MIGRATION PATTERNS OF *ANSER ANSER RUBRIROSTRIS* (ANSERIFORMES) ALONG THE CENTRAL ASIAN FLYWAY REVEALED BY GPS/GSM TELEMETRY

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Anser anser rubrirostris is one of the most widespread waterfowl species in Eurasia. However, its Central Asian populations have experienced pronounced historical declines. Between 2019 and 2022, we tracked 20 adult *Anser anser rubrirostris* breeding in Northern Kazakhstan using GPS/GSM telemetry, resulting in 34 complete migratory journeys from 15 individuals (21 autumn migration routes and 13 spring migration routes). During migration, individuals used between one and eight stopover sites per season, with stopover durations ranging from 1 to 51 days. Mean migration distances were 3289 ± 895 km in autumn and 3253 ± 453 km in spring. The mean migration speed was higher in autumn (132.4 ± 35.6 km day^{-1}) than in spring (98.3 ± 24.4 km day^{-1}), whereas route straightness remained similar between seasons (0.77–0.78). In total, 19 major stopover sites were identified along the Central Asian flyway, of which only 16.7% were located within Protected Areas. Most stopovers (83.3%) occurred at unprotected wetlands, including key staging areas in Uzbekistan (Jiltyrbas, Karakir, Aydarkol), Kazakhstan (Syrdarya floodplain), and the Caspian coastal zone of Turkmenistan and Russia. The longest stopovers were recorded at Barsakelmes State Nature Reserve (Kazakhstan, up to 41 days) and Lake Karakir (Uzbekistan, up to 51 days). This study provides the first telemetry-based assessment of migration ecology and stopover use of the Western Siberian *Anser anser rubrirostris* population along the Central Asian flyway, highlighting a strong dependence on unprotected wetlands and emphasising the urgent need to strengthen habitat protection across the flyway.

Key words: Central Asia, flyway connectivity, satellite telemetry, seasonal migration, stopover ecology, waterbird conservation, wetland networks

Introduction

Although *Anser anser rubrirostris* (Linnaeus, 1758) has long attracted scientific and conservation interest, dedicated studies on its ecology and migration dynamics remain scarce in recent decades (Boos et al., 2019; Månsson et al., 2022). The species occupies an extensive breeding range across Eurasia, from Iceland and Scandinavia to Western Siberia and Central Asia (Nilsson, 2017; Fox & Leafloor, 2018). However, populations in Central Asia have experienced dramatic declines, primarily due to the loss and degradation of wetlands, agricultural expansion, and intensive hunting pressure (Erokhov, 2003; Tarasov, 2016; AEWA, 2018). Most contemporary knowledge of *Anser anser rubrirostris* migration originates from Europe and Western Siberia, where ringing and GPS telemetry studies have described migration timing, staging ecology, and connectivity between breeding and wintering grounds (Nilsson et al., 2013; Kölzsch et al., 2016; Heldbjerg et al., 2024). In contrast, empirical information from Central Asia is almost entirely lacking (Wetlands International, 2015; AEWA, 2018). This gap hampers understanding of the Western Siberian population, which migrates primarily along the Central Asian Flyway (hereinafter – CAF) is one of the least studied global migration corridors (Li et al., 2020). Recent advances in satellite and GSM telemetry have enabled high-resolution tracking of individual movement patterns, providing new insights into migration timing, habitat connectivity, and species-specific responses to environmental change (Kleinhenz & Koenig, 2018; Boos et al., 2019). Yet until recently, such studies had never been conducted within the Central Asian region. The present research addresses this gap by analysing the spatial structure, timing, and stopover behaviour of the Western Siberian population of *Anser anser rubrirostris*, using satellite telemetry. The study provides the first quantitative dataset on migration parameters and site use along the CAF, offering valuable baseline information for conservation management and flyway-scale planning. These findings support the ongoing revision of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (International Single Species Management Plan, ISSMP) for *Anser anser* *rubrirostris* by providing new evidence necessary to update conservation priorities, threat assessments, and cross-border management actions. The main objectives were to (1) describe migration routes and parameters, (2) identify and evaluate major stopover sites, and (3) assess the level of protection of key wetlands used along the migration corridor.

