Flyway connectivity and population status of the Greylag Goose *Anser anser* in East Asia

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Abstract

European populations of the Greylag Goose *Anser anser* have been studied for over 50 years, but those in the East Asian flyway are less well known. Here we describe the breeding and wintering distribution of Greylag Geese wintering in China, based on historical and newly-reported telemetry data (from 31 individuals contributing complete migrations), wintering waterbird surveys and expert knowledge. Historical records, and also the data presented here, indicate that Greylag Geese breeding in the north of the Xinjiang Uygur Autonomous Region, China, and in Mongolia east of 93°E, through Inner Mongolia to western parts of Heilongjiang Province, China, likely almost all winter east of 107°E in China (97% in the Yangtze River floodplain and 3% in the Yellow River floodplain). Annual mid-winter waterbird counts confirm that very few Greylag Geese winter in Japan and South Korea. Count data suggest that the Far East Asia Greylag population wintering in China

currently numbers 30,000 individuals, a major increase compared to 3,263 counted in 2005. Historical records however indicate that the wintering distribution was far greater 30 years ago, and that Greylag Geese are now less common than previously in Guangdong, Guizhou, Hainan, Henan, Hunan, Anhui and Jiangsu Provinces, as the species has become more concentrated further north in the Yangtze and Yellow River floodplains. On the basis of count data from winters 2010/11–2019/20, we identified 21 current key wintering sites (holding ≥ 1% of the flyway population, *i.e.* 300 birds) in the Yangtze River floodplain and one in the Yellow River floodplain for this population. Increasing use of farmland in winter, as well as site protection and sympathetic local management of wintering sites, may have contributed to recent increases in Greylag Goose abundance in the flyway. These results provide a more robust basis for assessing the current status of the Far East Asia Greylag Goose population and a guide to priorities for further internationally coordinated research of the species. The need to improve monitoring and habitat management for maintaining the increasing numbers wintering in China is also emphasised.

Key words: distribution range, Far East Asia, flyway connectivity, Greylag Goose, key wintering sites, population status.

The Greylag Goose *Anser anser* is listed as Least Threatened by IUCN and shows favourable conservation status throughout much of the European part of its range, numbering 1,000,000–1,100,000 individuals globally (Fox & Leafloor 2018). The species has been divided into two subspecies. The Western Greylag Goose *A. a. anser* summers in Iceland, and in northern and central Europe and winters from Scotland south to northern Africa and east to Iran. The Eastern Greylag Goose *A. a. rubrirostris*, which summers from Romania, Turkey and eastern Russia to northeast China, winters from Asia Minor to eastern China (BirdLife International and Handbook of the Birds of the World 2019). Eight populations of naturally-occurring Greylag Geese have been described: the Iceland/UK & Ireland, British (NW Scotland), Northwest/Southwest European, Central Europe, Black Sea/Turkey, West Siberia-Caspian/Iraq, South Asian and Far East Asia populations (Fox & Leafloor 2018; Wetlands International 2020). Long-term count data show that numbers wintering in Europe are generally increasing, while those wintering in the Caspian and in Iraq are in decline (Fox & Leafloor 2018). Trends in abundance among the populations wintering in the Black Sea, Central Asia and East Asia are currently unclear. Despite recent research on Far East Asian Greylag Goose feeding habits, habitat utilisation, breeding ecology, and avian influenza (Melville & Shortridge 2006; Zhou *et al.* 2017; Meng *et al.* 2018), we still lack any detailed knowledge about their flyway structure, population status, abundance and distribution. This is despite the importance of such information for the

effective protection of this population which, until recently, was thought to be small and declining. For this reason, we here attempt to compile such information from recently completed surveys and from new research on the species in its East Asian breeding and wintering areas.

Greylag Geese generally exploit natural and artificial habitats of relatively high productivity, so may exploit farmland, wetlands with open water, lakes and coastal lagoons (BirdLife International and Handbook of the Birds of the World 2019). Previous accounts report Greylag Geese breeding in eastern Russia and throughout Mongolia, as well as being a summer visitor and breeding species in China: in the Xinjiang Uygar Autonomous Province, the Qaidam Basin and Qinghai Lake (Qinghai Province) and in the Qiqihar and Harbin areas of Heilongjiang Province (Cheng 1987; Fox & Leafloor 2018; Sundev & Leahy 2019). Further east, Greylag Geese used to breed and summer along the eastern parts of the Amur River, Russia, but numbers there have been decreasing since the 1950s, and since the 1980s very few have been reported from this area (Babenko & Poyarkov 1998; Antonov 2000). Although not confirmed by ringing recovery data or telemetry, it was suspected that Greylag Geese from these breeding areas overwintered in China, east of 107°E, potentially with the most eastern breeders wintering in Korea and Japan. In China, winter aggregations of Greylag Geese were known from the Caohai National Nature Reserve in Guizhou Province; Heigangkou, Nanwan Reservoir, Suyahu Reservoir and Shishankou Reservoir in Henan Province; East Dongting Lake in Hunan Province; the Yancheng Wetland National Nature Reserve and Gaobao Lake in Jiangsu Province; the Anqing Wetland Reserve along the Yangtze River in Anhui Province; Lufeng Beach in Guangdong Province; and from the Dongzhaigang National Nature Reserve and Bamen Bay Mangrove in Hainan Province (Perennou *et al.* 1994; Waterbird Specialist Group of Chinese Ornithological Association 1994; Xing *et al.* 1998; Xing & Zhai 1998; Chang *et al.* 1999; Ba *et al.* 2003; Li *et al.* 2009). However, accounts suggest that the core of their winter distribution in China has always been centred on the Yangtze River floodplain, stretches of the Yellow River and in eastern coastal areas (Cao *et al.* 2010; Fox & Leafloor 2018).

Results from winter bird surveys in recent years indicate that the winter distribution of the Greylag Goose is contracting in China. There have been fewer reports of Greylag Geese wintering in Guizhou, Hainan and Guangdong Provinces, and elsewhere in China away from the Yangtze, in the last 20 years. This has been linked to the species being reported as wintering in the middle and lower reaches of the Yangtze River floodplain and the middle reaches of the Yellow River, in Hubei (Hu *et al.* 2005), Anhui (Wang *et al.* 2015; Song & Zhou 2019), Henan (Ma *et al.* 2008; Wang 2016; Li *et al.* 2019a) and Jiangxi (Zhang *et al.* 2011) Provinces.

Previous telemetry studies of 12 Greylag Geese wintering at Poyang Lake in Jiangxi Province and at East Dongting Lake in Hunan Province found that these individuals summered in the Mongolian steppe region

at Daguur and Ulgai Lake (Lei *et al.* 2019). A similar study tracked eight Chinese-wintering Greylag Geese from the Yangtze River floodplain to their summering areas in the Wulagai Gaobi wetlands and the Huihe National Nature Reserve in Inner Mongolia, China, and to Buir Lake in Mongolia, with a further eight geese tagged at their breeding sites in the Mongolian steppes migrating to the Yangtze River floodplain to winter (Li *et al.* 2019b). Some of these individuals provided tracking data for > 1 year. Results from four tagged birds have described movements in Inner Mongolia (Meng *et al.* 2018). Although these studies provided the first evidence of connectivity along the Far East Asian Greylag Goose flyway, sample sizes remain too limited to define fully the population flyway structure of the species in East Asia.

