition and energy stores from agricultural subsidies on farmland habitats (as this can lead to agricultural damage issues, as in Europe and North America; see Fox & Madsen 2017). Nevertheless, it is undoubtedly worth exploring the potential to plan for sympathetic management of farmland to provide food for spring staging geese and perhaps even sacrificial crops to support them during the short spring staging period in focal areas (as suggested for the winter quarters; Si *et al.* 2020). We would encourage a burgeoning of field studies of spring-staging waterbirds in key areas identified by these studies, not just to establish the key overnight roosting sites and associated feeding areas, but to establish their diet, preferred *versus* available foods, and the levels of stress from local disturbance events. Such studies would support the development of site protection networks and enhancement of feeding opportunities for the species, in concert with public outreach programmes to engage local communities in the enjoyment and protection of this valuable resource for engaging people with wildlife.

Status and distribution

The special issue has summarised the status of 27 "flyway management units" for the ten waterbird species featured here (Table 1). Of these, we now have a good idea of the population size of 24; only for Mute Swan are robust abundance assessments missing for both management units in Far East Asia and with trends unknown for one of the Brent Geese groups. Of the remainder, 14 are increasing, two considered stable and eight are considered to be in decline (Table 1). This overview gives a sound basis for establishing priorities within the East Asian flyways. Most conspicuously, all the declining populations are those that winter in China, with the exception of the tiny numbers of Bewick's Swans and Swan Geese that winter in South Korea. We should be particularly concerned about declines in Bewick's Swans and Swan Geese (both those in the Inland and Coastal flyways) because until recently Chinese-wintering Bewick's Swans were thought to be of favourable conservation status. Both species are specialists that feed by grubbing the highly nutritional below ground storage organs of aquatic plants, sequentially exposed by water table recession in the Yangtze River floodplain wetlands (as elsewhere), sensitive to water level change. Too rapid water table drawdown and the substrate dries out, becoming impenetrable, making abundant rhizomes inaccessible, but too much flooding and neither species can reach into the shallow flooded substrates to extract their food items from the otherwise soft substrate. There is also evidence of widespread loss of their food plants due to large-scale environmental change (*e.g.* Fox *et al.* 2011; Jia *et al.* 2017), which may be to the advantage of more generalist species such as Eastern Tundra Bean Geese which can apparently more easily switch between alternative food sources, including several food items such as Water Chestnut *Trapa natans* fruits, apparently not exploited by other sympatric wintering waterbird species (*e.g.* Zhao *et al.* 2010). Of continued concern are the declines among Greater White-fronted Geese wintering in China (Deng *et al.* 2020), for which loss of recessional sedge meadows have been identified as the cause of the loss of the species at sites such as East Dongting Lake. Elsewhere, the gain of such sedge beds has resulted in the appearance of the species at sites such as at Shengjin Lake (Zhao *et al.* 2012), experiences which suggest that sensitive hydrological management to maintain and manage such graminoid stands could benefit the species at a number of sites (*e.g.* Guan *et al.* 2014, 2016). The status of the Lesser White-fronted Goose gives greatest concern of all, because of its precipitous decline in the last ten years (Ao *et al.* 2020b). Again, changes in hydrological management of sections of the East Dongting Lake National Nature Reserve have resulted in losses of monotypic graminoid swards, upon which this specialist short sward grazer seemed to specialise in feeding in autumn and spring (Cong *et al.* 2012; Wang *et al.* 2012, 2013). The same authors showed that in mid-winter, when such swards were denied them, the species was unable to maintain energy balance on more extensively available sedge meadows and lost body mass, underlining the birds' reliance on habitats that have now been lost from the site which once regularly supported several thousand individuals (Ao *et al.* 2020b). Perhaps more seriously, in one year when high water levels prevented the Lesser White-fronted Geese from using these favoured recessional grassland feeding areas in late autumn, their fat stores remained lower throughout the entire winter. The following spring, geese left for their breeding areas in poorer condition and later in spring than in the previous year, perhaps reflecting consequences of the need to gain threshold fat stores for migration, but potentially hinting at carry-over effects from feeding conditions in autumn continuing into spring (Wang *et al.* 2013).

What these trends identify is the urgent need to maintain and improve the current mechanisms put in place to monitor effectively the numbers of birds in these flyway groupings, which we are tentatively identifying as biogeographical populations. Building on the advances made in recent years, it is important to clarify further the flyway relationships within species, for understanding how best to treat their current and future management. Outside of this process, it remains essential to maintain the excellent mid-winter waterbird count programmes established in Japan and South Korea, and to extend these to some species such as the Mute Swan that may require other approaches for their effective annual population assessment. We have seen the enormous strides made in China since the 1990s, where waterbird monitoring has gone from being largely restricted to nature reserves to the extensive annual coverage of all wetlands in the Yangtze River floodplain that we see today. This effort must be maintained and enhanced but also extended to other major river systems and coastal areas, which offer potential waterbird wintering habitat elsewhere in China. This is especially the case for the Huai and Yellow Rivers where, despite the massive loss of wetlands in relatively recent times and the fact that they are mostly frozen in mid-winter, there are prospects for extensive waterbird habitats in the future, given climate change and the opportunity for widespread habitat restoration and remediation.

We should also be mindful of the need for demographic monitoring in parallel with mechanisms for estimating population size and trends, in order to understand the drivers behind changes in waterbird population abundance. Extensive annual age ratio determinations have been instigated on the wintering grounds in China, which enable assessments of year-specific recruitment of young to wintering populations. Although only currently available for a modest number of years, continuing and expanding such assessments (*e.g.* to Korea and Japan) will build a vital time series of measures that should establish the degree of between-year variation in reproductive success which can then be incorporated into population modelling, even in the absence of other informative population parameters, such as using capture-mark-recapture techniques to estimate annual survival rates (*e.g.* Johnson *et al.* 2018).