Material and Methods

Capture and tagging

Fieldwork took place during the breeding seasons of 2019–2021 in the Karatau area (54.4000° N, 68.6333° E) within the Smirnovsky State Zoological Sanctuary, Northern Kazakhstan. Smirnovsky State Zoological Sanctuary represents an important breeding, moulting, and staging area for several *Anser* species. Birds were captured using remotely triggered mechanical «Tainik» traps following standard waterfowl-trapping approaches adapted to local conditions (Kenward, 2001; Vilkov et al., 2018; Nilsson et al., 2022). Each captured individual was equipped with a collar-mounted GPS/GSM transmitter (Ornitela, Lithuania; 35–45 g), representing less than 3% of body mass, which is within accepted welfare limits (Casper, 2009; Fair et al., 2010). Solar-powered transmitters recorded positional fixes at one-hour intervals and transmitted data every 12 h.

The sex of each individual was determined immediately after capture by cloacal examination following established protocols for waterfowl (Dzubin & Cooch, 1992; Baldassarre & Bolen, 2006). In total, 20 adult birds were tagged: ten in 2019 (4♂, 6♀), three in 2020 (1♂, 2♀), and seven in 2021 (3♂, 4♀). All procedures complied with international ethical standards for the handling and marking of wild birds (Fair et al., 2010; Zuban et al., 2020a; Zuban & Timoshenko, 2025).

Data processing and migration metrics

We processed and visualised all positional data in Google Earth Pro and ArcGIS 10.8 (Kölzsch et al., 2015). Migration phases were defined as follows: spring migration was considered to be the movement from the last wintering location to the first breeding-site position, and autumn migration the movement from the last breeding (or pre-migratory) position to the first wintering record. Stopover sites were identified as areas where individuals remained for at least 0.3 days (Kölzsch et al., 2016). This shorter threshold is biologically justified, as even brief stopovers can markedly reduce physiological stress, enable partial refuelling, and maintain thermoregulatory balance after prolonged flights, particularly under resource-poor conditions, characteristic of arid Central Asian landscapes (Klaassen, 1996; Gómez et al., 2017; McWilliams et al., 2020). Of the 20 tagged individuals, we obtained 21 complete autumn migration tracks (from 15 birds) and 13 complete spring migration tracks (from nine birds). Only individuals providing data for at least one full migratory season were retained, resulting in a final dataset of 34 complete migratory journeys used for all analyses. Not all tagged individuals completed full migratory cycles due to transmitter failure or mortality; therefore, only complete migration routes were retained for analyses. The total migration distance was calculated as the cumulative sum of all travel segments between consecutive GPS positions. To evaluate route geometry, we calculated a straightness index (Benhamou, 2004) by expressing the ratio between the direct breeding–wintering distance and the cumulative travel path. Migration duration was defined as the combined time spent by travelling and stopping; pre-migratory local movements and staging events occurring before the first directed long-distance flight were not included in migration duration calculations.

The mean migration speed was calculated as the total migration distance divided by the total migration duration, including all stopover days. In addition, we calculated active-flight speed, defined as the cumulative distance travelled during days of directed movement divided by the number of active flight days (i.e. excluding stopover days). Active-flight speed thus represents the daily distance travelled during periods of active movement between stopover sites and does not reflect sustained flight speed. Active flight days were derived as migration duration minus stopover duration. This metric reflects movement intensity during limited periods of active displacement (Nilsson et al., 2013), rather than continuous airspeed or physiological flight limits. Because some individuals migrated within very narrow temporal windows, values of active-flight speed could become high when only one or two days of directed movement occurred; such cases therefore indicate behavioural strategy rather than maximum flight capability. For this reason, active-flight speed was used to compare relative variation in migratory movement intensity among individuals, whereas mean migration speed was retained for phenological comparisons across seasons. To assess the level of protection of key sites used along the CAF by *Anser anser rubrirostris*, we consulted the database of Important Bird Areas (BirdLife International, 2024).