To attempt to fill gaps in our current knowledge, this study integrates telemetry data, wintering waterbirds surveys, and expert knowledge, to update information on the breeding and wintering distribution of Greylag Geese in Far East Asia, for identifying their biological flyways and population status. Our objective is to compile existing research on the flyway structure and waterbird census data for this species. The results should provide a basis for future international cooperation, for improving monitoring programmes, promoting the conservation of a network of critical sites along the entire migration route, and adopting coordinated conservation strategies and actions to enhance the conservation status of this Greylag Goose population for future generations.

Methods

Migration data from telemetry

We combined tracking data from Greylag Geese in East Asia with expert knowledge to define flyways in the region. Fifty-one flightless individuals were captured during their annual moult, using boats to surround the flocks and drive the geese from the lake into temporary funnel nets and from there into a corral on the shore. Geese were caught at several sites: at Uvs Lake (50°13'N, 93°8'E), Bayan Lake, Zuungobi (49°56'N, 93°55'E), Khar-Us Lake (47°49'N, 92°14'E) and Dorgon Lake (47°37'N, 93°24'E) in western Mongolia; at Bayan Lake, Dashinchilen (47°51'N, 104°18'E) in central Mongolia; and at Buir Lake (47°42'N, 117°35'E) in eastern Mongolia during the summers of 2017 and 2018 (see Supporting Materials Table S1 for full details). Additionally, on the wintering grounds, Greylag Geese were captured either from boats at night, using beams of powerful lamps to dazzle the birds which were then secured in hand nets, or by the geese flying into heavy-duty mist-nets (designed for catching large birds) set at their roosts. Fifteen Greylag Geese (including seven adults, sex unknown; three juveniles, sex unknown; and five birds of unknown age and sex) were captured in this way on the wintering grounds, including at Poyang Lake (29°0'N, 116°24'E) and the Anhui Lakes (30°53'N, 117°42'E) in the winters of 2014/15 and 2016/17 (see Supporting Materials Table S1). Among the 66 Greylag Geese caught, 51 tagged individuals provided data on at least one complete spring or autumn migration episode during 2014–

2018. Of these, 31 individuals (21 caught in summer, 10 in winter) overwintered in China, and 20 individuals wintered in southern Asia outside the area covered in this paper. For the purposes of this analysis, we define the Far East Asia Greylag Goose population as comprising only those individuals that wintered in China, Korea and Japan.

Captured geese were fitted with several types of neck collar solar-powered transmitters (Druid tech, China, 35 g or 45 g; Ornitela, Lithuania, 45 g; Hunan Global Messenger Technology Company [HQXS], China, 26 g), which recorded GPS positions and transmitted data via the GSM mobile telephone networks. The transmitters provided 48 ± 41 (mean ± s.d., range = 9–136) GPS positions per day, contingent upon power supply (Supporting Materials Table S1). Data from individuals with at least one complete spring or autumn migration were used to contribute to the identification of flyway connectivity. First-day movement data after the birds were captured and tracked, and last-day data before birds died or lost contact, were excluded from all analyses as being potentially atypical, associated with circumstances associated with capture and fitting the tags and the ultimate loss of the bird or its logger. Additional migration data for relevant studies were sought in Web of Science, by using the expression: (GPS OR Argos OR PTT OR CTT OR (satellite* AND (track* OR transmitter* OR telemetr*))) AND ("Greylag Goose" OR "Greylag Geese") in the search function. No other migration data were available for Greylag Geese in Far East Asia, however, except for the data generated by Li *et al.* (2019b) which were included in this study (birds gg001–gg007 and gg029–gg031).

Distribution and migration range

The core Greylag Goose distribution range was defined in ArcGIS 10.2, based on the maps compiled and published by BirdLife International and Handbook of the Birds of the World (2019). These had been updated with information gathered up until 2017, which we supplemented with more recent data to improve the distribution maps. The revised map incorporated data from Cao *et al.* (2010), compiled from counts recorded during winter surveys, and also information on the winter/summer distribution derived from the telemetry tracking data (see *Methods* and *Results* described below). We combined these sources of information with expert knowledge, including data from the recent scientific literature, observations reported on birding websites and ornithological record portals (*e.g.* ebird, birdreport), as well as from published survey reports of counts made of waterbirds wintering in East Asia.

In October 2019, the "*2nd International Symposium on Developing Effective Coordinated Monitoring of East Asian Waterbirds in the 21st Century*" was held in Beijing, China. During the symposium, a workshop of eight experts from six countries (see Supporting Materials Table S2) discussed and contributed to the delineation of the geographical migration range of the Far East Asia Greylag Goose population, as well as compiling and reviewing the information presented in this analysis.

Counts and trends of Greylag Goose in East Asia

Counts of Greylag Geese wintering in China during 1989/90–1991/1992 were obtained from the Waterbird Specialist Group of the Chinese Ornithological Association (1994; Supporting Materials Table S3), supplemented by results from wintering surveys and information in the grey literature. Our aim was to compile the maximum counts for each lake in each winter (from November–February), as an indication of the total numbers present at a given site in that year. In addition, supplementary information was derived from synchronised waterbird surveys undertaken by our group in the Yangtze River floodplain during mid-December to early February in 2003/04, 2004/05, 2015/16, 2017/18, 2018/19 and 2019/20, as well as coordinated Yellow River waterbird surveys undertaken in January 2019. Between these major surveys, the vast majority of locations supporting wintering Greylag Geese in China were thought to have been covered (Cao *et al.* 2010).

The Korean Ministry of Environment and its associated institutes – the National Institute of Environmental Research (until 2007) and the National Institute of Biological Resources (since 2008) – have conducted an annual nationwide census at most lakes, reservoirs and coastal sites known to be important for wintering waterbirds since 1999. The coordinated 2-day field counts, undertaken annually in mid- or late January by ornithologists, experienced birdwatchers and volunteers, provide estimates of the distribution and abundance of waterbirds wintering in the country.

In Japan, annual mid-winter (*c.* 15 January) surveys of waterfowl populations have been conducted since 1970 by the Ministry of the Environment with the assistance of prefectural governments. This nationwide survey covers all principal wintering sites for swan, goose and duck species throughout the country each year (Ministry of the Environment of the Government of Japan 2019).

Numbers of Greylag Geese wintering in China were estimated as the mean of the totals recorded during surveys undertaken in China in winters 2017/18, 2018/19 and 2019/20. Throughout the study period, numbers wintering in South Korea and Japan were too few to make a significant contribution to the overall annual totals (see *Results* below). We therefore consider that the numbers of Greylag Geese wintering in China effectively equated to the entire Far East Asia Greylag Goose population.

Key wintering sites of Greylag Goose in East Asia

For the purpose of this study, a key wintering site is defined as a site where numbers in any survey year were ≥ 1% of the latest population estimate for the Far East Asia population (in accordance with Ramsar Convention criteria for sites of international importance), based on abundance recorded over the last three winters (*i.e.* 2017/18–2019/20). For the Greylag Goose, this was taken to be ≥ 300 birds (see *Results* below).

We retrospectively assessed changes in abundance and distribution of Greylag Geese at key Chinese wintering sites over the past three decades by comparing annual

maximum counts at these sites from 1989/90 to 2019/20. In addition to the survey data described above, surveys of key sites (Poyang Lake, Dongting Lake, Hubei and Anhui Lakes) along the Yangtze River floodplain in winters 2007/08–2014/15 and 2016/17 were also included.

