Contrasting changes in abundance of Falcated Duck *Mareca falcata* wintering in the Yangtze River floodplain and on the eastern coast of China

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Abstract

The Falcated Duck *Mareca falcata*, which is considered Near Threatened by IUCN, winters almost exclusively in East Asia, with greatest numbers occurring in the Yangtze River floodplain and along the coasts of eastern China. Given gaps in knowledge of its distribution and population status, we combined tracking studies, winter surveys and expert knowledge, to revise the geographical definition of its summer range in eastern Russia, Mongolia and Japan, and the main wintering range in China, South Korea, Japan and India. Data from six tagged individuals tracked on migration between their wintering and breeding grounds, combined with a single ring recovery, indicated that Falcated Ducks wintering in the Yangtze River migrate via the Northeast China Plain to breed over an extensive area in eastern Russia and northeast China. However, in the absence of telemetry data from birds wintering in the Indian sub-continent, Japan and the Korean Peninsula, we cannot yet define a flyway structure for the species. Mid-winter field surveys of Yangtze River floodplain wetlands in January 2004/05, 2015/16 and 2019/20 showed Falcated Ducks to be widely distributed, with 17 key sites supporting > 93% of the total wintering numbers counted in the region. Falcated Ducks in the Yangtze River floodplain increased from *c.* 15,000 counted in winter 2004/05, to *c.* 40,000 in 2015/16, and 88,000 in 2019/20, ascribed to a combination of improved survey coverage as well as increases in local abundance (based on sequential counts at key sites in 2004/05, 2015/16 and 2019/20). Coastal surveys undertaken in eastern China in winters 2003/04–2006/07 identified two key sites, which together supported 84.9% of the 14,904 individuals recorded. Between 2015/16 and 2019/20, abundance at these two sites had declined by 78.8% and 99.4%, respectively, likely attributable to habitat loss through land reclamation during that period. More telemetry research, combined with comprehensive surveys of wintering, stopover and breeding sites is required to improve our understanding of migratory connectivity and the major migration routes of this species. The wide distribution of Falcated Duck also requires further comprehensive surveys in other wintering areas (*e.g.* central China and along the eastern coasts of China) to track changes in local abundance within its winter quarters, which in turn should confirm whether increases in abundance in the Yangtze River floodplain reflect an increase or a redistribution of the population. Long-term monitoring and sympathetic management of key staging and wintering sites used by the Falcated Duck in China, and across the rest of its range, are also required to ensure the efficacy of conservation measures for the long-term survival of the species.

Key words: distribution, East Asia, Falcated Duck, migration routes, population status.

The Falcated Duck *Mareca falcata* is listed as a Near Threatened species by the International Union for Conservation of Nature (IUCN) in the global Red List of Threatened Animals (BirdLife International and Handbook of the Birds of the World 2019). Its summer distribution ranges from southeast Siberia to Kamchatka, Mongolia (Call *et al.* 2019), northeast China and northern Japan, and the birds migrate to winter mainly in southern Japan, South Korea, eastern China and India (Carboneras & Kirwan 2020). Only one population of Falcated Duck – the Central and East Asian population – is currently recognised, (Carboneras & Kirwan 2019), which is restricted mainly to East Asia. The global population size has been estimated at 78,000–89,000 individuals in 2007 and the species is considered to be in long-term decline (Cao *et al.* 2008; Wetlands International 2012).

In the mid-2000s, when it was recognised that the key wintering area in eastern China lay within the Yangtze River floodplain and along the coasts of eastern China, numbers of Falcated Duck wintering in eastern China comprised at least 88% of the East Asian population (78,000 individuals; Cao *et al.* 2008). Literature and survey data showed a wide inland and coastal distribution (Cao *et al.* 2008), and highly variable counts/estimates of numbers wintering in eastern China. These ranged between 100,000–1,000,000 birds over the last 30 years, but highly variable between-winter count totals reduces our capacity to determine a clear population trend (S. Chan, unpubl. data; Perennou *et al.* 1994; Waterbird Specialist Group of Chinese Ornithological Association 1994; Cao *et al.* 2008). At present, both the wintering abundance and overall status of the species in eastern China remain unknown. There is also a lack of specific information on the migration strategies and routes used by Falcated Duck, except for one telemetry tracking study (n = 6), which showed that birds summering in eastern Russia and northeast China migrated southwest to winter at Poyang Lake (Takekawa *et al.* 2010).

Elsewhere across its range in East Asia, numbers in Japan have shown a significant decline at summering sites, but stable trends in wintering numbers and distribution, with around 10,000 counted in most recent years (Kasahara & Koyama 2010, 2011; Ministry of the Environment Government of Japan 2019). In South Korea, the *c.* 2,600–6,000 or so wintering numbers reported between winters 2013/14–2019/20 (NIBR 2020) indicates a continued decline, as previously reported by Moores *et al.* (2014). To the south and west of China, the Falcated Duck is reported only in very small numbers across large parts of northern India, but with regular numbers reported in eastern parts of the country (Rahmani & Islam 2008; Abhinav & Dhadwal 2017). It occurs only as a vagrant in Bangladesh (Begum 2015) and Nepal (Inskipp *et al.* 2016) as well as in northern Thailand (Robson 2016), Myanmar (Zöckler & Kottelat 2017), Laos (Duckworth *et al.* 1999) and Vietnam (Mundkur *et al.* 2017).

This study integrates new telemetry data with ring recoveries, wintering waterbird surveys, birdwatching reports and expert knowledge, to: (1) update our knowledge of the breeding (summer) and wintering ranges, and the migration routes linking these areas, (2) estimate abundance and population trends, (3) identify key sites in the Yangtze River floodplain and at coastal key sites in eastern China, (4) determine whether variation in numbers counted at key sites is attributable to differences in survey coverage and/or genuine changes in abundance, and (5) describe the migration behaviour, chronology and habitat use at stopover sites of tracked Falcated Duck wintering in the Yangtze River floodplain. Overall, we aim to summarise current knowledge of the species to provide a basis for its conservation, especially along the Yangtze River floodplain which, according to recent surveys, probably supports the largest known concentrations in winter.

Methods

Migration data

Fourteen Falcated Ducks (six adult males and eight of unknown age: six males and two females) were caught at Anhui Lakes (30°54'N, 117°40'E) in the Yangtze River floodplain, China, between October and March, from 2015/16–2017/18. Ducks were dazzled in the beams of powerful lamps and captured in hand-nets from boats at night, or were caught in heavy-duty mist nets (designed for catching large birds) set at their roosts.

Approval for bird capture and transmitter deployment in China was obtained from the Anhui Shengjin Lake National Nature Reserve, and from the Animal Ethics Committee at the Research Centre for Eco-Environmental Sciences, Chinese Academy of Sciences. Data on Falcated Duck ring recoveries were provided by the Bird Ringing Centre of Russia IEE RAS, Moscow, Russia.

Each of the captured birds were fitted with one of two types of solar-powered backpack transmitters: Druid Technology, China (18.7 g) and Hunan Global Messenger Technology Company, China (16 g), which recorded GPS positions with concurrent time and date stamps and transmitted data via the GSM mobile network (Supporting Materials Table S1). These transmitters provided 8 ± 4.87 (mean ± s.d., range = 1–15) GPS positions per day, contingent upon power supply. Only individuals with at least one complete spring or autumn migration were used to contribute to identifying the migration routes. Movement data in the day after the birds were captured and tracked, and from the day before a bird died and/or signals from a transmitter were lost, were excluded from the analyses as likely to represent atypical activity.

Distribution and migration range

The BirdLife International and Handbook of the Birds of the World (2019) map of Falcated Duck distribution was uploaded in ArcGIS 10.2 (ESRI 2013) and then modified on the basis of new data. These included survey results presented in Cao *et al.* (2010), newly compiled winter count data (see *Methods* below) and information on the winter/summer distributions derived from satellite tracking data (see *Methods* above), combined with expert knowledge of the Falcated Duck breeding distribution in East Asia.