Habitat use

As evident from the Lesser White-fronted Goose example above, access to specific food resources that can meet the seasonal energetic, nutritional and mineral needs at key points throughout the annual cycle is potentially critical for optimal survival and reproduction. Not surprisingly, across all species, results from tracking presented here show that, during the breeding season, most of the studied waterbirds exploit natural habitats in tundra and taiga biomes that are generally less affected by human activities (with the exception of local impacts in the vicinity of settlements and the wider effects of climate change) than is the case in the staging and wintering areas further south. The case of the Lesser White-fronted Goose is one of the few in the region where autecological studies provided some insight into the potential causes of declines resulting from habitat loss or modification on the wintering grounds (see above). The loss of an extensive area of a single species graminoid community demonstrably affected the fat store acquisition in this species compared to a previous year (when such habitat was available) in a quasi-experiment which was also associated with reduced fat stored and delayed spring departure (Wang *et al.* 2013). Permanent loss of such habitat apparently resulted in disappearance of the species from the site and declines in the Lesser White-fronted Goose flyway population as a whole (Ao *et al.* 2020b). This is a clear warning about how loss of a relative modest area of specific habitat within a National Nature Reserve due to changes in aquaculture can affect rare species of high conservation status, and the vital importance of sympathetic management at such sites for species of unfavourable conservation status.

Lesser White-fronted Geese are arguably among the more specialised of feeders of the waterbird guild examined in the accounts of this special issue, so they are perhaps among the most likely to suffer from specific habitat loss compared to more robust species that show greater ability to switch between food supplies. Nevertheless, for all the species featured here, their effective conservation requires an understanding of their habitat use and ideally a framework for the effective protection of their habitat in a condition to maintain current population levels and, in the case of populations showing declines, some mechanism for reinstating lost habitat or providing new food sources. One of the early findings from tracking habitat use by five goose species at Poyang Lake was to show that they rarely fed outside of the wetlands on farmland areas (Yu *et al.* 2017) and that the way these goose species exploited the various natural habitats that provided them with food was intimately related to patterns of water table drawdown that affected plant growth and community composition patterns, as well as accessibility to that food supply in time and space (Aharon-Rotman *et al.* 2017). The same seems true to some extent for duck species as well (Meng *et al.* 2019), whereas cranes (for example the Hooded Crane *Grus monacha* at Shengjin Lake, Anhui Province) have shown an increasing tendency to feed away from wetlands on farmland, especially on paddy fields (Zhou *et al.* 2009; Fox *et al.* 2011), where they are highly disturbed by human activities there (*e.g.* Li *et al.* 2015). The energetic costs of susceptibility to high levels of human disturbance, as well as the very real risk of mortality from human agency, has been suggested as the reason why particularly the goose species which use farmland in Korea (*e.g.* Lee *et al.* 2006; Kim *et al.* 2016) and Japan (*e.g.* Amano 2009; Fujioka *et al.* 2010) do not do so in the Yangtze River floodplain (Yu *et al.* 2017; Zhao *et al.* 2018). As a result, the wintering habitat of Chinese-wintering geese has been interpreted as being limited by the extent of traditionally used wetland habitat and their generally declining population trends interpreted as a sign of reductions in the extent and quality of those wetlands upon which they are dependent (*e.g.* Jia *et al.* 2018). As we have seen from the results of several of the studies presented here, we have support for the hypothesis that the declines in Chinese-wintering birds are unlikely to be responsible for the increases in Korea and Japan over similar time scales because geese using these flyways seem largely discrete. This represents further support for the hypothesis that Japanese- and Korean-wintering goose numbers are increasing as a result of exploitation of new, formerly unoccupied habitats in the form of surpluses of food available to them on agricultural land, whilst Chinese-wintering birds are limited in a density dependent fashion by the extent and quality of declining natural habitats there. This presumably contributes to the explanation why this is the case compared to elsewhere in the Northern Hemisphere, where the same species of geese are generally increasing after the transition to feeding on farmland in winter (Fox & Madsen 2017).

Further evidence that human persecution and disturbance keeps these large-bodied waterbirds from foraging on farmland close to wetlands on their Chinese-wintering quarters comes from the fact that the tracking data presented here conspicuously confirm that several of the same species are largely restricted to wetlands in winter, whereas they somewhat surprisingly stage on agricultural habitats in China during spring and autumn. So, for instance, data from the tracked Whooper Swans showed that > 80% of the positions were recorded from open water or wetlands combined in winter, but > 70% came from grassland or crops during spring *en route* to ultimate breeding areas (Ao *et al.* 2020a). Even among tagged Lesser White-fronted Geese, which were almost entirely confined to wetlands in Poyang Lake (Yu *et al.* 2017) and overall > 80% were on wetlands in winter (Ao *et al.* 2020b), 52% of spring staging positions came from farmland (Ao *et al.* 2020b). This supports similar evidence from another tracking study which showed that Greater White-fronted and Eastern Tundra Bean Geese intensively used farmland at their Chinese stopover sites, but hardly at all at their wintering site, even though farmland was available in similar proportions in both regions (Si *et al.* 2020). These authors inferred that human pressure on both farmland and wetland/grass was significantly lower at the stopover region compared to the wintering region and in both regions, the two goose species selected for farmland and/or wetlands/grasslands with relatively low human pressure close to roosting sites.

Clearly site protection is not enough to safeguard long-distance migratory waterbirds at all stages of their life cycle. The message coming from the results of using tracking data to map *habitat use* is that such data need to be combined with field-based studies to reveal *habitat selection* and the processes driving these patterns. Habitat use is shaped not just by the attractiveness of the food supply at a given point but also by the range of choices available within a given radius and the other factors affecting the relative attractiveness of these choices (such as human disturbance, predation risk, food availability and depletion). Such studies need to be undertaken interactively on site in order to understand how to deliver effective conservation on the ground, for instance with regard to managing the food resource to best effect (*e.g.* through water level management; Aharon-Rotman *et al.* 2017), reducing disturbance to allow access to natural habitat, but potentially also to farmland food resources (Si *et al.* 2020) or indeed, in the extreme, providing artificial feeding, as in the case for Lesser White-fronted Geese in Japan (Ao *et al.* 2020b) and Whooper Swans in Shandong and Henan Provinces, China (Ao *et al.* 2020a).