Results

Summering and wintering distribution range

Tracking data showed that Greylag Geese caught at Khar-Us Lake and Dorgon Lake in western Mongolia wintered in southern Asia, while those caught at Uvs Lake in western Mongolia divided to winter in different areas; specifically, of 29 geese tagged at Uvs Lake which provided full migration routes, 17 wintered in southern Asia and 12 in China (L. Cao, unpub. data). Overall, the tracking data indicated that Far Eastern Greylag Geese summered throughout Mongolia and the adjacent Dauria region in Russia, as well as in Inner Mongolia, western Heilongjiang Province and in the northern part of the Xinjiang Uygur Autonomous Region, China, an assessment confirmed by expert opinion. Telemetry also showed that these birds wintered mainly in the Yangtze River floodplain in China, but with a few occurring in the Yellow River floodplain. Elsewhere, the long-term annual waterbird surveys revealed up to 37 wintering Greylag Geese in Japan since 1970 and only one irregularly in South Korea since 1999, confirming that these two countries do not support significant numbers of Greylag Geese in this flyway (see Supporting Materials Table S4).

Expert opinion presented at the symposium, combined with information derived from the tagged geese, provided the basis for adjustments to the range previously defined for the Far East Asia Greylag Goose population. In comparison with the breeding range described by BirdLife International and Handbook of the Birds of the World (2019), it is considered that the breeding range should now be reduced to exclude the former breeding areas east of 124°E, which included the lower Amur River (Fig. 1). Experts advised that breeding areas in the eastern Amur River region have been largely empty of breeding Greylag Geese since the 1950s, and that the species is now extinct as a breeder in the main part of the former breeding range of the Far East Asia population in Siberia. However, new information also indicated that the summer distribution should be extended to include Inner Mongolia in China, where the species now breeds in modest numbers. In recent years, up to 50 pairs of Greylag Geese have become established in Zagastai, western Inner Mongolia, which confirms that the species has the potential to expand its breeding range when conditions are favourable. Furthermore, count data from the breeding areas suggest that the Greylag Goose enjoys favourable conservation status in many parts of the summer range, especially in eastern Mongolia and adjacent parts of Dauria in Russia. If numbers of Greylag Geese continue to increase in Dauria, the species may eventually recolonise formerly occupied breeding areas in eastern Heilongjiang, China and east of the Amur River in the future, provided that conservation measures designed to protect

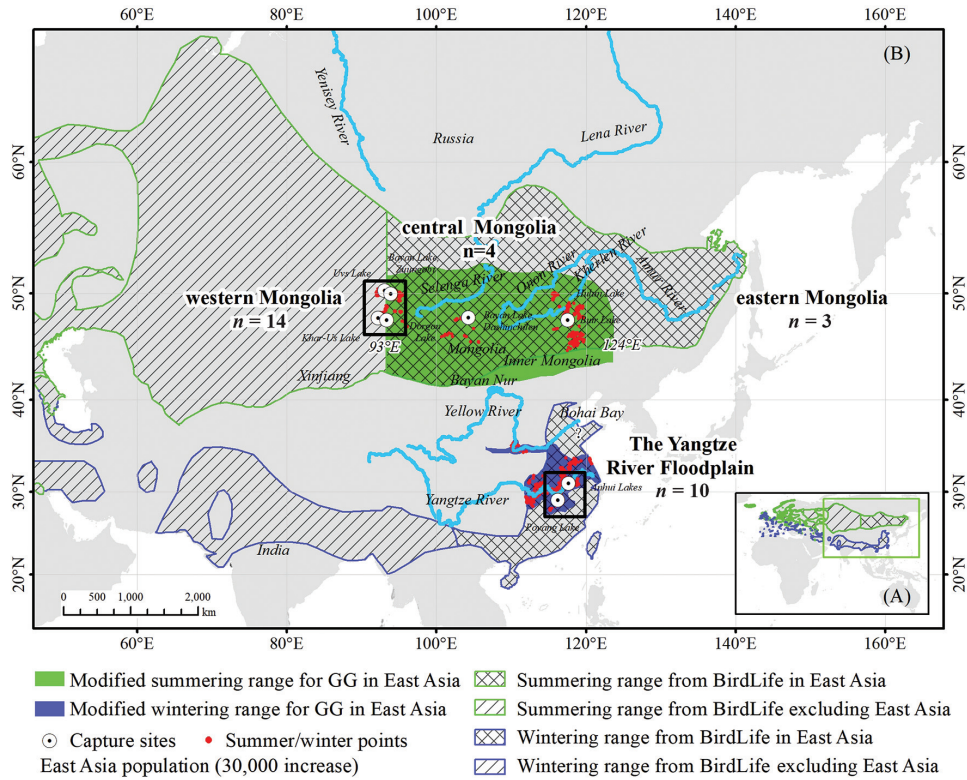

Figure 1. Revised distribution map of the Greylag Goose in Far East Asia, derived and modified from BirdLife International and Handbook of the Birds of the World (2019), based on new information presented here. Green shading = summering/breeding range (throughout Mongolia from 93°E, Dauria in Russia, Inner Mongolia, west of Heilongjiang Province and the northern part of the Xinjiang Uygur Autonomous Region in China). Blue shading = wintering range (mainly in the Yangtze River floodplain and the Yellow River floodplain, China). Global distribution of the Greylag Goose is shown as inset Fig. 1A, with the enlarged map illustrating the Greylag Goose distribution in East Asia given as Fig. 1B. Information for revising the summering range was based on tracking data (red dots = GPS points recorded for each individual between arrival in spring and departure in autumn, from 1 April–31 October) and expert knowledge. Revision of the wintering range was based on tracking data (red dots = GPS points recorded for each individual point between arrival in autumn and departure in spring, namely from 31 October–11 March), field surveys data (see *Methods* for details), expert knowledge and a literature survey. Sixty-six individuals were caught in three areas during summer (western, central and eastern Mongolia) and at one site in winter (the Yangtze River floodplain, China). White circles with black dots = capture sites; *n* = number of Greylag Geese from each capture area that completed at least one spring or autumn migration (total = 31 individuals), see Supporting Materials Table S1 for full details. We defined the western boundary of East Asia as 93°E in summer and 107°E in winter. All the major site/area names mentioned in the text are labelled on the map.

Greylag Geese there can be implemented. The distribution of the tracked birds, combined with expert opinion also resulted in realigning the northern boundary of the breeding range well south of its previous position (Fig. 1).

Migration routes in Far East Asia

Results from the telemetry studies showed that Far East Asian Greylag Geese wintering in China originated from Mongolia and that many summering geese caught in the eastern part of the Mongolian steppe region overwintered in China (Fig. 2). We obtained full migration data from 31 tagged individuals (comprising 36 autumn tracks and 33 spring tracks; Supporting Materials Table S1). They segregated between two migration corridors linking breeding and winter quarters: a western/central Mongolia-China corridor