GPS points accumulated for tracked individuals during the summer months were analysed to validate and supplement the experts' knowledge of Falcated Duck breeding distribution in the region.

Expert opinion was sought during the "*2nd International Symposium on Developing Effective Coordinated Monitoring of East Asian Waterbirds in the 21st Century*", held in Beijing, China, in October 2019, when six experts from four countries in the East Asian flyway discussed and contributed to delineation of the revised distribution and migration range of the species (Supporting Materials Table S2).

Abundance estimates and changes in the Yangtze River floodplain

Wintering abundance data were obtained from systematic surveys of the Yangtze River floodplain undertaken during mid-January in winters 2004/05, 2015/16 and 2019/20. Counts were summed to provide estimates of total numbers present for each year. Information on Falcated Duck wintering at lakes in the Yangtze River floodplain during

1987/88–1990/91 was also gathered from the literature. For each lake, the maximum count recorded during December–February between 1987/88–1990/91 was used as the number wintering at the lake in that period, and the wintering numbers counted at all lakes were then summed to provide an estimate of total numbers wintering in the Yangtze River floodplain at that time. There was a lack of systematic surveys before 2000, so we were unable to evaluate the completeness of the count data recorded during the 1987/88–1990/91 period. Not only were few lakes counted but we also had only limited information on the degree of coverage for each lake, compared with the systematic surveys of 2004/05, 2015/16 and 2019/20. Total numbers estimated for winters 1987/88–1990/91 therefore must be regarded as relatively coarse and incomplete.

Simple linear regression was applied to detect trends in the abundance of Falcated Duck in the Yangtze River floodplain, using log-transformed annual population estimates (based on the total numbers counted) as the dependent variable and year as the independent variable. Exploration of linear regression residuals of temporal trends in the count data, fitted using the nlme package (Pinheiro *et al.* 2020), found no evidence for statistically significant residual temporal autocorrelation in the data.

Key wintering sites and changes in abundance in the Yangtze River floodplain

Key sites were determined from the survey data recorded in winters 2004/05, 2015/16 and 2019/20, and were taken as being those that held ≥ 830 birds in any one of the surveys, as this number represented 1% of the total population estimate for Falcated Duck in East Asia (78,000–89,000 individuals; Wetlands International 2012).

Changes in numbers and distribution of Falcated Ducks at key sites were investigated by comparing the counts recorded in 2004/05, 2015/16 and 2019/20. Over this period, not only has it become possible to survey more lakes and more within-lake sites in the Yangtze River floodplain, but it has also generally been the case that more individuals were counted at many sites. This clearly creates challenges to interpreting changes in numerical abundance throughout the floodplain. To assess the relative contribution to the changes in bird number at key sites, it is important to differentiate the change in local abundance caused by: (1) changes in the survey coverage by including new survey sites or by excluding previous survey sites, and (2) genuine increases in local abundance. When numbers have increased with extra count sites within a lake, this suggests that improved survey efforts potentially contribute to increased numbers of birds counted; whereas increased counts occurring where count coverage has remained constant, provides us with more confidence that increased counts reflect genuine increases in the number of wintering Falcated Duck at a site. Because of the lack of systematic surveys in 1987/88–1990/91, numbers at key sites and changes in their abundance were not estimated from that period.

Abundance changes at coastal sites in eastern China

Key wintering sites (*i.e.* with ≥ 1% of the total population estimate) on the coast of eastern China were determined from the results of coastal waterbird surveys undertaken in Shandong, Jiangsu, Zhejiang and Fujian Provinces from December–February during 2003/04–2006/07 (Cao *et al.* 2008). Because of the lack of systematic coastal surveys in recent years, maximum counts at the key coastal sites made between December and February in 2015/16–2018/19 inclusive, reported in published reports and birdwatching websites, were used to estimate changes in abundance at these sites in the 15 years since 2003/04.

Migration parameters

The migration departure date was defined as the date on which the tagged individual was first located away from its wintering site or its breeding/moulting site, and distances travelled within a particular time period indicated whether it was in migratory flight, as described by Wang *et al.* (2018). Arrival date was defined as the first date on which the individual was judged to have arrived at its wintering or breeding sites, using GPS location data to identify a non-relocation period following a period of migratory flight. Migration duration was calculated as the time that the bird took to travel (including stopovers) between the breeding/moulting sites and its first wintering site (autumn migration) or between the last wintering and the first summering site (spring migration). A site where individuals remained within a predefined area during migration for > 2 days was defined as stopover site (Kölzsch *et al.* 2016), and the number of stopovers was calculated accordingly. Stopover duration was calculated as the sum of all days spent at all stopover sites during each migration season. Thus, the days spent travelling (travel days) was calculated as total migration duration minus the stopover duration. A migratory leg was defined as the journey connecting subsequent stopover, wintering or breeding sites, to generate the number of migratory legs involved in each spring/autumn migration episode. Migration distance was defined as the cumulative travel distance between wintering and breeding/summering sites. Step length was calculated as the migration distance divided by the number of migratory legs during each migration season (Benhamou 2004). Based on the results above, migration speed was calculated as migration distance divided by migration duration, and the travel speed was calculated by dividing migration distance by travel days.

To ensure only reliable results, one spring migration episode was excluded from the analyses because of large sampling gaps caused by low power supply to the transmitter.

Land use type during spring, summer, autumn and winter period

We used a land cover dataset from 2017 with a resolution of 10 m × 10 m to evaluate the land use in areas used by the birds. This is based upon a total of ten discrete relevant land cover classification types, namely: bare ground (where vegetation is hardly detectable, but dominated by a background of exposed soil, sand, gravel or rock), cropland, forest, grassland, impervious surfaces (invariably artificial surfaces and associated areas), shrubland, snow/ice, tundra, open water and wetlands (Gong *et al.* 2013, 2019). Land cover types at pixels with GPS fixes, for sites where tracked birds alighted, were extracted and summarised in ArcGIS 10.2 (ESRI 2013).

Results

Migration route

Satellite tracking data for seven complete migrations, obtained from six individuals (six in spring; one in autumn), confirmed the link between Falcated Duck breeding areas in Russia/northeast China and their wintering sites in the Yangtze River floodplain (Fig. 1). One individual summered in Russia and northeast China, and five summered in northeast China. Nine stopover sites of five individuals were identified in inland and coastal areas of China (Table 1).

The recovery in Yakutia, Russia, in May 2017 of a Falcated Duck ringed in Inner Mongolia, China, during October 2016 reflected the general connection between breeding and wintering areas.

Distribution in summer and winter

The summer distribution of the East Asian Falcated Duck mainly encompasses southeast