Conservation

So for these species, the material presented here provides an improved overview of the flyway structures of these waterbird populations in Far East Asia which enables the responsible authorities (both supra-national NGOs such as The East Asian-Australasian Flyway Partnership and Wetlands International, as well as statutory national agencies) to make more informed decisions about which biogeographical groupings of birds constitute logical population management units, for the purposes of monitoring and management (as is the case elsewhere, see for instance Marjakangas *et al.* 2015). On the basis of the preliminary findings regarding flyway structure, it has been possible to see that the goose species wintering in Japan and Korea generally have more favourable conservation status than those wintering in China, which immediately provides the basis for the most effective deployment of scarce conservation resources. In China too, it is evident that for many species the winter range has contracted and, in particular, habitat loss along the coast has resulted in the concentration of wintering swans and geese increasingly in the Yangtze River floodplain where, until very recent years, the annual cycle of summer monsoonal inundation followed by winter water table recession offered vast areas of suitable wintering habitat. However, even here, the combination of aquaculture, pollution, habitat loss and degradation has also concentrated wintering waterbirds into the fewer and fewer basins less degraded by development, urban and agricultural pressures (Fang *et al.* 2005, 2006). In very recent years, for instance, individual basins have suffered disproportionately from development pressures, as was the case at Huangda Lake, a large shallow lake in Anhui Province which suffered major habitat loss combined with heavy catchment pollution effects (including a major pollution event that seriously affected the western part of the lake in 2016) that contributed to very poor water quality (Hong *et al.* 2018) and the lowest recorded levels of water transparency among 50 monitored Yangtze River floodplain lakes (Feng *et al.* 2019). Poor water transparency inevitably impacts on submergent plants such as Tape Grass *Vallisneria* sp. (*e.g.* Fox *et al.* 2013), which are so vital for wintering waterbird species. As a result of the encroachment of such development pressures (*e.g.* Zhang *et al.* 2019; Gao *et al.* 2020) and hydrological isolation of lakes from the Yangtze (Xia *et al.* 2017), we see more species being lost from lakes throughout Hubei and Anhui Provinces. Even worse, we see species being lost from East Dongting Lake (despite its vast area and connection to the Yangtze), not only because of changes in aquaculture (described above), but also through hydrological changes resulting from water management associated with the Three Gorges Dam (Zhao *et al.* 2012; Zhang *et al.* 2016; Jing *et al.* 2017; Zou *et al.* 2017, 2019). The net results of such losses throughout the Yangtze River floodplain is to concentrate more and more waterbirds at the vast Poyang Lake which remains the "jewel in the crown" of Yangtze waterbird reserves, the most important and well protected of all the Yangtze wetlands. Yet this site too, one of the few Yangtze River floodplain wetlands not currently subject to sluice control (Xia *et al.* 2017), is being threatened by the construction of many dams in its own catchment and a major dam to isolate it from the main river. To combat wetland loss, the Jiangxi Provincial Government submitted a Poyang Lake water control project proposal in 2012 to retain high winter water levels within the lake (*c.* 4 m higher during November–March than the average winter levels, based on those measured at the nearby Wusong monitoring station) to protect the lake ecosystem from further deterioration (Zhang *et al.* 2014). The proposal has raised scientific concerns because it will maintain constantly high water levels throughout the dry season (*e.g.* Jiao 2009), which would have detrimental effects on the feeding opportunities of many waterbird species (Aharon-Rotman *et al.* 2017). As we write in November 2020, despite the scientific opposition, this threat has not gone away.

Equally, it is important to stress that there has been great progress made in protecting and restoring lost habitats in some lakes. At Shengtian Lake (Shanxi Province) sympathetic management has been instigated and waterbirds have returned, while at Longgan Lake (Anhui Province) ecological restoration of wetland areas that had formerly been used for farmland, as well as the banning of fishing net areas has seen the recovery of many species, including Greylag Geese (Yan *et al*. 2020). At this site, restoration of formerly cultivated land to shallow water areas have created extensive beds of Wild Rice *Zizania latifolia*, which large numbers of Greylag and Eastern Tundra Bean Geese have begun to exploit in winter. However, there are indications that these geese are also increasingly feeding out on adjacent farmland, potentially further extending the more natural carrying capacity of the system (Yan *et al.* 2020). At Chen Lake (Hubei Province), local improvements to wetland management have greatly improved local conditions for wintering waterbirds, and removal of seine nets from 70% of the lake area has also made a major contribution (Yang *et al.* 2017). Removal of all fishing nets, cages and dams at Huanggai Lake (Hunan Province) had similar effects, and at Wuchang Lake (Anhui Province) the reconstruction of lost waterbird habitats and wetland restoration has also been implemented to the benefit of wintering waterbird numbers (Yan *et al.* 2020).

To protect this vital migratory waterbird resource, the first line of attack must be to restore all the Yangtze wetlands to their former states along similar lines to those undertaken as described above, no matter how damaged, because as demonstrated by the examples presented, as long as the physical wetland conditions remain, restored lost and degraded habitats and wetland functions can attract the numbers and diversity of waterbirds that they formerly supported. This is especially the case for provincial and national nature reserves which are actually already protected, amongst other things, for their importance for wintering waterbirds, which as we have seen, are of continental and global significance. Ideally, restoration and the implementation of sympathetic management will involve research and monitoring to provide an adaptive management framework to understand how best to implement actions for restoring wetland functions and enhancing waterbird populations, but also to continue improving knowledge of species ecology and their interaction with their environment. Nature is a great healer and the dynamism of the seasonally ephemeral Yangtze River floodplain wetlands makes it easier to start each flooding season afresh, with the potential for renewal in time for each following wintering waterbird season. Such restoration can also contribute to economic improvements and ecosystem service provision to human livelihoods in the region, such a flood alleviation (Cao *et al.* 2018).