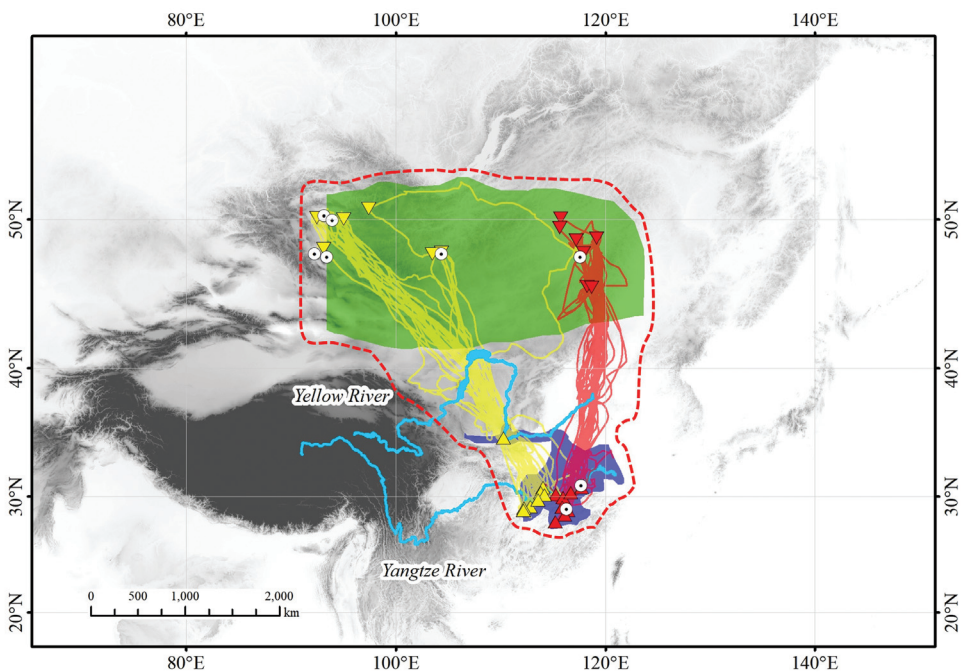

Figure 2. Distribution and two migration corridors used by the Far East Asia Greylag Goose population (defined by the red dashed line). The eastern Mongolia/Inner Mongolia-China flyway (red tracks, from telemetry devices fitted to birds) comprised geese that bred in Dauria in Russia, other areas across Mongolia, Inner Mongolia, west of Heilongjiang Province and northern parts of the Xinjiang Uygur Autonomous Region, China, and wintered in the Yangtze River floodplain in China. The western/central Mongolia-China flyway corridor (yellow tracked individuals) migrated through the Bayan Nur in China, to winter in the Yangtze River floodplain and the Yellow River floodplain in China. See text for full details. Green shaded areas = our revised suggested breeding range; dark blue areas = revised wintering range. Inverted and regular triangles represent breeding/summering and wintering areas used by tracked individual(s), respectively.

and an eastern Mongolia/Inner Mongolia-China corridor.

The western/central Mongolia-China corridor was described by tracks from 20 individuals whose loggers provided full migration data, with 22 autumn and 15 spring migrations recorded. Fourteen of these, caught at Uvs and Bayan Lakes in Zuungobi, western Mongolia, migrated through the Bayan Nur in China, and subsequently wintered along the Yangtze River floodplain in China, mainly at Huanggai and Dongting Lakes in Hunan Province, and at Longgan Lake and the Fu River in Hubei Province. Four birds caught at Bayan Lake, in the Dashinchilen district of central Mongolia, also migrated through the Bayan Nur in China. Two of these (gg026 and gg027) subsequently wintered at the Sanmenxia Reservoir (34°42'N, 110°57'E) in Henan Province, and at Shengtian Lake (34°42'N, 110°53'E) and along the middle reaches of the Yellow River in Fenglingdu, Shanxi Province in 2018. The remainder wintered at Futou Lake in Hubei Province and Huanggai Lake in Hunan Province in the Yangtze River floodplain. Two wintering birds caught in the Yangtze River floodplain also followed this corridor, migrating through the Bayan Nur to western Mongolia for the summer. Of nine tracked Greylag Geese whose loggers provided wintering site data in two or more successive years, only one individual shifted between major wintering areas. This bird (gg026, an adult female) wintered in the middle reaches of the Yellow River floodplain in 2017/18, then at Futou Lake further down the Yangtze River floodplain in 2018/19.

The eastern Mongolia/Inner Mongolia-China corridor was defined by 11 individuals, which provided full migration tracking data for 14 autumn and 18 spring migrations. Three of these birds, which were caught at Buir Lake in eastern Mongolia, summered in the Mongolian-Manchurian grassland steppe ecoregion, then migrated through Bohai Bay in China to winter in the Yangtze River floodplain, mainly at Poyang Lake. The other eight birds, caught in the Yangtze River floodplain, similarly migrated through Bohai Bay to summer in the grassland steppes of Mongolian-Manchuria.

Nineteen tracked Greylag Geese provided moulting site data in two or more successive years. There was one case of a bird changing its moulting site, with gg026 moulting at Bayan Lake, Dashinchilen (Mongolia) in 2018, but at Hulun Lake (Inner Mongolia, China) the following year. The other 18 birds all moulted in their main summering area.

Winter abundance and population trends

The long-term count data indicate that Far East Asian Greylag Geese winter almost exclusively in China, because despite regular waterbird counts, very few Greylag Geese have been recorded in Japan (maximum annual count = 37 birds since 1970) and South Korea (maximum = 1 bird since 1990; Supporting Materials Table S4). Total numbers of Greylag Geese counted in China have been highly variable due to large differences in coverage, so we cannot conclude much about trends from the national totals. Surveys found 22,122 in China during 1989/90–1991/92, but since

then total counts from the Yangtze River have suggested increases there, although coverage has improved over time: 2003/04 (890), 2004/05 (3,263), 2015/16 (3,441), 2017/18 (25,035), 2018/19 (29,800) and 2019/20 (31,602). The average of the total Greylag Goose counts for the Yangtze River floodplain recorded each winter in recent years (from waterbird surveys in 2017/18–2019/20) was 28,812 birds, with a further 1,032 recorded during waterbird surveys of the Yellow River made in winter 2018/19 (results shown in Fig. 3), suggesting that *c.* 30,000 Greylag Geese currently winter in China.

Changes in numbers of Greylag Geese wintering at key sites in Far East Asia

Based on our new estimate of the population size for Greylag Geese wintering in China, we now define the 1% criterion for qualifying sites as being of international importance at ≥ 300 birds. Twenty-eight key wintering sites have now been identified for Greylag Geese in China on the basis of this threshold (Table 1, Fig. 4) with the number of sites recorded with > 1% of the population each winter increasing from seven in 1989/90–1991/92 to 19 in 2018/19–2019/20 (Fig. 5).