Mortality inference

Causes of individual mortality were inferred based on a combination of telemetry-derived indicators, including abrupt cessation of signal transmission during the wintering period, movement from natural habitats into human settlements, apparent transport along road networks, short-distance relocations within settlements, and prolonged stationary transmissions consistent with transmitter removal and subsequent discard. In the absence of independent field confirmation (e.g. carcass or tag recovery), such events were classified as suspected or likely human-caused mortality rather than confirmed causes of death.

Statistical analysis

We compared seasonal differences across seven key migration parameters: total migration duration, number of stopovers, mean stopover duration, total distance, mean migration speed, daily travel speed, and route straightness. Because the data did not meet normality assumptions, we applied the Mann-Whitney U test to test for differences between spring and autumn migrations. To explore relationships among parameters, we computed Spearman's rank correlation coefficients between migration duration, distance, and travel speed. We also used analysis of variance (ANOVA) to examine inter-annual variation and possible differences between breeding and non-breeding individuals. Significance was assessed at $p < 0.05$. All statistical computations were performed in Statistica 13.0 (StatSoft Inc., USA).

Results

From 20 tagged individuals monitored between 2019 and 2022, we obtained data for 21 complete autumn migration routes (2019: n = 7; 2020: n = 7; 2021: n = 5; 2022: n = 2) (Table 1). One bird was tracked over four consecutive field seasons, three birds were followed across two seasons, and 11 birds provided data for a single season only. In total, 13 complete spring migration routes were recorded (2020: n = 5; 2021: n = 3; 2022: n = 3; 2023: n = 2), comprising two routes from a single individual and one route each from six others. Of the 20 marked birds, seven individuals were lost as a result of human-related causes, potentially including illegal hunting, on the wintering grounds in Iran, Uzbekistan, Iraq, and the Chechen Republic (Russia). The fate of the remaining individuals remains unknown, likely due to transmitter failure or loss of GSM coverage.

Pre-migratory aggregations

After the breeding period and prior to the onset of autumn migration, individuals concentrated at large water bodies (Fig. 1), forming distinct premigratory aggregations (Si et al., 2018; Boos et al., 2019; Damba et al., 2021; Rozenfeld et al., 2024; Rogova et al., 2025). This stage plays a crucial role in the annual cycle, as individuals within the population accumulate essential fat reserves, while juveniles complete growth and strengthen flight muscles required for sustained long-distance flights (Damba et al., 2021; Heldbjerg et al., 2024). Satellite tracking revealed several major pre-migratory staging sites across northern Kazakhstan, many of which also function as important stopover areas for migratory waterfowl during both seasonal movements (Cuthbert et al., 2018; Zuban et al., 2020b). The mean arrival date at staging sites was 11 September (± 12.3 days; n = 21), and the mean duration of stay was 30.4 ± 22.1 days. Inter-annual variation was tested using a one-way ANOVA (factor: year), which showed no significant differences in aggregation timing ($F = 1.177$, $p = 0.320$), departure dates ($F = 3.237$, $p = 0.066$), or duration of stay ($F = 0.809$, $p = 0.465$). Sample sizes per year were small and unbalanced, which limits statistical power; therefore, these non-significant results should be interpreted cautiously. In 2022, the mean duration of stay increased to 51 days, but this estimate was based on only two individuals and should not be considered representative. Additional tracking data are required to determine whether this pattern reflects genuine temporal variation or arises from sampling bias.