A major potential management issue is the thorny question of whether we should encourage Chinese-wintering waterbirds to feed on agricultural subsidies (such as waste grain, maize and rice) on farmland adjacent to wetlands as a way of extending the carrying capacity of the winter grounds for these birds. We would encourage that the implementation of all possible measures to restore the more natural carrying capacity of Yangtze River floodplain wetlands (and those elsewhere in China) are initiated first, before resorting to such artificial methods. There is no doubt that while goose populations around the rest of the Northern Hemisphere have benefitted from exploiting temperate farmland landscapes for food (in a way Chinese-wintering geese have failed to do) they have done so at a price. The conflicts caused by the explosion in goose numbers on farmland in North America and Europe (at a time when all other aspects of farmland biodiversity are generally crashing, *e.g.* Butler *et al.* 2007) are well described (see Fox & Madsen 2017 and references therein). The unusually intense levels of human activity and persecution of waterbirds on Chinese farmland seems to constitute the reason that geese cannot exploit farmland in their wintering sites and hence are confined to their deteriorating natural habitat. If this were to be case, creating areas free from human disturbance on farmland close to wetlands clearly offers an opportunity to conserve their numbers in the face of continued habitat loss and degradation. As we have seen, geese used farmland intensively at Chinese staging stopover sites, but hardly at all on their winter quarters (Si *et al.* 2020). All these findings suggest that reductions in human pressure on farmland close to wetlands might enable wintering geese in the Yangtze to benefit from feeding on energy-rich food items left in fields on farmland post-harvest, especially in areas already subject to low levels of human activity. However, this would also increase the extent of interactions between domestic ducks feeding in areas close to nature reserves and wild migratory waterbirds, which already creates potential for transmission of parasites and disease between the two (*e.g.* Prosser *et al.* 2015). For these powerful reasons, we remain hesitant to recommend this as a first line of attack to enhance population sizes, because of letting the "genie out of the bottle" and creating conflict from burgeoning goose populations in the future that are already evident elsewhere in the Northern Hemisphere (Fox *et al.* 2017). We do, nevertheless, acknowledge, that for species like the Lesser White-fronted Goose, that has physically lost suitable habitat due to changed aquaculture management at Dongting Lake and which seems to have taken to feeding on provisioned grain in Japan (Ao *et al.* 2020b), this may offer a stop-gap solution. If no other means of reinstating natural habitat can be found, providing artificial food may be a legitimate short-term means of contributing to ensuring the survival of this small and rapidly declining population in the first instance, especially if limited in time and space. The Lesser White-fronted Goose is not alone in this instance; Hou *et al.* (2020) showed loss of Tape Grass tubers at Poyang Lake caused Siberian Cranes *Leucogeranus leucogeranus* to abandon traditional wetland habitats to resort to farmland, especially during a major loss of tubers in 2015/16. Those authors also suggested that "agricultural fields can be important refuges for Siberian Cranes, mitigating the negative impacts of wetland deterioration". Artificial feeding of wintering cranes in Japan is long-established and widespread, a practice which is also exploited by many other species of migratory waterbirds there (*e.g.* Masatomi & Masatomi 2018). In South Korea, the tiny group of Swan Geese which winters on the Seocheon River estuary fed on the overwintering tubers of intertidal Alkali Bulrush *Bolboschoenus* sp., which formed the main dietary item throughout the entire winter period, but the species also increasingly resorted to rice paddies from November onwards, suggesting depletion of natural food resources and/or a change in dietary requirements that was fulfilled by the shift to agricultural land (Choi *et al.* 2017). We therefore need to be mindful of the opportunities as well as the hazards of artificial feeding, provision of sacrificial crops and establishing disturbance-free areas on farmland in close proximity to wetlands, as contributions to our strategies to protect these populations for future generations, whilst not resorting to them in the first instance before attempting to improve natural habitats.

While there are particular problems associated with waterbirds on their wintering ground within China, we should not lose sight of problems to be solved elsewhere along the flyways. In many of the population accounts presented in this special issue, we analysed the levels of site protection among the places visited by our telemetry tagged birds throughout their annual cycle. Although it is difficult to set hard and fast thresholds for what constitutes acceptable levels of site protection for a given population, there was little doubt that for all species there was room for improvement. For Whooper Swans, for instance, tagged birds almost never used spring staging areas that enjoyed any level of site protection whereas during winter (35%) and summer (47%) greater proportions of sites used by tagged individuals were protected (Ao *et al.* 2020a). Clearly there is much to be done to undertake similar, more detailed analyses for these and other species, to assess how well the currently designated network of protected areas contribute to the specific protection of population flyways, simply by analysing the degrees to which tagged birds were using sites with some level of protection. Ground surveys of staging birds on spring and autumn passage should be targeted at areas which appeared especially important which are currently unprotected, with a view to assessing numbers and distribution of staging birds to determine their relative importance and qualification for site designation, and to assess the key food items, sources of food and habitat requirements in the vicinity (*e.g.* safe-drinking and night-roosting areas) that contribute the integrity and functional importance of the site should it qualify for protection.

Where next?

Despite the many leaps forward presented in this special issue, there have been many issues that we have not touched upon. For instance, infrastructure development (including wind turbines, cables, towers and masts) built across waterbird flyways can also be a threat, but at least now that we are more aware of the migration corridors of these large-bodied and vulnerable species, we are better able to identify potential conflict areas and provide suitable advice. Over-harvesting and persecution remain serious threats, particularly at key migration locations; this requires international coordination to identify, quantify and find legal and enforcement solutions. Climate change is clearly already affecting many avian species, including those described here, but the patterns we have established in time and space will serve as a baseline for future studies. Climate change is expected to exacerbate all these pressures, and may also increase competition between migratory and non-migratory species and between those who perhaps have never before been sympatric but which now are so because of climate-induced range changes. Waterbird conservation requires a multitude of complementary approaches to be truly successful. Such long-distance migrants require cohesive networks of protected areas, but in order for these to be successful, they need targeted effective management at these sites. Important Bird Areas (IBAs) provide an important foundation for such action; however, to function effectively in conserving migratory species, IBAs need to be protected and the coherence of the network requires regular review, both for site integrity and function but also to optimise management for the birds that use them. Because so many of the species we have dealt with here are distributed across truly vast expanses of tundra, taiga and steppe biomes often at very low breeding or summering densities, we also need to be mindful of how to address human-induced changes at the wider landscape scale, even if this constitutes a particularly difficult set of challenges. However, again, the data presented here are among the very first to establish spatially explicit migration routes and occupancy of breeding ranges for all the species considered, so at least we cannot hide from the knowledge of where these challenges may occur.