Poyang Lake in Jiangxi Province has, on average, accommodated 40% of all

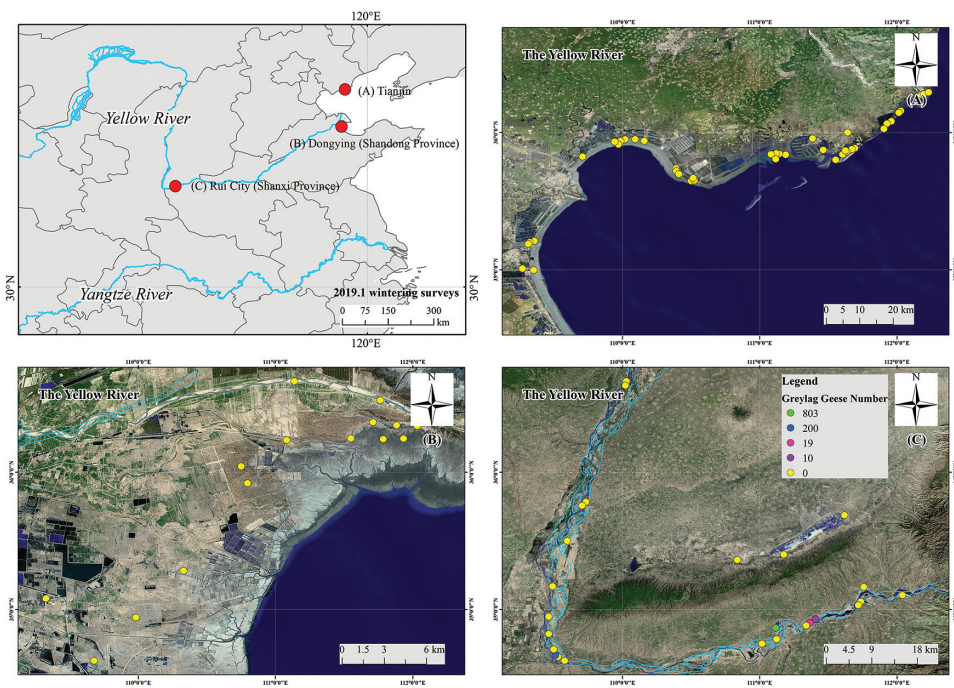

Figure 3. Inset map showing areas counted for waterbirds in the Yellow River Basin in January 2019. Expanded maps show the numbers and distributions of Greylag Geese in three areas: (A) along the northern coast of Bohai Bay, near Tianjin, (B) Dongying on the southern shore of Bohai Bay, and (C) along the Yellow River floodplain in the vicinity of Rui City (Shanxi Province).

Table 1. Maximum annual numbers of Far East Asian Greylag Geese counted at key wintering sites in China during November to March 1991/1992–2019/2020.

ID	Province	Lakes	Maximum nos. counted	Year of max. count
C1	Shanxi	Shengtian Lake	803	2020
C2	Hunan	South Dongting Lake	483	2019
C3		East Dongting Lake	12,358	1990
C4		Huanggai Lake	1,027	2020
C5	Hubei	Taibai Lake	2,020	2019
C6		Chen Lake	2,775	2020
C7		Zhu Lake	435	2020
C8		Zhangzheng Lake	450	2018
C9		Futou Lake	2,502	2019
C10		Tuandun Lake	1,290	2020
C11		Wu Lake	350	2018
C12		Zhangdu Lake	300	2019
C13		Wang Lake	461	2019
C14		Longgan Lake	9,060	2018
C15	Anhui	Bo Lake	376	2020
C16		Huangda Lake	1,700	2005
C17		Wuchang Lake	1,676	2020
C18		Shengjin Lake	1,300	2017
C19		Caizi Lake	300	2019
C20		Anqing Wetland Reserve along the Yangtze River	1,000	1990
C21	Jiangxi	Saicheng Lake	1,330	2019
C22		Poyang Lake	13,476	2019
C23		Taibo Lake	350	2019
C24	Guizhou	Caohai National Nature Reserve	2,337	1991
C25	Henan	Heigangkou	510	1992
C26		Nanwan Reservoir	300	1991
C27	Jiangsu	Yancheng Wetland National Nature Reserve	4,279	1991
C28		Gaobao Lake	880	1992

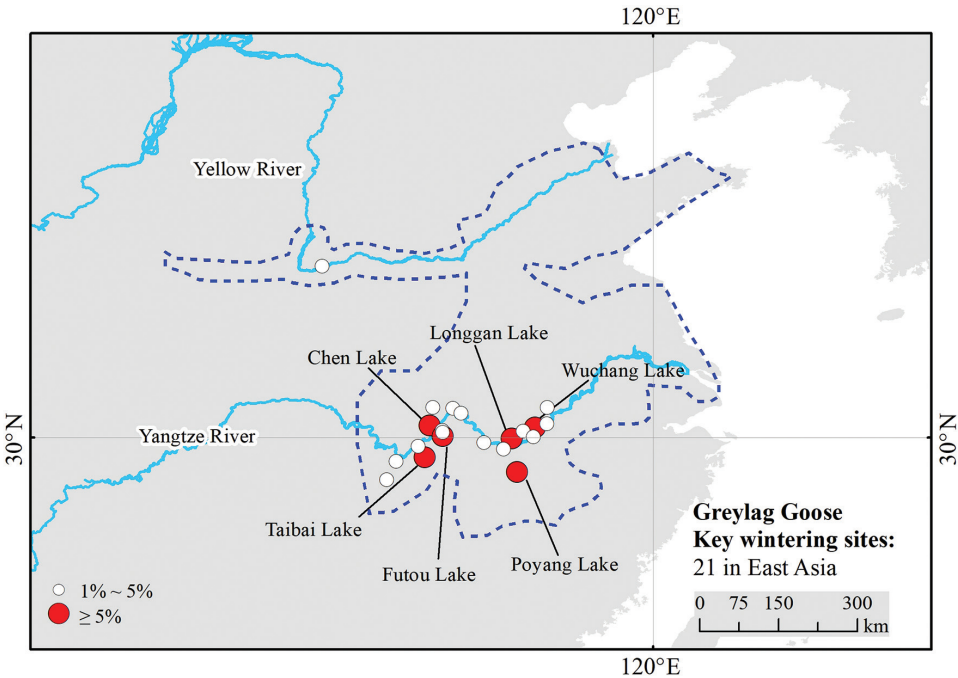

Figure 4. Twenty-one key wintering sites for the Far East Asia Greylag Goose population in China, distributed between the Yellow River (one 1% key site) and the Yangtze River floodplain (six 5% key sites and 15 1% key sites). Key sites qualify by supporting ≥ 1% of the flyway population (≥ 300 individuals) during 2011–2020, based on the maximum site count in the last ten years (see *Results*). White and red circles = the numbers counted as a proportion of the overall numbers in East Asia (*i.e.* 30,000 birds). Blue dashed lines = the wintering range of the Far East Asia Greylag Geese population, as defined by this study.

wintering Greylag Geese in East Asia in recent years, being numerically the most important site for the species from 2003/04 to 2019/20 (except in 2014/15), and where numbers have increased from 580 to 13,476 over this period. Longgan Lake in Hubei Province has also remained an important key wintering site for Greylag Geese in recent years, supporting *c.* 21% of Far East Asia Greylag Goose population in winter. Although Greylag Geese were not found to be wintering there in 2003/04, survey results from 2015/16 to 2019/20 found a sharp increase, with 8,000–9,000 Greylag Geese counted at the lake in 2017/18 and 2019/20.

Wintering surveys in 2003/04 and 2004/05 showed that wintering Greylag Geese were absent from many formerly occupied lakes. This contrasts with surveys in the last five years, when larger numbers of Greylag Geese were recorded (Table 1). More than 1,000 Greylag Geese were found at several lakes, including Huanggai Lake in Hunan Province, Taibai, Chen and Futou Lakes in Hubei Province; Wuchang and Shengjin Lakes in Anhui Province; and at Saicheng