Autumn migration parameters

Autumn migration of *Anser anser rubrirostris* begins in early October and continues until late November. The mean departure date from staging sites is 20 October (± 7.9 days; n = 21), and arrival at the wintering grounds is typically completed by 6 November (± 11.5 days). On average, the migration lasts 17.8 ± 11.8 days (n = 21), during which individuals cover approximately 3289 ± 895 km (n = 21). Along the flyway, birds make between one and eight stopovers, each lasting 1–40 days. The straightness index of the migratory trajectory averages 0.77 ± 0.12.

The mean migration speed, calculated as total migration distance divided by total migration duration (including stopover days), was 132.4 ± 35.6 km day^{-1}. In contrast, the active-flight speed during days of directed movement was much higher and more variable, reflecting short migration windows rather than sustained flight performance (see Table 2). These values describe movement intensity rather than physiological flight limits and should therefore be interpreted with caution.

Table 1. Summary of tagged individuals of *Anser anser rubrirostris*, availability of GPS/GSM migration data, and inferred transmitter fate in Northern Kazakhstan and along the CAF (2019–2023)

Bird ID	Sex	Year tagged	Autumn routes (years)	Spring routes (years)	Included in analysis (yes/no)	Mortality classification	Evidence basis (telemetry indicators)
CAF_AAR_01	Male	2019	0	0	no	unknown	signal loss/tag failure
CAF_AAR_02	Female	2019	0	0	no	unknown	signal loss/tag failure
CAF_AAR_03	Male	2019	0	0	no	unknown	signal loss/tag failure
CAF_AAR_04	Female	2019	1	0	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_05	Female	2019	1	1	yes	unknown	signal loss/tag failure
CAF_AAR_06	Female	2019	4	4	yes	unknown	signal loss/tag failure
CAF_AAR_07	Male	2019	1	1	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_08	Female	2019	2	1	yes	unknown	signal loss/tag failure
CAF_AAR_09	Female	2019	2	1	yes	unknown	signal loss/tag failure
CAF_AAR_10	Male	2019	1	0	yes	unknown	signal loss/tag failure
CAF_AAR_11	Male	2020	1	0	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_12	Female	2020	2	2	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_13	Female	2020	2	2	yes	unknown	signal loss/tag failure
CAF_AAR_14	Female	2021	1	0	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_15	Male	2021	1	0	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_16	Male	2021	1	0	yes	likely human-caused (potentially hunting-related) mortality	settlement entry, road-following, within-settlement relocations, stationary
CAF_AAR_17	Female	2021	0	0	no	unknown	signal loss/tag failure
CAF_AAR_18	Female	2021	0	0	no	unknown	signal loss/tag failure
CAF_AAR_19	Male	2021	2	1	yes	unknown	signal loss/tag failure
CAF_AAR_20	Female	2021	0	0	no	unknown	signal loss/tag failure

Note: Individual codes (e.g. CAF_AAR_01) refer to GPS/GSM-tagged individuals of *Anser anser rubrirostris*, where CAF denotes the Central Asian Flyway and AAR denotes *Anser anser rubrirostris*.