With this point in mind, it is of course self-evident that efforts to conserve migratory birds at one stage of their annual cycle are potentially rendered totally useless if other pressures or threats are reducing these species' populations, and the extent and quality of their habitats, at other times of the year. We have to work together and coordinate actions if we are to be at all effective. International collaboration and coordinated action along migration flyways as a whole are thus key elements in any strategy for the conservation of migratory birds. The flyway approach is the only way forward in the first instance, and we have now embarked upon this to greater or lesser extents for all the species described here. The next priority is to identify the particular issues encountered by populations in unfavourable conservation status and tackle the problems faced by each, identifying the causes of declines and establishing where we can have maximum effect through targeted management interventions along the flyway. This requires coordination and joined-up thinking, international consultation and coordination through organisations such as the East-Asian Australasian Flyway Partnership. The accounts presented in this special issue already represent a massive development of collaboration between the parties of the flyways and the long lists of co-authors and their affiliations bear witness to the huge leaps in coordination and cooperation achieved to date. Although the analyses have inevitably concentrated upon problems faced by waterbirds on the wintering grounds, especially in China, there are a new set of challenges to be met in the immediate future at other stages of the annual cycle, which we also need to tackle collaboratively. We must not fail those who come after us by protecting what we still have right now, but in the face of ever-increasing pressures on these unique birds, it is evermore urgent that we safeguard these waterfowl populations for future generations.

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References

Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA). 2005. *Proposal for Guidance on the Definition of Biogeographical Populations of Waterbirds*. AEWA, Bonn, Germany. Available at https://www.unep-aewa.org/sites/default/files/document/mop3_12_guidance_biographical_population_waterbird_0.pdf (last accessed 22 July 2020).

Aharon-Rotman, Y., McEvoy, J., Zheng, Z., Yu, H., Wang, X., Si, Y., Xu, Z., Zeng, Y., Jeong, W., Cao, L. & Fox, A.D. 2017. Water level affects availability of optimal feeding habitats or threatened migratory waterbirds. *Ecology and Evolution* 7: 10440–10450.

Amano, T. 2009. Conserving bird species in Japanese farmland: past achievements and future challenges. *Biological Conservation* 142: 1913–1921.

Ao, P., Wang, X., Meng, F., Batbayar, N., Moriguchi, S., Shimada, T., Koyama, K., Park, J.-Y., Kim, H., Ma, M., Sun, Y., Wu, J., Zhao, Y., Wang, W., Zhang, L., Wang, X., Natsagdorj, T., Davaasuren, B., Damba, I., Rees, E.C., Cao, L. & Fox, A.D. 2020a. Migration routes and conservation status of the Whooper Swan *Cygnus cygnus* in East Asia. *Wildfowl* (Special Issue No. 6): 43–72.

Ao, P., Wang, X., Solovyeva, D., Meng, F., Ikeuchi, T., Shimada, T., Park, J., Gao, D., Liu, G., Hu, B., Natsagdorj, T., Zheng, B., Vartanyan, S., Davaasuren, B., Zhang, J., Cao, L. & Fox, A.D. 2020b. Rapid decline of the geographically restricted and globally threatened Eastern Palearctic Lesser White-fronted Goose *Anser erythropus*. *Wildfowl* (Special Issue No. 6): 206–243.

Atkinson-Willes, G.L. 1976. The numerical distribution of ducks, swans and coots as a guide in assessing the importance of wetlands in midwinter. *In* M. Smart (ed.), *Proceedings of the International Conference on the Conservation of Wetlands and Waterfowl, Heiligenhafen, Federal Republic of Germany, 2–6 December 1974*, pp. 199–254. International Waterfowl Research Bureau, Slimbridge, UK.

Butler, S.J., Vickery, J.A. & Norris, K. 2007. Farmland biodiversity and the footprint of agriculture. *Science* 315: 381–384.

Cao, L. & Fox, A.D. 2009. Birds and people both need China's wetlands. *Nature* 460: 173.

Cao, L., Wang, X. & Fox, A.D. 2018. Sponge wetlands: restoring functional flood relief to China's great rivers. *Wetland Ecology and Management* 26: 729–731.

Choi, Y.S., Joo, S., Kim, M.S., Han, D. & Jeong, G. 2017. Habitat use and food materials of the endangered Swan Goose (*Anser cygnoides*) during the wintering season. *Korean Journal of Ecology and Environment* 50: 266–274.

Cong, P., Wang, X., Cao, L. & Fox, A.D. 2012. Within-winter shifts in Lesser White-fronted Goose *Anser erythropus* distribution at East Dongting Lake, China. *Ardea* 100: 5–11.

Damba, I., Fang, L., Yi, K., Zhang, J., Batbayar, N., You, J., Moon, O.-K., Jin, S.-D., Liu, B.F., Liu, G., Xu, W., Hu, B., Liu, S., Park, J. Kim, H., Koyama, K., Natsagdorj, T., Davaasuren, B., Lee, H., Goroshko, O., Zhu, Q., Ge, L., Cao, L. & Fox, A.D. 2020. Flyway structure, breeding, migration and wintering distributions of the globally threatened Swan Goose *Anser cygnoides* in East Asia. *Wildfowl* (Special Issue No. 6): 97–123.

Davidson, N., Bryant, D. & Boere, G. 1999. Conservation uses of ringing data: flyway networks for waterbirds. *Ringing & Migration* 19: 83–94.

Delany, S., Scott, D., Dodman, T. & Stroud, D. 2009. *An Atlas of Wader Populations in Africa and Western Eurasia*. Wetlands International, Wageningen, the Netherlands.