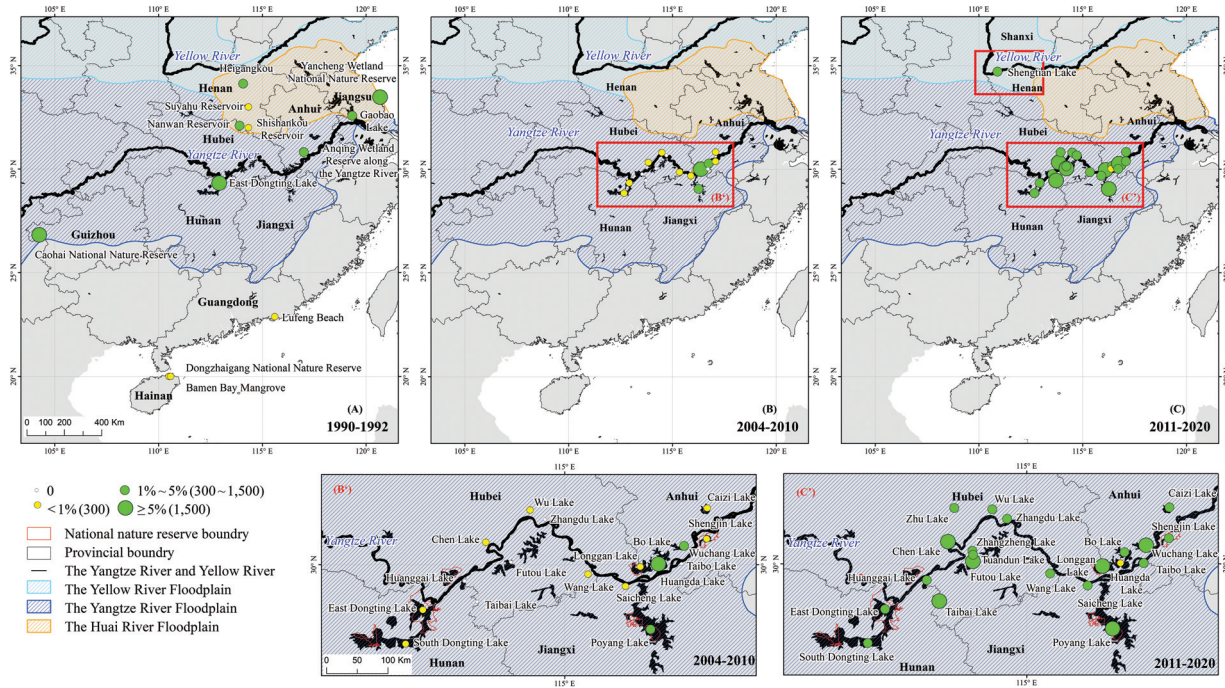

Figure 5. Map showing the changes in the numbers and distribution of key wintering sites for Greylag Geese in East Asia. (A) seven key wintering sites during 1989/90–1991/92 (four 1% key sites: Anqing Wetland in the Yangtze River floodplain, and Heigangkou, Nanwan Reservoir and Gaobao Lake in the Huai River floodplain, China; and three 5% key sites: Caohai National Nature Reserve and East Dongting Lake in the Yangtze River floodplain, Yancheng Wetland National Nature Reserve in the Huai River floodplain). (B) three key wintering sites in 2003/04 and 2009/10 (two 1% key sites: Poyang and Wuchang Lakes in the Yangtze River floodplain; and one 5% key site: Huangda Lake in the Yangtze River floodplain). (C) 21 key wintering sites in the Yangtze River floodplain and the Yellow River floodplain in 2010/11 and 2019/20 (15 1% key sites: Shengtian Lake in the Yellow River floodplain, and East Dongting, South Dongting, Huanggai, Zhu, Zhangzheng, Tuandun, Wu, Zhangdu, Wang, Shengjin, Caizi, Saicheng and Taibo Lakes in the Yangtze River floodplain; and six 5% key sites: Taibai, Chen, Futou, Longgan, Wuchang and Poyang Lakes in the Yangtze River floodplain). Despite the increase in numbers of sites qualifying as key sites with increasing population size, the main wintering distribution of Greylag Geese has concentrated at Poyang Lake and Longgan Lake. White circles = sites visited but where no Greylag Geese were present; size of the green circles (for all time periods) = numbers counted as a proportion of individuals in relation to the total population estimate for the Far East Asia Greylag Goose population (*i.e.* 30,000 birds).

Lake in Jiangxi Province. In addition, Shengtian Lake in Shanxi Province was found to qualify as a key wintering site for the Far East Asian Greylag Goose, though it had not been surveyed before 2019.

In contrast, Huangda Lake (Anhui Province) was the most numerically important wintering site for the Far East Asian Greylag Geese in 2004/05, accommodating 6% of the population in that year, yet numbers had declined to almost zero when counted during the 2009/10, 2010/11 and 2014/15–2019/20 winter surveys.

Although 12,358 Greylag Geese were counted at East Dongting Lake, Hunan Province, in 1989/90 there have been < 500 Greylag Geese counted there in all waterbird surveys since then. Counts of 2,337 Greylag Geese wintering at Caohai National Nature Reserve in Guizhou Province, 510 at Heigangkou and 300 at Nanwan Reservoir in Henan Province; and 4,279 at the Yancheng Wetland National Nature Reserve and 880 at Gaobao Lake in Jiangsu Province during 1990–1992 also suggest greater abundance and wider dispersal of Greylag Geese at that time compared to the current situation.

Discussion

Summer and winter distributions of Greylag Geese in Far East Asia

For the first time, satellite-tracking data, survey data and expert opinion have been integrated to update knowledge and understanding of the breeding and wintering distribution range of the Greylag Goose in Far East Asia. Our results show a retraction of the breeding range within Russia, where the species apparently no longer breeds east of 124°E, but an apparent recolonisation of breeding areas within Inner Mongolia (China), and indication that the Greylag Goose is of favourable conservation status in the Daurian region of eastern Mongolia and adjacent parts of Russia. Data from tracking and expert opinion also suggested contraction of the northern edge of the breeding range further south. In winter, our results similarly show a retraction of the previously described distribution, as the species has become increasingly concentrated within the Yangtze River floodplain, with smaller numbers using the Yellow River floodplain. Counts carried out during 1989/90–1991/92 found that Greylag Geese wintered mainly in Guangdong, Guizhou, Hainan, Henan, Hunan, Anhui and Jiangsu Provinces at that time (Waterbird Specialist Group of the Chinese Ornithological Association 1994). Yet the waterbird surveys of the middle and lower reaches of the Yangtze River floodplain and eastern coastal China during 2003/04–2004/05 found large numbers in these areas, well north of the former range (Cao *et al.* 2010). Since 2010, the wintering range of the species seems to have become even more concentrated, with > 50% of Far East Asian Greylag Geese wintering at Poyang Lake and Longgan Lake within the Yangtze River floodplain. This picture suggests that the wintering distribution of Greylag Geese may have relocated from the middle Yangtze River floodplain and south of China to the lower Yangtze River floodplain, which is consistent with Xu *et al.* (2019), although whether these changes are climate related or attributable to

geographical changes in habitat quality and/or persecution remains unknown (Fig. 1).

The telemetry studies also showed, for the first time, that Greylag Geese of the Far East Asia and Central Asia populations share the same breeding sites, at least at Uvs Lake in western Mongolia, where 59% of tagged geese wintered in southern Asia and the rest in China. Telemetry also indicated that at least one bird shifted wintering areas between southern Asia and China. A more detailed analysis of the biology and migration routes of Greylag Geese wintering in southern Asia is the subject of ongoing analysis. Lack of comprehensive survey data during the breeding season restricts our ability to map accurately the true breeding range of the Greylag Goose, which awaits the instigation of systematic summer surveys, including periodic aerial surveys, to determine the full extent of the breeding and moulting distribution of the species.