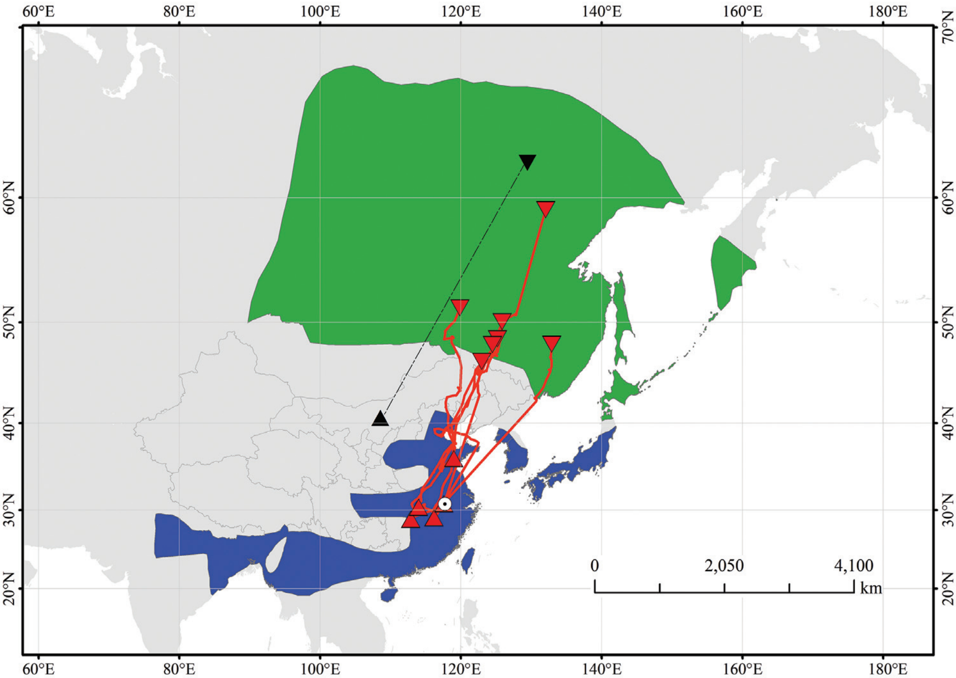

Figure 1. Movements between the Russia/northeast China breeding areas and wintering sites on the Yangtze River floodplain recorded for individual Falcated Ducks tracked in East Asia (red solid lines; *n* = 6). A single direct ringing recovery of a Falcated Duck (black dashed line and triangles), metal-ringed on 18 October 2016 in China and recovered in Russia on 15 May 2017 is also shown. Circles with black dots = capture sites; light green shaded areas = our revised suggestion for the breeding range; dark blue areas = revised wintering range; inverted and regular triangles = breeding/summering and wintering areas used by tracked individual(s), respectively.

Table 1. Stopover sites and stopover duration for tagged Falcated Ducks during autumn and spring migration. Only two of the nine stopover sites (used during 11 stopover periods recorded for five individuals) were in coastal areas.

No.	Location	Site type	Bird ID	Year	Season	Arrival date	Departure date	Duration (days)
1	Zhengyang County, Henan, China (32°27'N, 114°26'E)	Inland	fd001	2016	Spring	1 May 16	16 May 16	16
2	Hamatong Reservoir, Heilongjiang, China (46°20'N, 132°52'E)	Inland	fd006	2018	Spring	3 Apr 18	13 Apr 18	10
3	Hamatong Reservoir (as above)	Inland	fd006	2018	Spring	13 Apr 18	20 Apr 18	7
4	Xingkai Lake, Heilongjiang, China (45°15'N, 132°38'E)	Inland	fd006	2018	Spring	30 Mar 18	3 Apr 18	4
5	Baicheng City, Jilin, China (45°36'N, 122°50'E)	Inland	fd003	2016	Spring	19 May 16	22 May 16	3
6	Baicheng City (as above)	Inland	fd004	2018	Spring	9 Apr 18	19 Apr 18	10
7	Chifeng City, Inner Mongolia, China (43°39'N, 119°58'E)	Inland	fd002	2016	Spring	10 Jun 16	18 Jul 16	39
8	Gannuoer Lake, Inner Mongolia, China (42°54'N, 119°18'E)	Inland	fd002	2016	Spring	4 Jun 16	9 Jun 16	6
9	Gubei Reservoir, Shandong, China (38°00'N, 118°49'E)	Coastal	fd002	2016	Spring	5 May 16	2 Jun 16	29
10	Dongying City, Shandong, China (37°45'N, 119°04'E)	Coastal	fd003	2016	Spring	29 Apr 16	18 May 16	20
11	Qingfengling Reservoir, Shandong, China (35°50'N, 118°49'E)	Inland	fd001	2017	Autumn	31 Oct 17	15 Nov 17	16

Siberia in Russia, extending south to northern Mongolia, China and Japan. From expert knowledge, we confirm that the summering range map needs to be expanded north in south-eastern Siberia compared to the previously described distributions (Fig. 2). The new range distribution now includes Buir Lake (47°47'N, 117°43'E) and Tashgain Tavan Lake (47°21'N, 118°29'E), both in Mongolia. However, it excludes northern Kamchatka, as well as the Mongolian Lakes Uvs (50°18'N, 92°47'E), Oigon (49°10'N, 96°36'E) and Telmen (48°49'N, 97°20'E) where, due to local

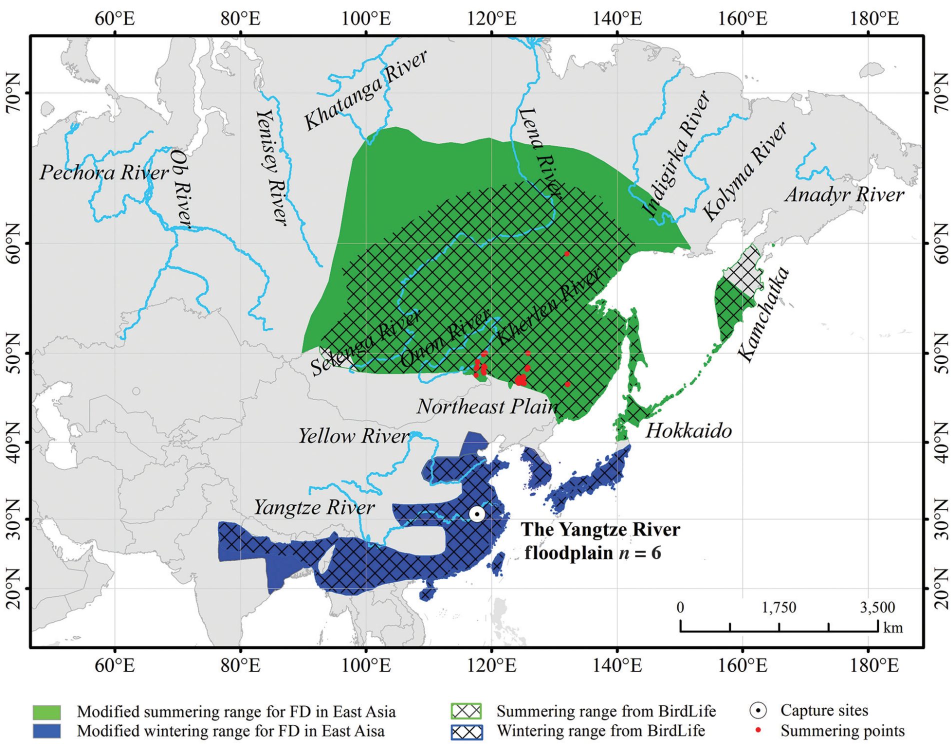

Figure 2. Revised distribution map for Falcated Duck in East Asia, modified from BirdLife International and Handbook of the Birds of the World (2019). Green shading = summering range (mainly in southeast Siberia, Russia, extending south to northern Mongolia, China and Japan); blue shading = wintering range (eastern China, northeast India, South Korea and southern Japan, including vagrants occurring in northern Vietnam, Myanmar, Bangladesh and Thailand). Revised summer distribution was based on expert knowledge and tracking data (red dots = GPS locations for each tagged individual point whilst on the summering grounds, from 1 May to 30 October). Revised wintering range was based on field survey data and expert knowledge (see *Methods* for details). Six individuals tracked successfully were caught in one key wintering area (the Yangtze River floodplain). Circle with a black dot = the capture site, *n* = the number of birds that completed at least one spring or autumn migration (see Supporting Materials Table S1). All the site/area names mentioned in the paper are illustrated on the map.

contemporary drought conditions, the species is now absent.

The known wintering range has increased modestly in eastern China and south-western India, but also in South Korea, southern Japan, and from northern Vietnam to Myanmar, Bangladesh and Thailand. The updated distribution map of the wintering distribution also now includes some additional coastal areas in eastern China (Fig. 2).