Deng, X., Zhao, Q., Solovyeva, D., Lee, H., Bysykatova-Harmey, I., Xu, Z., Ushiyama, K., Shimada, T., Koyama, K., Park, J., Kim, H., Liu, G., Xu, W., Hu, B., Gao, D., Zhang, Y., He, B., Natsagdorj, T., Davaasuren, B., Moriguchi, S., Barykina, D., Antonov, A., Stepanov, A., Zhang, J., Cao, L., & Fox, A.D. 2020. Contrasting trends in two East Asian populations of the Greater White-fronted Goose *Anser albifrons*. *Wildfowl* (Special Issue No. 6: 181–205.

Fang, J., Wang, Z., Zhao, S., Li, Y., Tang, Z., Yu, D., Ni, L., Liu, H., Xie, P., Da, L., Li, Z. & Zheng, C. 2006. Biodiversity changes in the lakes of the Central Yangtze. *Frontiers of Ecology and Environment* 4: 369–377.

Fang, J., Rao, S. & Zhao, S. 2005. Human-induced long-term changes in the lakes of the Jianghan Plain, Central Yangtze. *Frontiers of Ecology and Environment* 3: 186–192.

Fang, L., Zhang, J., Zhao, Q., Solovyeva, D., Vangeluwe, D., Rozenfeld, S.B., Lameris, T., Xu, Z., Bysykatova-Harmey, I., Batbayar, N., KoNishi, K., Moon, O.-K., He, B., Koyama, K., Moriguchi, S., Shimada, T., Park, J.-Y., Kim, H., Liu, G., Hu, B., Gao, D., Ruan, L.D., Natsagdorj, T., Davaasuren, B., Antonov, A., Mylnikova, A., Stepanov, A., Kirtaev, G., Zamyatin, D., Kazantzidis, S., Sekijima, T., Damba, I., Lee, H., Zhang, B., Xie, Y., Rees, E.C., Cao, L. & Fox, A.D. 2020. Two distinctive flyways with different population trends of Bewick's Swan *Cygnus columbianus bewickii* in East Asia. *Wildfowl* (Special Issue No. 6): 13–42.

Feng, L., Hou, X. & Zheng, Y. 2019. Monitoring and understanding the water transparency changes of fifty large lakes on the Yangtze Plain based on long-term MODIS observations. *Remote Sensing of Environment* 221: 675–686.

Fox, A.D. & Leafloor, J.O. (eds.) 2018. *A Global Audit of the Status and Trends of Arctic and*

Northern Hemisphere Goose Populations (Component 2: Population accounts). Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland.

Fox, A.D. & Madsen, J. 2017. Threatened species to super-abundance: The unexpected international implications of successful goose conservation. *Ambio* 46 (Supplement 2): 179–187.

Fox, A.D., Cao, L., Zhang, Y., Barter, M., Zhao, M., Meng, F. & Wang, S. 2011. Declines in the tuber-feeding waterbird guild at Shengjin Lake National Nature Reserve, China – a barometer of submerged macrophyte collapse? *Aquatic Conservation: Marine and Freshwater Ecosystems* 21: 82–91.

Fox, A.D., Meng, F., Shen, X., Yang, X. Yang, W. & Cao, L. 2013. Effects of shading on *Vallisneria natans* (Lour.) H. Hara growth. *Knowledge and Management of Aquatic Systems* 410: 07.

Fox, A.D., Elmberg, J., Tombre, I. & Hessel, R. 2017. Agriculture and herbivorous waterfowl: a review of the scientific basis for improved management. *Biological Reviews* 92: 854–877.

Fujioka, M., Lee, S.D., Kurechi, M. & Yoshida, H. 2010. Bird use of rice fields in Korea and Japan. *Waterbirds* 33: 8–29.

Gao, B., Gong, P., Zhang, W., Yang, J. & Si, Y. 2020. Multiscale effects of habitat and surrounding matrices on waterbird diversity in the Yangtze River Floodplain. *Landscape Ecology* doi:10.1007/s10980-020-01131-4.

Guan, L., Wen, L., Feng, D., Zhang, H., & Lei, G. 2014. Delayed flood recession in central Yangtze floodplains can cause significant food shortages for wintering geese: results of inundation experiment. *Environmental Management* 54: 1331–1341.

Guan, L., Lei, J., Zuo, A., Zhang, H., Lei, G. & Wen, L. 2016. Optimizing the timing of water level recession for conservation of wintering geese in Dongting Lake, China. *Ecological Engineering* 88: 90–98.

Hong, Y., Luo, Y. & Wang, Z. 2018. Analysis on the current situation of water quality of Longgan Lake and Huangda Lake during low-water period in Susong County of Anhui Province. *Journal of Anhui Agricultural Sciences* 46: 75–79.

Hou, J., Liu, Y., Fraser, J.D., Li, L., Zhao, B., Lan, Z., Jin, J., Liu, G., Dai, N. & Wang, W., 2020. Drivers of a habitat shift by critically endangered Siberian cranes: evidence from long term data. *Ecology and Evolution online early* doi: 10.1002/ece3.6720.

Jia, Q., Yesou, H., Hiber, C., Cao, L. & Fox, A.D. 2017. Combating aggressive macrophyte encroachment on a typical Yangtze River lake: lessons from a long-term remote sensing study of vegetation. *Aquatic Ecology* 51: 177–189.

Jia, Q., Wang, X., Zhang, Y., Cao, L. & Fox, A.D. 2018. Drivers of waterbird communities and their declines on Yangtze River floodplain lakes. *Biological Conservation* 218: 240–246.

Jiao, L. 2009. Scientists line up against dam that would alter protected wetlands. *Science* 326: 508–509.

Jing, L., Lu, C., Xia, Y., Shi, L., Zuo, A., Lei, J., Zhang, H., Lei, G. & Wen, L. 2017. Effects of hydrological regime on development of *Carex* wet meadows in East Dongting Lake, a Ramsar Wetland for wintering waterbirds. *Scientific Reports* 7: 41761.

Johnson, F.A., Alhainen, M., Fox, A.D., Madsen, J. & Guillemain, M. 2018. Making do with less: must sparse data preclude informed harvest strategies for European waterbirds? *Ecological Applications* 28: 427–441.