Far East Asian Greylag Goose flyway structure

Results from the telemetry studies support the identification of a single population for the Greylag Goose in Far East Asia. This connects birds that breed in the Mongolian-Manchurian grassland steppe ecoregion (Olson *et al.* 2001) from Inner Mongolia (China), Dauria in Russia, and the eastern, central and some parts of western Mongolia with Chinese wintering grounds (consistent with results of previous studies; Lei *et al.* 2019; Li *et al.* 2019b). Tracking however showed a marked dichotomy in routes used by geese from the eastern and western elements of the population, which also reflects the staging areas (and potentially the wintering sites) used by these two sets of geese along their migration corridors (Fig. 2). Just how isolated, ecologically, individuals from these two corridors may be from each other should be investigated, as there could potentially be reduced gene flow between individuals using the two corridors compared to those using the same routes. Such separation may also help explain differences in trends in abundance and distribution of the species on the breeding areas and in winter in China. In addition, we need to explore in further detail the relationship between 20 individuals which wintered in southern Asia and the migration flyway in Far East Asia. Moreover, tracking data for Greylag Geese migrating to central Asia is incomplete, and it is currently difficult to draw any conclusions about this flyway.

Current knowledge of the breeding and wintering range of the Greylag Goose in Far East Asia remains somewhat rudimentary, despite vast improvements on ten years ago, requiring more research to verify the full extent of the summer and winter quarters, spring and autumn staging areas and the relative numbers using these sites. However, this synthesis has provided much new information and a clear understanding of the core breeding and wintering areas upon which to base effective internationally coordinated site-safeguard networks and monitoring systems, for assessing annual abundance and breeding success. The international collaboration can continue to gather more tracking data, not only to identify important staging areas along the migration routes (forming a scientifically sound basis for protecting the species at

these critical sites), but also to shed more light on the ecological and management requirements of the individuals using the two discrete migration corridors. To date, tracking of Greylag Geese has been from relatively few sites on the Mongolian breeding grounds and the Yangtze River floodplain in China in winter. In future, the geographical extent of the capture programme should be expanded to include Russia, the Yellow River floodplain, the northern Xinjiang Uygur Autonomous Region and Inner Mongolia, so that the sampling strategy incorporates individuals from the full geographical range of this population.

Status of the Far East Asia Greylag Goose population

A new assessment is presented on the status and abundance of the Far East Asian Greylag Geese up to 2019/20. Since the 1990s, annual numbers of Greylag Geese wintering in China have shown no significant trend, although it is the case that numbers since 2017/18 have been 1.5 times those that were counted in the 1990s. A major contributory factor is likely to be that, in the 1990s, both the number and extent of wetlands covered during wintering surveys may have been considerably lower than during surveys carried out since 2003/04. Nevertheless, the current absence of the species from sites formerly occupied in the 1990s is evidence of a shift and contraction in range that has probably been continuing since the early 2000s, yet the total numbers of Greylag Geese identified during winter surveys since then have increased. While this could be due to the improved waterbird survey coverage in the Yangtze River floodplain in recent years, at some consistently monitored sites there are clear signs of increased local wintering abundance. By combining systematic extended ground counts with satellite tracking technology, we can become better able to find important areas used by Greylag Geese throughout the annual cycle. For example, the most recent winter surveys, in 2018/19, covered the centre of Poyang Lake better than in the past, coverage which not only increased significantly waterbird numbers counted in this part of the lake (Table 1, Fig. 6) but also inflated the total numbers counted at the site overall (45.2% of the total counts in 2018/19). Although the breeding range of the Greylag Goose has retracted within Russia, numbers of Greylag Geese are still gradually increasing in East Asia, possibly due to the increase in the numbers breeding in western Mongolia. Some of our tracked geese that bred in western Mongolia wintered at Longgan Lake, a site that has supported large increases in numbers of wintering Greylag Geese in recent years. In addition, there has been no systematic waterbird survey of the Yellow River estuary in Shandong Province, which could still potentially hold sufficient numbers in winter to affect the estimated size of the Far East Asia population. Unlike the annual systematic surveys in Japan and South Korea, only four systematic surveys of China have been conducted since 2012. During 2011/12–2014/15 and 2016/17, winter surveys covered only a portion of the key wetlands in the Yangtze River floodplain, making it hard to estimate the true abundance and trends of Greylag

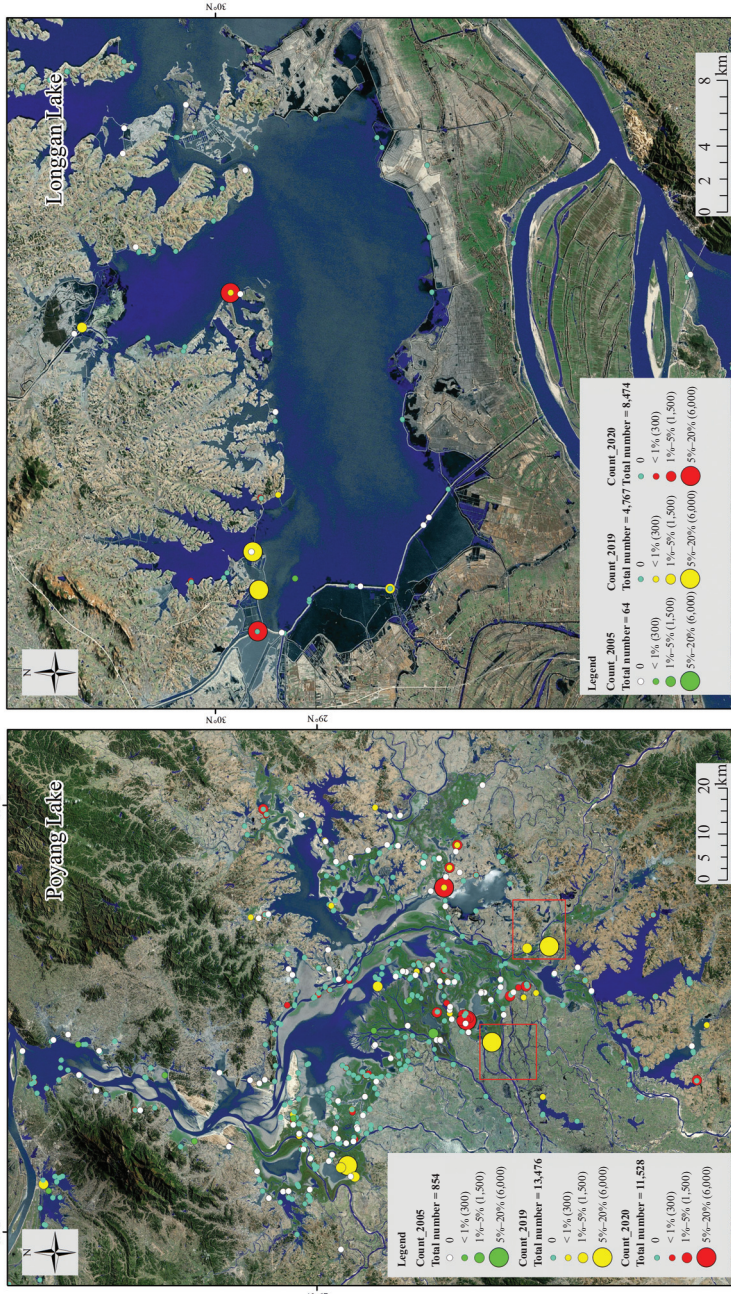

Figure 6. Map of survey points, numbers and distribution of wintering Greylag Geese at Poyang Lake (left) and Longgan Lake (right) in winters 2004/05, 2018/19 and 2019/20. Numbers at Poyang Lake and Longgan Lake combined accounted for 28% of Far East Asian Greylag Geese in 2004/05, and subsequently 59% and 63% in 2018/19 and 2019/20. In recent years, survey points were increased, but the observation coverage is basically the same as in 2004/05, with a slight increase (in areas shown within the red squares). Comparing 2019/20 data with the results from the 2004/05 winter survey, shows increases of 12- and 131-fold in wintering numbers at Poyang Lake and Longgan Lake, respectively. The size of circles indicates the numbers counted as a proportion of individuals compared to the total numbers counted for the Far East Asia population in the Yangtze River that winter (1% criterion = 300 individuals; see *Methods*).