Changes in abundance in the Yangtze River floodplain

Numbers of Falcated Ducks wintering in the Yangtze River floodplain have shown major fluctuations during 1987/88–1990/91 to 2019/20 (Fig. 3), with no overall significant trend ($F_{1,3}$ = 0.12, r^2 = 0.006, P = 0.85, n.s.) although utilising counts from different years during 1987/88–1990/91 (see *Methods*) may have influenced the results. The 1987/88–1990/91 counts indicated that the Jiangxi and Hunan lakes supported the largest number of Falcated Ducks in the region at this time, but since then numbers at the Jiangxi lakes have declined, while those in Hunan increased slightly and those in Hubei increased considerably; in 2019/20, Hubei supported > 37% of the all Falcated Ducks counted in the Yangtze

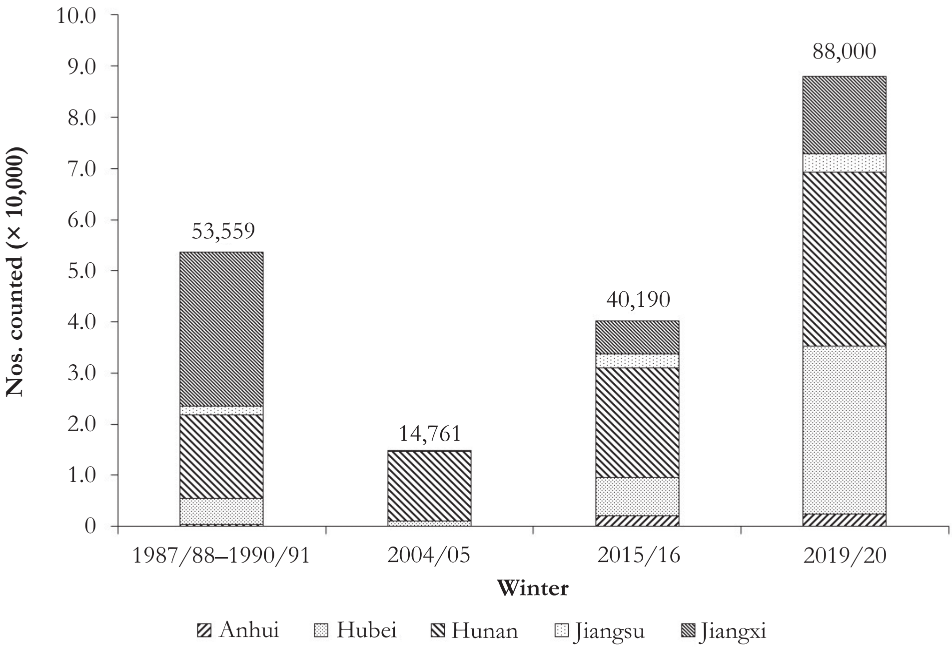

Figure 3. Falcated Duck counts from each province in the Yangtze River floodplain from 1987/88–1990/91 to 2019/20. The total for winters 1987/88–1990/91 was the sum of the maximum count for each lake during this period (see *Methods*), based on published information from Li & Jiang (1990), Li *et al.* (2009) and the Waterbird Specialist Group of Chinese Ornithological Association (1994). Counts from 2004/05, 2015/16 and 2019/20 were based on unpublished data from the Cao group's wintering surveys in the Yangtze River floodplain. See Supporting Materials Table S3 for detailed counts.

River floodplain (Supporting Materials Table S3).

Key wintering sites of the Falcated Duck

Seventeen key wintering sites were identified for the Falcated Duck in the Yangtze River floodplain and two more on the eastern coast of China (Table 2, Fig. 4, Table S6). Key sites supported the majority of the total numbers of Falcated Ducks counted in the Yangtze River floodplain in winters 2004/05 (93.5%), 2015/16 (93.4%) and 2019/20 (94.0%) (Table S3, Table S6), as well as 84.9% of total numbers wintering on the coasts of eastern China during 2003/04–2006/07 (Table S4).

Changes in numbers of Falcated Ducks at key wintering sites

Numbers of Falcated Duck counted in the Yangtze River floodplain increased at most key wintering sites between 2004/05 and 2019/20, while the number of key sites that supported > 1% of the population estimate also increased (Fig. 5, Table S6). In 2004/05, 2015/16 and 2019/20, one, nine and 13 of the key sites supported > 1% of the population estimate, respectively. The total number of birds counted at the key sites also increased, from 13,805 in 2004/05, and 37,545 in 2015/16, to 82,727 in 2019/20. In general, key sites in Hubei, Jiangsu and Jiangxi showed continuous and considerable increases in Falcated Duck numbers, including Chen Lake, Fuhe, Tuandun Lake, Wu Lake, Chishan Lake, Tai Lake, Chi Lake and Poyang Lake; whilst many key sites in Anhui and Hunan showed fluctuating numbers, including Caizi Lake, East Dongting Lake and West Dongting Lake.

The numbers of Falcated Duck counted at key sites increased by 22,240 individuals between 2004/05 and 2015/16, comprising 87% of the total increase in the Yangtze

Table 2. Maximum number of Falcated Duck counted at key coastal wintering sites of eastern China during December to February in winters 2006/07, 2016/17 and 2018/19. Citations: [a]from surveys conducted along the coast in winters 2003/04–2006/07 (L. Cao unpubl. data); [b]Cornell Lab of Ornithology (2019).

No.	Province	Wetland	Location	Counts in winters 2003/04–2006/07		Counts in winters 2015/16–2018/19	
				Date	Count	Date	Count
1	Shandong	Laizhou Wan	37°21'N, 118°47'E	13/02/2007	7,000[a]	16/12/2017	40[b]
2	Zhejiang	Hangzhou Wan	30°18'N, 121°21'E	19/01/2007–21/01/2007	5,660[a]	25/02/2019	1,200[b]

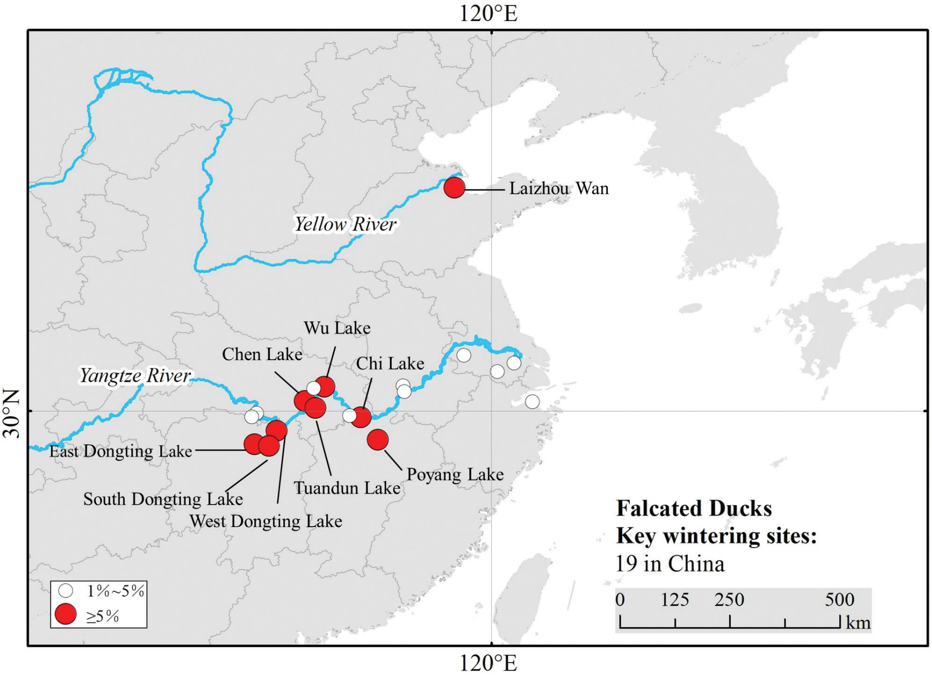

Figure 4. Map showing 19 key wintering sites identified for Falcated Duck in China. These include 17 sites in the Yangtze River floodplain (of which nine supported > 1% and eight sites supported > 5% of the total population estimate of 83,000 individuals) and two sites on the eastern coast of China (one with > 1% and one with > 5% of the total population estimate), based on maximum counts at each site from mid-January surveys of the Yangtze River floodplain in winters 2004/05 and 2015/16–2019/20, and surveys of the coast of China in December–February during winters 2003/04–2006/07.