Kim, M.K., Sang, I.L. & Lee, S.D. 2016. Habitat use and its implications for the conservation of the overwintering populations of Bean

Goose *Anser fabalis* and Greater White-fronted Goose *A. albifrons* in South Korea. *Ornithological Science* 15: 141–149.

Lee, C.W., Kim, G.Y., Jang, J.D. & Joo, G.J., 2006. Evaluation of Winter Barley Fields as Feeding Habitat for Waterfowl in the Dongup Reservoir System, Korea. *Journal of Ecology and Environment* 29: 165–169.

Lei, J.L., Jia, Y.F., Zuo, A.J., Zeng, Q., Shi, L.L., Zhou, Y., Zhang, H., Lu, C., Lei, G.C. & Wen, L. 2019. Bird satellite tracking revealed critical protection gaps in East Asian-Australasian Flyway. *International Journal of Environmental Research and Public Health* 16: 1147.

Li, C., Zhou, L., Xu, L., Zhao, N. & Beauchamp, G. 2015. Vigilance and activity time-budget adjustments of wintering hooded cranes, *Grus monacha*, in human-dominated foraging habitats. *PLoS One* 10: 0118928.

Li, C., Zhao, Q., Solovyeva, D., Lameris, T., Batbayar, N., Bysykatova-Harmey, I., Lee, H., Emelyanov, V., Rozenfeld, S.B., Park, J., Shimada, T., Koyama, K., Moriguchi, S., Hou, J., Natsagdorj, T., Kim, H., Davaasuren, B., Damba, I., Liu, G., Hu, B., Xu, W., Gao, D., Goroshko, O., Antonov, A., Prokopenko, O., Tsend, O., Stepanov, A., Savchenko, A., Danilov, G., Germogenov, N., Zhang, J., Deng, X., Cao, L. & Fox, A.D. 2020. Population trends and migration routes of the East Asian Bean Goose *Anser fabalis middendorffi* and *A. f. serrirostris*. *Wildfowl* (Special Issue No. 6): 124–156.

Lincoln, F.C. 1935. The waterfowl flyways of North America. *United States Department of Agriculture Circular* 342: 1–11.

Madsen, J., Cracknell, G. & Fox, A.D. (eds.) 1999. *Goose Populations of the Western Palearctic: a Review of Status and Distribution*. Wetlands International Publication No. 48. National Environmental Research Institute, Rønde, Denmark.

Marjakangas, A., Alhainen, M., Fox, A.D., Heinicke, T., Madsen, J., Nilsson, L. & Rozenfeld, S. (Compilers) 2015. International Single Species Action Plan for the Conservation of the Taiga Bean Goose *Anser fabalis fabalis*. AEWA Technical Series No. 56. AEWA, Bonn, Germany.

Masatomi, H. & Masatomi Y. 2018. Ecology of the Red-crowned Crane and conservation activities in Japan. *In* F. Nakamura (ed.), *Biodiversity Conservation Using Umbrella Species,* pp. 83–105. Ecological Research Monographs, Springer, Singapore.

Meng, F., Li, H., Wang, X., Fang, L., Li, X, Cao, L. & Fox, A.D. 2019. Size matters: wintering ducks stay longer and use fewer habitats on largest Chinese lakes. *Avian Research* 10: 27.

Meng, F., Chen, L. Fang, L., Zhang, B., Li, C., Zhao, G., Batbayar, N., Natsagorj, T., Damba, I., Liu, S., Woods, K.A., Cao, L. & Fox, A.D 2020. The migratory Mute Swan *Cygnus olor* population in East Asia. *Wildfowl* (Special Issue No. 6): 73–96.

Prosser, D.J., Palm, E.C., Takekawa, J.Y., Zhao, D., Xiao, X., Li, P., Liu, Y. & Newman, S.H. 2015. Movement analysis of free-grazing domestic ducks in Poyang Lake, China: a disease connection. *International Journal of Geographical Information Science* 30: 869–880.

Ramsar Secretariat 2014. *The Ramsar Sites Criteria: The nine criteria for identifying Wetlands of International Importance for identifying Wetlands of International Importance.* Ramsar Secretariat, Gland, Switzerland. Accessible at: https://www.ramsar.org/document/the-ramsar-sites-criteria (last accessed: 22 July 2020).

Robertson, G.J. & Cooke, F. 1999. Winter philopatry in migratory waterfowl. *Auk* 116: 20–34.

Rozenfeld, S., Volkov, S., Rogova, N., Soloviev, M.Y., Kirtaev, G., Zamyatin, D. & Vangeluwe, D. 2019. The Bewick's Swan (*Cygnus bewickii*):

an expansion of Asian populations to the west, does it exist? *Zoologichesky Zhurnal* 98: 302–313.

Sawa, Y., Tamura, C., Ikeuchi, T., Fujii, K., Ishioroshi, A., Shimada, T., Tatsuzawa, S., Deng, X., Cao, L., Kim, H. & Ward, D. 2020. Migration routes and population status of the Brent Goose *Branta bernicla nigricans* wintering in East Asia. *Wildfowl* (Special Issue No. 6): 244–266.

Scott, D.A. & Rose, P.M. 1996. *Atlas of Anatidae Populations in Africa and Western Eurasia*. Wetlands International Publication No. 41. Wetlands International, Wageningen, the Netherlands.

Si, Y., Wei, J., Wu, W., Zhang, W., Hou, L., Yu, L. & Wielstra, B. 2020. Reducing human pressure on farmland could rescue China's declining wintering geese. *Movement Ecology* 8: 35.

Syroechkovskiy, E.E. 2006. Long term declines in Arctic goose populations in eastern Asia. *In* G.C. Boere, C.A. Galbraith & D.A. Stroud (eds.), *Waterbirds Around the World,* pp. 649–662. The Stationery Office, Edinburgh, UK.

Vangeluwe, D., Rozenfeld, S.B., Volkov, S.V., Kazantzidis, S., Morosov, V.V., Zamyatin, D.O. & Kirtaev, G.V. 2018. Migrations of Bewick's Swan (*Cygnus bewickii*): new data on tagging the migration routes, stopovers, and wintering sites. *Biology Bulletin* 45: 706–717.