Geese wintering in China in these years. Regular coverage of the Yellow River simultaneously with Yangtze River waterbird counts would also greatly add to our knowledge of Greylag Goose distribution and abundance. We therefore urge the establishment of a continuous, standardised annual waterbird monitoring system in China to enhance substantially our ability to obtain better estimates of wintering abundance, and to detect the trends in numbers at site, regional and national levels for the Greylag Goose and other species in China.

Of all goose species, the tagged Greylag Geese wintering at Poyang Lake showed the greatest use of farmland habitats at that site (although only constituting < 20% of all habitat use; Yu *et al.* 2017). However, in recent years, studies are showing that > 50% of Chinese-wintering Greylag Geese have begun using farmland as a source of food (Li 2019). The switch from natural to agricultural habitats in winter is considered to have greatly enhanced the energetic and nutritional intake rates of geese elsewhere in the Northern Hemisphere (Fox & Abraham 2017; Fox *et al.* 2017). In addition, an average of 40% of Greylag Goose wintering sites were protected by some form of nature conservation legislation, and 46% of their breeding sites were also protected, all major factors that could have contributed to the increase in abundance of the species (Li 2019). We had one instance of a Greylag Goose (No. 181255) which changed its winter quarters from India to China (L. Cao, unpubl. data). Although we do not know how prevalent such behaviour may be in the population as a whole, changes in winter provenance could represent another mechanism that explains increasing numbers of Chinese-wintering Greylag Geese in recent years. Throughout Siberia and the Far East, numbers of Greylag Geese are generally showing declines in abundance, with the apparent exception of the Daurian region of Mongolia and adjacent parts of Russia. Quite why this should be is difficult to explain, especially given recent drought conditions in the Mongolian breeding areas. It could be related to improvements in wintering rather than breeding conditions, but more research effort is required to assess and understand the situation.

Changes in habitat quality at key wintering sites in East Asia

In this account, identification of key wintering sites for Greylag Geese in Far East Asia has been attempted for the first time. Around 2010, the number and distribution of major wintering sites for the Greylag Goose increased in the Yangtze River floodplain, and trends in numbers of Greylag Geese counted at most of these sites (except Huangda Lake) have varied markedly over the past decade. Numbers at some lakes have increased, especially dramatically at Poyang Lake in Jiangxi Province, but also at Longgan Lake in Hubei Province since 2018. New key wintering sites, such as Shengtian Lake in Shanxi Province, have been found in recent years, which can now be subject to sympathetic conservation management for Greylags and other species. Since 2010, other goose species also have become increasingly abundant, not only at Poyang Lake but also at Chen, Futou, Longgan and Taibai Lakes

in Hubei Province. This suggests that environmental conditions at these Yangtze River wetlands may have been maintained or improved relative to sites elsewhere in the wintering range, where we have witnessed declines and disappearances of Greylag Geese and other waterbird species. The increase in the numbers of Greylag Geese wintering at Longgan Lake after 2017 is probably attributable to the implementation of an ecological restoration policy at the site, and a programme to return farmland to wetlands at the Longgan Lake Reserve. These measures included the banning of net fishing operations at the site, specifically to protect migratory birds and to restore a greater extent of suitable waterbird habitat. More than 80,000 ha of paddy fields around the core lake area are still the main attraction to large numbers of migratory birds in autumn. Greylag Geese wintering at Longgan Lake are mainly concentrated in the reed beds, but there are increasing signs of enhanced feeding activity on adjacent farmland, which has likely extended the potential carrying capacity of the site for the geese. In contrast, Greylag Geese at Poyang Lake are mainly concentrated in the centre of the lake, and show limited feeding activity on farmland (Yu *et al.* 2017).

The almost complete disappearance of Greylag Geese wintering at Huangda Lake is likely due to intense local socio-economic development pressures since 2010. These have severely reduced the area of natural wetlands, greatly degraded ecosystem services and caused heavy catchment pollution loads (including a serious pollution event in the western lake in 2016), which have had a major impact on the water quality in the lake (Hong *et al.* 2018). In contrast, at Chen Lake (Hubei Province), the promotion of the relevant environmental protection laws and regulations and of nature conservation activities and outreach to the general public through the media, has had a positive effect on public awareness and improved environmental quality at the site (Yang *et al.* 2017). At Futou Lake (Hubei Province), seine-net aquaculture that formerly covered 70% of the total lake area in 2016 has since been banned, and all fisheries structures have been dismantled and removed, restoring large areas of natural wetlands. Huanggai Lake (Hunan Province) launched a comprehensive ecological remediation of the lake environment in 2017, removing fish nets, cages and dams with similar effect. Wuchang Lake in Anhui Province has also launched waterfowl habitat reconstruction and wetland vegetation restoration projects in recent years. While we require effective on-site monitoring to determine the specific beneficial effects of such restoration projects to Greylag Geese and other species of waterbirds, there can be little doubt that the simple net gain in wetland habitat will have contributed to increases in the numbers of wintering Greylag Geese.

Conservation and research recommendations

Factors limiting the Far East Asian Greylag Geese in its breeding areas remain largely unknown. Burning and mowing of reeds have been considered as threats to the species in Russia (Boere *et al.* 2006). Additionally, hunting disturbance reduces their feeding opportunities and affects

survival (Adam *et al.* 2016). In Russia, it is considered that extensive poaching, as well as spring grassfires, and conflicts between sport hunters and game managers are responsible for the alarming decline of the species in this region (Rozenfeld & Smirensky 2001; Goroshko 2012). As well as initiating more research into factors affecting Greylag Geese on the breeding areas, it is recommended that hunting laws and regulations are established in areas where recolonisation by breeding Greylag Geese remains unlikely while current hunting on the species prevails. Such a programme requires parallel public education programmes to bring awareness to local communities about the loss of biodiversity and specifically about the effects of hunting on the breeding distribution of Greylag Geese in East Asia. Such actions to improve the scientific literacy and public understanding within local communities are essential if we are ever to restore the Greylag Goose to areas formerly occupied as breeding habitat. In addition, due to the susceptibility of Greylag Geese to avian influenza, we must accept that the species may be affected by future outbreaks of the virus (Melville & Shortridge 2006).

To understand fully the distribution, numbers, important habitats and annual life cycle events for the Far East Asia population of Greylag Geese, it is necessary to continue, strengthen and develop the excellent working relationships established that unite Russia, Mongolia, South Korea and Japan and other Far East Asian countries, to establish a full, collaborative programme of long-term scientific research and monitoring. We believe that more extensive telemetry studies will continue to identify important sites and habitats as well as gaps in our effective conservation programmes for the Greylag Goose in East Asia. We see this knowledge as being essential to guide future responses to climate change, which potentially will create more wintering habitats than are currently available due to shifts in the 0°C mean January isotherm in the region.

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Photograph: Greylag Goose head, by Dominic Heard/WWT.