River floodplain (Table S6, Fig. 3, Fig. 6). The increase in numbers at revisited sites where count coverage had not changed amounted to 52% of the total count increase at the key sites. If we consider the numbers of Falcated Ducks that were counted at lakes where coverage changed between surveys, then the addition/removal of new survey sites contributed the remaining 48% of the increase in local count totals.

Numbers of Falcated Ducks counted at key sites increased by 45,182 individuals between 2015/16 and 2019/20, comprising 95% of the total increase in the species counted in the Yangtze River floodplain (Table S6, Fig. 3, Fig. 6). The increase at revisited sites explained 41% of total count increase in the key sites, and the increase because of the addition/removal of survey sites explained 59% of the increase in total counts.

The literature-based counts from 1987/88–1990/91 showed that surveys at that time provided poor coverage of the Yangtze River floodplain (although we lack detailed information on coverage of lakes) compared

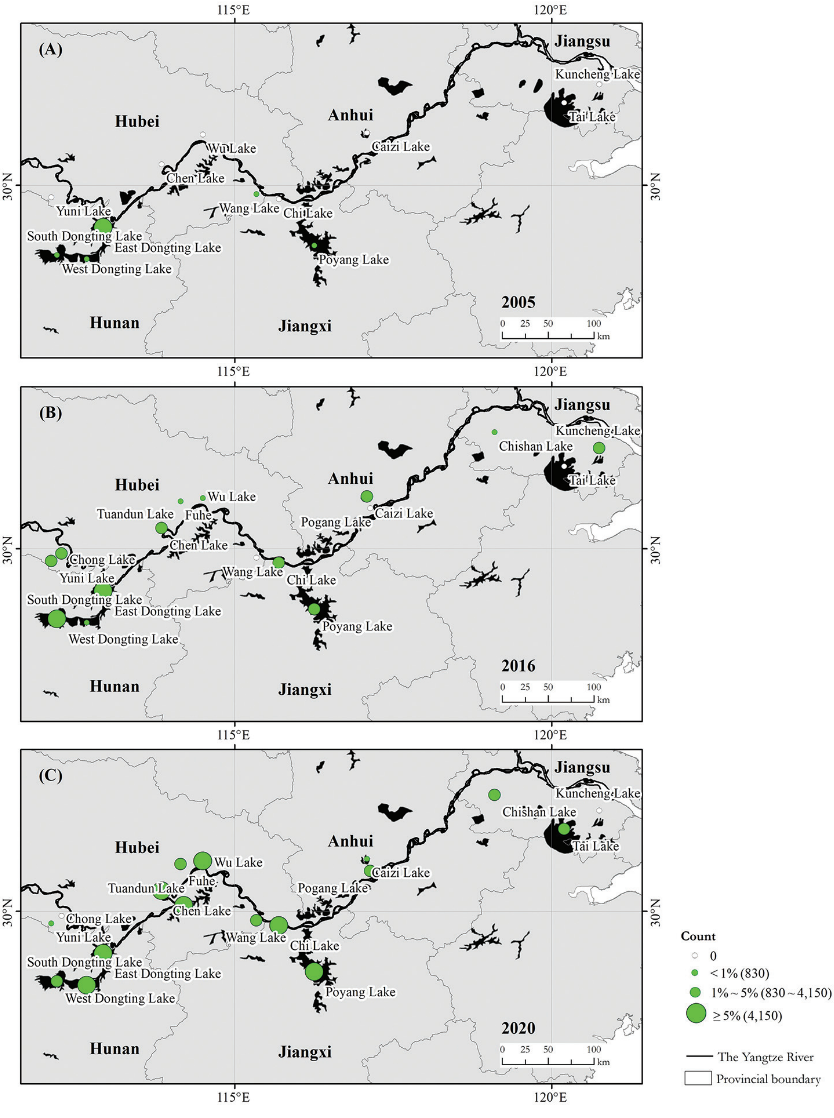

Figure 5. Changes in the numbers and distribution of key wintering sites (with ≥ 1% and in some cases ≥ 5% of the total population) for Falcated Ducks in the Yangtze River floodplain in China. One of 12 key wintering sites surveyed had internationally important numbers (> 5%) in 2004/05 (A); nine of 17 key wintering sites surveyed (seven with > 1% and two with > 5%) in 2015/16 (B); and 13 of 17 key wintering sites surveyed (six with > 1%; seven with >5%) in 2019/20 (C). The number of key wintering sites for Falcated Duck in the Yangtze River floodplain therefore has increased from 2004/05 to 2019/20 and, from being concentrated at East Dongting Lake in 2004/05, distribution has extended to South Dongting, West Dongting and Hubei Lakes, with a marked increase in the numbers wintering on the Hubei Lakes. White circles = sites that were visited but no ducks were present. The size of the green circles indicates the numbers counted, as a proportion of individuals compared to the total numbers estimated in the Central & East Asia population.

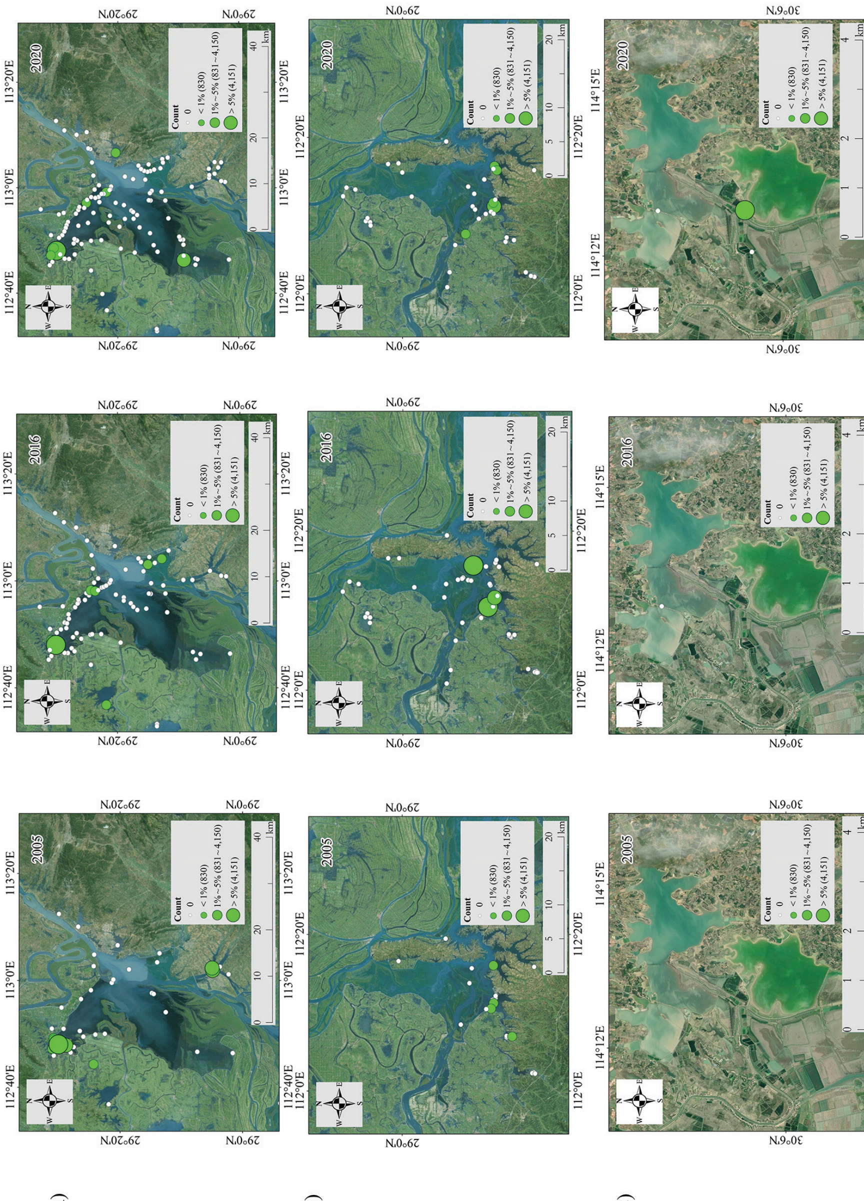

Figure 6. Changes in the distribution of the Falcated Duck within three key sites: (A) East Dongting Lake, (B) West Dongting Lake and (C) Tuandun Lake, which held the largest numbers counted between winters 2004/05, 2015/16 and 2019/20. White circles = zero birds counted. Size of the green circles = the numbers counted as a proportion of individuals, in relation to the total numbers estimated for the Central and East Asia population.

with the systematic wintering survey coverage achieved in 2004/05, 2015/16 and 2019/20. For this reason, it is difficult to compare with confidence the changes in counts at key sites since the late 1980s. However, relatively high numbers were counted at many lakes during 1987/88–1990/91, such as Shengjin Lake (400), Hannan Lake (135), Hong Lake (4,774), Gaobao Lake (1,070), East Dongting (16,470) and Poyang Lake (30,000), which suggests numbers present in 1987/88–1990/91 were likely to be higher than in the early 2000s.