Wang, X., Fox, A.D., Cong, P., Barter, M. & Cao, L. 2012. Changing distribution and abundance of Lesser White-fronted Geese *Anser erythropus* in eastern China. *Bird Conservation International* 22: 128–134.

Wang X., Fox, A.D., Cong P. & Cao L. 2013. Food constraints explain the restricted distribution of wintering Lesser White-fronted Geese *Anser erythropus* in China. *Ibis* 155: 576–592.

Warren, S.M., Walsh, A.J., Merne, O.J., Wilson, H.J. & Fox, A.D. 1992. Wintering site interchange amongst Greenland White-fronted Geese *Anser albifrons flavirostris* captured at Wexford Slobs, Ireland. *Bird Study* 39: 186–194.

Wetlands International 2020. *Waterbird Population Estimates*. Wetlands International, Ede, the Netherlands. Accessible at wpe.wetlands.org (last accessed 22 July 2020).

Wilson, H.J., Norriss, D.W., Walsh, A., Fox, A.D. & Stroud, D.A. 1991. Winter site fidelity in Greenland White-fronted Geese *Anser albifrons flavirostris*: implications for conservation and management. *Ardea* 79: 287–294.

Xia, S., Wang, Y., Lei, G., Liu, Y., Lei, J., Wen, L. & Zhou, Y. 2017. Restriction of herbivorous waterbird distributions in the middle and lower Yangtze River floodplain in view of hydrological isolation. *Wetlands* 37: 79–88.

Xu, W., Fan, X., Ma, J., Pimm, S.L., Kong, L., Zeng, Y., Li, X., Xiao, Y., Zheng, H., *et al.* 2019. Hidden Loss of Wetlands in China. *Current Biology* 29: 3065–3071.

Yan, M., Yi, K., Zhang, J., Batbayar, N., Xu, Z., Liu, G., Hu, B., Zheng, B., Antonov, A., Goroshko, O., Zhao, G., Davaasuren, B., Erdenechimeg, T., Nergui, J., Damba, I., Cao, L. & Fox, A.D. 2020. Flyway connectivity and population status of the Greylag Goose *Anser anser* in East Asia. *Wildfowl* (Special Issue No. 6): 157–180.

Yang, J., Du, D., Tian, S., Dong, W., Yang, X. & Min, S. 2017. Biodiversity evaluation of typical lakes and wetlands in Hubei province. *Journal of Hydroecology* 38: 15–22.

Yu, H., Wang X., Cao, L., Zhang L., Jia Q., Lee, H., Xu, Z., Liu, G., Xu, W. Hu, B. & Fox, A.D. 2017. Are declining populations of wild geese in China "prisoners" of their natural habitats? *Current Biology* 27: R376–R377.

Zhang, B., Wang, X., Meng, F., Kharitonov, S., Hu, B., Gao, D., Liu, G., Zhang, Y., Antonov, A., Batmunkh, D., Goroshko, O., Mundkur, T., Cao, L. & Fox, A.D. 2020. Contrasting changes in abundance of Falcated Duck *Mareca falcata* wintering in the Yangtze River floodplain and on the eastern coast of China. *Wildfowl* (Special Issue No. 6): 267–292.

Zhang, C., Yuan, Y., Zeng, G., Liang, J., Guo, S., Huang, L., Hua, S., Wu, H., Zhu, Y., An, H., & Zhang, L. 2016. Influence of hydrological regime and climatic factor on waterbird abundance in Dongting Lake Wetland, China: Implications for biological conservation. *Ecological Engineering* 90: 473–481.

Zhang, Q., Ye, X., Werner, A.D., Li, Y., Yao, J., Li, X., & Xu, C. 2014. An investigation of enhanced recessions in Poyang Lake: Comparison of Yangtze River and local catchment impacts. *Journal of Hydrology* 517: 425–434.

Zhang, Y., Fox, A.D., Cao, L., Jia, Q., Lu, C., Prins, H.H.T. & de Boer, W.F. 2019. Effects of ecological and anthropogenic factors on waterbird abundance at a Ramsar site in the Yangtze River floodplain. *Ambio* 48: 293–303.

Zhao, M., Cao, L. & Fox, A.D. 2010. Distribution and diet of wintering Bean Geese *Anser fabalis serrirostris* at Shengjin Lake, Yangtze floodplain, China. *Wildfowl* 60: 52–63.

Zhao, M., Cong, P., Barter, M., Fox, A.D. & Cao, L. 2012. The changing abundance and distribution of Greater White-fronted Geese *Anser albifrons* in the Yangtze River floodplain: impacts of recent hydrological changes. *Bird Conservation International* 22: 135–143.

Zhao, Q., Cao, L., Wang, X. & Fox, A.D. 2018. Why Chinese wintering geese hesitate to exploit farmland. *Ibis* 160: 703–705.

Zhou, B., Zhou, L., Chen, J., Xu, W. & Cheng, Y. 2009. Assemblage dynamics and territorial behaviour of hooded crane in winter at Shengjin Lake. *Chinese Journal of Wildlife* 30: 133–136.

Zhu, Q., Hobson, K.A., Zhao, Q., Zhou, Y., Damba, I., Batbayar, N., Natsagdorj, T., Batmunkh, D., Antonov, A., Guan, J., Wang, X., Fang, L., Cao, L. & Fox, A.D. 2020. Migratory connectivity of Swan Geese based on species' distribution models, feather stable isotope assignment and satellite tracking. *Diversity and Distributions* 26: 944–957.

Zou, Y., Tang, Y., Xie, Y., Zhao, Q. & Zhang, H. 2017. Response of herbivorous geese to wintering habitat changes: conservation insights from long-term population monitoring in the East Dongting Lake, China. *Regional Environmental Change* 17: 879–888.

Zou, Y., Zhang, P., Zhang, S., Chen, X., Li, F., Deng, Z., Yang, S., Zhang, H., Li, F. & Xie, Y. 2019. Crucial sites and environmental variables for wintering migratory waterbird population distributions in the natural wetlands in East Dongting Lake, China. *Science of the Total Environment* 655: 147–157.