The counts at coastal key sites declined considerably between 2003/04–2006/07 and 2015/16–2019/20 (Table 2). The counts in Hangzhou Wan, Zhejiang Province, declined from 5,660 in 2006/07 to 1,200 in 2018/19, while the counts in Laizhou Wan, Shandong Province, declined from 7,000 to 40 individuals in 2016/17, which lost its international importance for this species.

Autumn and spring migration

Detailed movements of one full autumn migration of one Falcated Duck, and five full spring migrations of five others were obtained from the tagged birds (Table 1, Table 3, Fig. 7). Autumn departure date from the summering area was 28 October 2017 and arrival at the winter quarters was on 16 November. The tagged duck used one inland stopover site for 18.4 days. Migration distance was 1,608.7 km, while migration speed was 87.6 km/day. The number of travel days was 2.7 in two legs.

Mean spring departure date was 19 April (ranging from 30 March to 3 May), mean arrival date was 26 May (ranging from 4 May to 19 July, see Table 3 for full details). The tagged ducks used an average of two stopover sites (range = 1–3) for between 9.5 and 73.4 days; 80% of the stopover sites are located in the inland areas, but only 20% are in coastal areas. Mean migration distance was 2,653.6 km (range = 1,919.9–3,556.1 km), while mean migration speed was 92.9 km/day (range = 35.1–146.3 km/day). The mean number of travel days was 7.7 (range = 1.5–16.9) in a mean of three legs (range = 2–4) of mean length 982.6 km (range = 597.1–1778.1). Mean travel speed was 741.7 km/day (range = 141.2–1,280.0).

Land use types used during spring, summer, autumn and winter period

During their spring stopover periods, birds were much more confined to water (68.7%), followed by use of cropland (16.2%; Fig. 8, Supporting Materials Table S5). During the summer period, the tagged duck (fd001) mainly used grassland (46.3%) and water (42.0%; Fig. 8, Table S5). During the autumn stopover period, grassland (31.8%) was the most commonly used habitat, followed by cropland (23.0%), wetland (19.5%) and water (19.1%; Fig. 8, Table S5). During winter, the ducks mainly used water (50.3%) and cropland (28.9%), followed by wetland (18.6%; Fig. 8, Table S5). Only 18% of all of the stopover sites were in coastal areas, of which the stopover duration during the spring migration comprised a mean ± s.d. of 14.4 ± 11.8 days; the one individual tracked during the autumn migration used a stopover site for 16 days (Table 1).

Table 3. Six migration parameters of the migration process of five Falcated Ducks in autumn and spring, including one complete autumn migration route and five complete spring migrations. To obtain reliable results, one spring migration presented in Fig. 2 was excluded from migration analyses because of large sampling gaps caused by low power supply. The results showed that most of the stopover sites of Falcated Ducks were inland rather than coastal areas, implied that the increasing number of Falcated Ducks inland may be related to the destruction of coastal habitats.

Bird ID	Year	Season	Departure date	Arrival date	Migration duration (days)	Migration distance (km)	Migration speed (km/day)	Travel days (days)	Travel speed (km/day)	Step length (km)	No. of migration legs	No. of stopover sites	Stopover duration (days)
fd001	2016	Spring	30 Apr 16	18 May 16	17.2	1,919.9	111.6	1.5	1,280.0	960.0	2	1	15.7
fd002	2016	Spring	3 May 16	19 Jul 16	76.3	2,680.6	35.1	2.9	918.9	670.1	4	3	73.4
fd003	2016	Spring	27 Apr 16	23 May 16	25.3	2,722.7	107.8	2.4	1,127.4	907.6	3	2	22.8
fd004	2018	Spring	9 Apr 18	4 May 18	24.3	3,556.1	146.3	14.8	240.9	1,778.1	2	1	9.5
fd006	2018	Spring	30 Mar 18	7 May 18	37.6	2,388.5	63.5	16.9	141.2	597.1	4	3	20.7
fd001	2017	Autumn	28 Oct 17	16 Nov 17	18.4	1,608.7	87.6	2.7	585.8	804.4	2	1	15.6

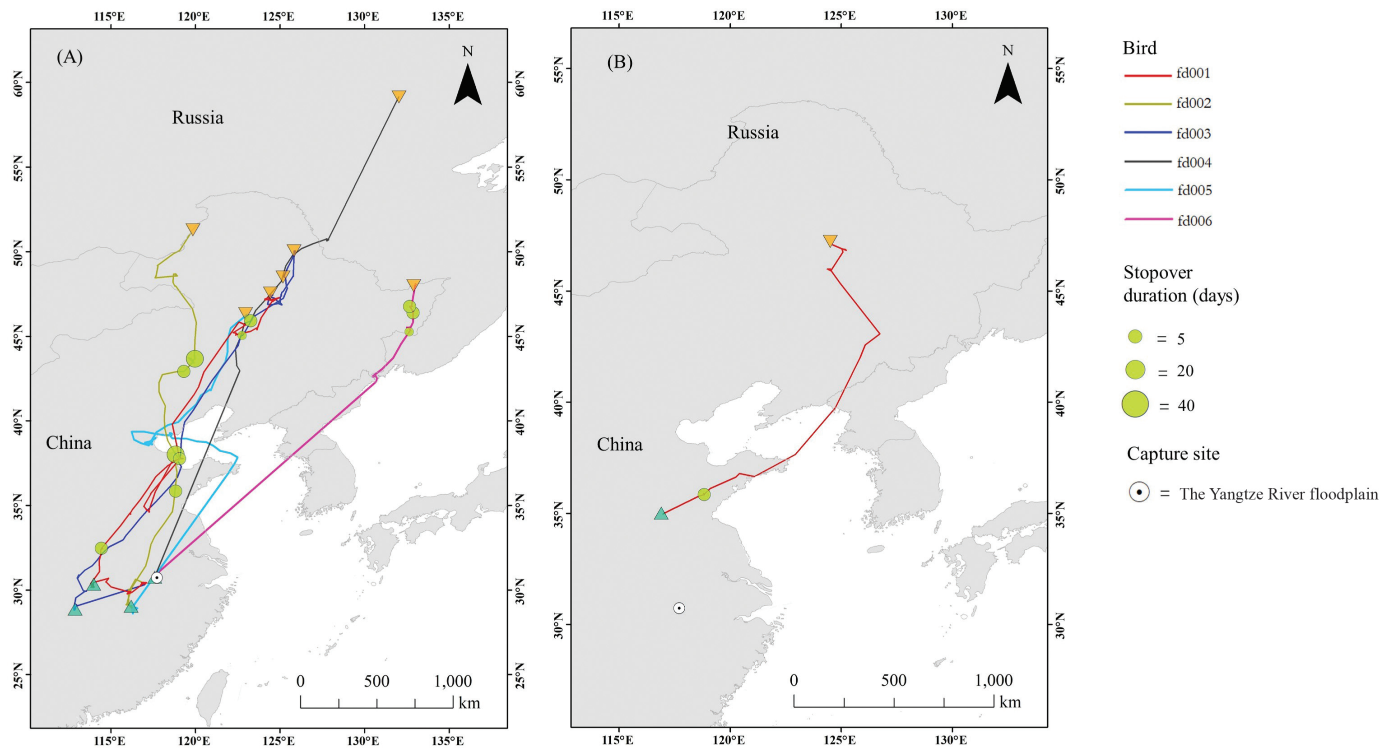

Figure 7. (A) Spring and (B) autumn migration routes of six Falcated Duck tracked, using GPS/GSM telemetry devices, between Russian/Chinese moulting areas and Chinese wintering sites during 2015/16–2017/18. Orange and cyan triangles = post-breeding and wintering sites, respectively; green circles = individual stopover sites and their size corresponds to stopover duration. Solid lines show the individual migration tracks.

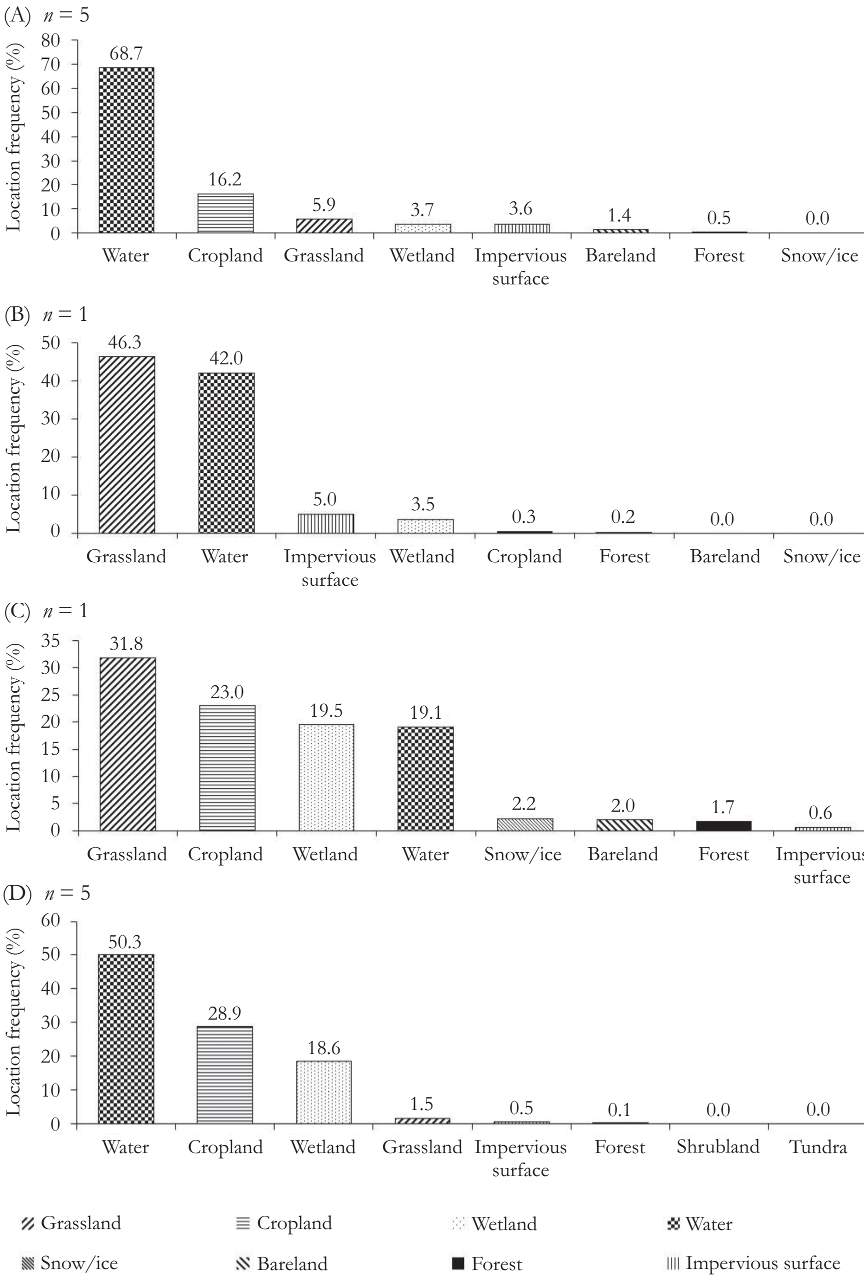

Figure 8. Land use by Falcated Ducks in: (A) spring (at 10 stopover sites of five individuals), (B) summer (one summering site of one individual), (C) autumn (one stopover of one individual), and (D) winter (five wintering sites of five individuals), based on individual tracking data.

Discussion

Distribution range

It has long been known that the Yangtze River floodplain and coasts of eastern China are key wintering areas for Falcated Ducks (Cao *et al.* 2008). This study has confirmed that the species winters at sites throughout the Yangtze River floodplain, but especially in the river's middle to lower reaches, in line with models of habitat selection developed for the species (Prosser *et al.* 2018). Since 2005, the improved quality and extent of waterbird survey coverage achieved in the Yangtze River floodplain is believed to have greatly enhanced our ability to monitor abundance of Falcated Duck in what appears to be an increasingly critical wintering area for the species. However, we recognise that while the species is well monitored at many sites in the Yangtze system, South Korea and Japan, we lack more recent mid-winter counts from areas where it was formerly thought to be much more common, in central and coastal China. Additionally, the species has been reported in Bangladesh, India, Myanmar and Thailand, so extended and regular coordinated monitoring as part of the annual Asian Waterbird Census is essential for effective future assessment of the global abundance of this Far East specialist duck species.

Flyway structure

The migration patterns first identified by Takekawa *et al.* (2010) linking northeast China/eastern Russia breeding areas with Poyang Lake were confirmed in this study. However, we still lack information about the connectivity and migration routes taken by Falcated Duck wintering in central China, east China coasts, South Korea and Japan, as well as the smaller numbers that winter elsewhere in the region. As our limited tracking data implied no connections with birds from these regions, additional telemetry studies, involving birds caught at a wider range of summering and wintering areas are urgently needed to improve our knowledge and understanding of overall Falcated Duck migration patterns. This would potentially identify discrete flyway and separate breeding/wintering management units within the overall global population range, which would permit more precise estimation of population sizes and trends, as well as providing a basis for effective conservation interventions for such management units.

Changes in abundance in the Yangtze River floodplain

These results confirm that, numerically, the Yangtze River floodplain is now the only critical wintering area of the Falcated Duck in East Asia, as recent surveys showed that other historical key wintering areas, *e.g.* Lianyun Gang and Sheyang River (Cao *et al.* 2010) have lost their former importance. Our systematic surveys provided a comprehensive estimate of at least 88,000 wintering individuals in the floodplain in 2019/20, after an apparent increase over the last two decades (although the lack of adequate survey data precluded extensive comparisons with numbers counted at restricted sites in 1987/88–1990/91). However, the high numbers counted at many lakes in the 1980s, such as at Hong Lake and Poyang Lake, suggest a potential decline from the numbers at these sites from that time to the present. Falcated Duck can be difficult to count because they typically roost by day far out in the middle of large lakes and fly out to feed at night, often on fields adjacent to wetlands where they are subject to poaching (Tao *et al.* 2010). This behaviour could potentially contribute to the large fluctuations in abundance over the last 30 years, as our counting techniques have improved, but could also mean that increased poaching might contribute to real declines in abundance (Li & Jiang 1990). While there is no doubt that more extensive survey coverage during 2004/05 to 2019/20 contributed to the increase in overall counts, there is also little doubt that on sites subject to constant count coverage, wintering numbers have increased by over 50% (Supporting Materials Table S6). Hence, for whatever reason, there seems to be more Falcated Duck in the Yangtze River floodplain now compared to 10–15 years ago.

Whether this reflects a genuine increase in the global population or simply a redistribution of wintering birds from elsewhere on the winter quarters remains a matter of speculation. Stable numbers in Japan over the last 30 years rather suggest no change there (Kasahara & Koyama 2010), and although recent declines in South Korea (Moores *et al.* 2014) could perhaps have contributed to increases in the Yangtze, the small numbers involved in both countries cannot explain the overall increases in China. We lack data from coastal Chinese wetlands in recent years, where in 2003/04–2006/07 more than 61% of Chinese Falcated Duck were counted in winter (Cao *et al.* 2010). However, counts by birdwatchers have shown considerable declines at two coastal key sites and most of the tracking data recorded at stopover sites indicate that only 18% of these sites were in coastal areas, possibly suggesting an overall decline in coastal use (Table 1, Table 2). This possibility conforms with the long-term habitat loss of coastal tidal wetlands (Murray *et al.* 2014), which may have forced the population to shift to wetlands elsewhere, resulting in the increase in abundance in the Yangtze River floodplain, without reflecting changes in overall population size. Admittedly, the comparison of earlier surveys and recent birdwatching counts may overestimate the decline, because the birdwatching data may have been less comprehensive or accurate than systematic monitoring. Therefore, more systematic coverage of Chinese coastal wetlands and elsewhere, and also more tracking studies are required for this species, to gain a clearer understanding of the situation.

Alternatively, there is some evidence from Falcated Duck breeding areas in Russia to suggest there could have been an increase in abundance, which would support the hypothesis of a local or global population growth. For example, in the summering area in Transbaikalia, Russia, numbers declined until 2000, but then rose subsequently (Goroshko 2012). Such an increase was recorded throughout the entire Transbaikalia area, including the Argun River where one Falcated Duck (fd002) tracked from the Yangtze River spent the summer. The increase in local densities in Transbaikalia occurred despite local habitat deterioration caused by the severe long-term drought in the area, which resulted in wetland loss and degradation during 2000–2019 (O. Goroshko, unpubl. data). It is possible that local increases in density may also reflect an aggregation of the species responding to local habitat loss, but could also correspond with the increase in the numbers wintering on the Yangtze River, some of which are known to originate from this region.

Given the wide distribution of the species and the enormous number of lakes in the Yangtze, it would be important to enhance survey efforts to cover additional lakes in the Yangtze River floodplain to obtain an enhanced understanding of the total numbers wintering there, as well as exchanges of numbers between sites within and between years (Meng *et al.* 2019). This should be carried out in conjunction with the deployment of more telemetry devices to understand the potential within- and between-winter movements between these wintering areas, despite the lack of evidence for this from our very limited study.

Key wintering sites of Falcated Ducks in eastern China

The growing importance of lakes in Hubei for the Falcated Duck is noticeable, given the increase in the number of key sites and the number of ducks at those sites. It was known that habitat destruction and illegal hunting in Hubei seriously threatened waterbirds at the end of the last century, which corresponded to the apparent decline in duck numbers since the 1980s. Water pollution and eutrophication also have become a serious problem since the 1980s, compounded by hunting at the fewer, smaller and degraded wetlands since that time (Li & Jiang 1990; Wang *et al.* 2002; Shi *et al.* 2004; Yu 2006). However, since 2010, the need for wetland conservation in Hubei has been recognised, promoted and enhanced by the government and local communities (Qing 2018). The Chen Lake and Wang Lake Nature Reserves were designated as Ramsar sites in 2013 and in 2018, respectively, and in 2019 Chong Lake was listed as a National Wetland Park (National Forestry and Grassland Administration 2019). It is considered that local wetland conservation actions have benefited wintering waterbirds (*i.e.* ducks, geese and swans) at the Hubei lakes (L. Cao, unpubl. data).

Although we should be prudent not to conclude too much from the few surveys at two locations, the decline in abundance at the two coastal key wintering sites – at Laizhou Wan, Shandong and at Hangzhou Wan, Zhejiang – was likely to have been caused by habitat loss and degradation. The reclamation of mudflats in Laizhou Wan has been ongoing since 1985 and the coastal waters were highly polluted in 2010 (State Oceanic Administration 2015; Wei *et al.* 2018). The mudflats in Hangzhou Wan have been reclaimed for aquaculture since 1986, which peaked during 2010–2014, losing 166.95 km^2 mudflats in the four decades (Jiao *et al.* 2017). By inspecting historical satellite images in Google Earth, we found direct evidence of habitat loss at the exact location of key coastal wintering sites (Supporting Materials Fig. S1). This pattern of long-term loss of tidal wetlands in eastern China has been dramatic and widespread (Murray *et al.* 2014).

Land use feeding habits at stopover sites

During the spring migration, a previous study has shown that a Falcated Duck used a stopover site near Qingdao in Shandong Province (Takekawa *et al.* 2010). This, together with the use of two coastal stopover sites by two individuals (fd002, fd003) in 2016 and also of five inland stopover sites with lakes and reservoirs (Gannuoer Lake, Xingkai Lake, Hamatong Reservoir, Qingfengling Reservoir) in our study, illustrate the importance of the aquatic environment for Falcated Ducks during the spring migration (Table 1, Fig. 8). Falcated Ducks also used croplands during spring migration, as is known from Korea and Japan where Falcated Duck regularly use rice fields in autumn and winter (Fujioka *et al.* 2010). The patterns of land use by tracked Falcated Duck at their stopover sites reflects dietary studies, which found that this species mainly feeds on aquatic vegetation including algae, but sometimes moves to farmland to feed on rice and seedlings, and occasionally eats crustaceans, aquatic insects and molluscs (Zhao 1999). Generally, the Falcated Duck shows flexible feeding behaviour, exploiting a range of food items gleaned while feeding in shallow water as well as foraging on dry and arable land (Carboneras & Kirwan 2019).

Conservation recommendations

Although all the current indications suggest that the numbers of wintering Falcated Ducks in the Yangtze River floodplain have increased since 2005, it remains unclear if this represents an increase in overall population size or simply a redistribution within the wintering range. Nor does the increasing concentration in the Yangtze mean that this species will not face other potential risks, such as continued habitat loss and degradation (Xu *et al.* 2019). In an earlier analysis, we showed that Falcated Duck stayed longer at larger lakes (as at Poyang and Dongting), and had much shorter residency times and more frequent shifts when associated with small wetlands on the winter quarters compared to their more sedentary behaviour at the larger lakes (Meng *et al.* 2019). Both Poyang and Dongting Lakes, key sites for Falcated Duck and the largest of the Yangtze lakes, face the threat of dam constructions that are likely to affect feeding conditions for waterbirds at these sites (Yang 2012; Wang *et al.* 2017). Poaching also poses a threat to the ducks in many places in the Yangtze River floodplain (MaMing *et al.* 2012), as well as in the summering areas in Russia, where the breeding birds are additionally threatened by extensive spring grass-fires on wetlands (Goroshko 2012).

Reclamation has probably caused the loss of important habitat and the decline in abundance of Falcated Ducks at the two key coastal wintering sites in eastern China. As one of the main threats to coastal waterbirds to date has been the loss of intertidal and associated coastal habitat, it is important that these reclamations are stopped and habitats restored. It is hoped that enforcement of the 2018 national policy to halt coastal reclamation projects that contravene national policies, as well as the demolition of illegal structures on unlawfully reclaimed land, may protect the remaining coastal wetlands of importance to Falcated Duck and reinstate some of the lost areas (Zhao 2018).

Moreover, public education and the enhancement of the scientific literacy of citizens is needed to heighten public awareness and support for protecting waterbirds and wetlands. The conservation and management of ecosystem services provided by coastal wetlands, as well as by the Yangtze River floodplain wetlands and those in other areas across its breeding and non-breeding range, are required for the effective protection of the Falcated Duck, which is an iconic species of these wetlands.

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Photograph: Falcated Duck at Tsagaa Lake, northern Mongolia, in 2020, by Iderbat Damba.