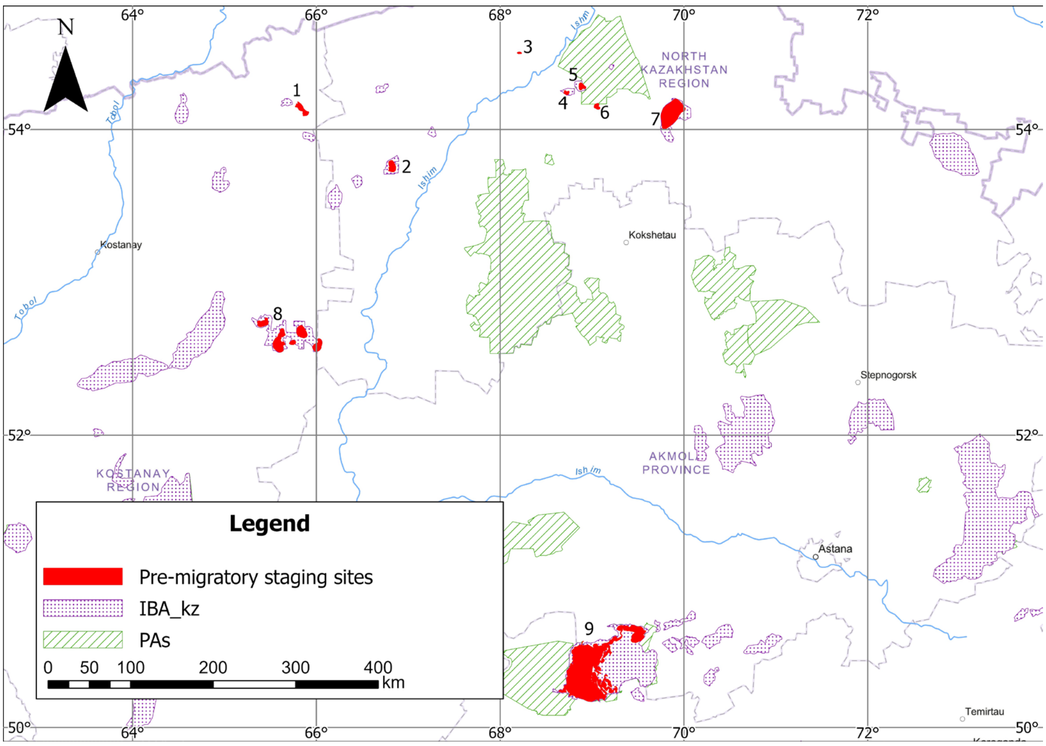

Fig. 1. Pre-migratory staging sites and duration of stay of the Western Siberian population of *Anser anser rubrirostris* in Northern Kazakhstan (2019–2022). Designations of staging sites: 1 – Saryoba; 2 – Maly Kak; 3 – Karatau tract; 4 – Zhylandy; 5 – Balykty; 6 – Uzynkol; 7 – Shaglyteniz; 8 – Koibagor-Tyuntyugur Lake System; 9 – Tengiz-Korgalzhyn Lake System.

Table 2. Detailed autumn migration parameters of *Anser anser rubrirostris* based on GPS/GSM telemetry along the CAF (2019–2022)

ID	Year	MS	ME	MD (d)	SD (d)	NS	Dist (km)	MMS (km d^{-1})	AFS (km d^{-1})
CAF_AAR_04	2019	20.10.2019	22.10.2019	2.5	1.38	2	2987	1194.8	2676.8
CAF_AAR_10	2019	20.10.2019	16.11.2019	27	26	2	4634	171.6	4634.0
CAF_AAR_07	2019	19.10.2019	16.11.2019	28	26	2	3453	123.3	1726.5
CAF_AAR_08	2019	19.10.2019	16.11.2019	28	26	2	3499	125.0	1749.5
CAF_AAR_09	2019	20.10.2019	17.11.2019	29	27	2	3575	123.3	1787.5
CAF_AAR_05	2019	06.10.2019	16.11.2019	41	40	2	2698	65.8	2698.0
CAF_AAR_06	2019	19.10.2019	16.11.2019	27	26	3	3527	130.6	3527.0
CAF_AAR_11	2020	13.10.2020	3.11.2020	20	18.1	8	5994	299.7	3154.7
CAF_AAR_13	2020	04.10.2020	12.10.2020	8	7.1	2	2591	323.9	2878.9
CAF_AAR_06	2020	18.10.2020	24.10.2020	6	5	2	2447	407.8	2447.0
CAF_AAR_08	2020	18.10.2020	21.10.2020	3	1.5	3	2190	730.0	1460.0
CAF_AAR_09	2020	23.10.2020	13.11.2020	21	18	4	3589	170.9	1196.3
CAF_AAR_12	2020	30.10.2020	2.11.2020	3	1.1	2	2125	708.3	1118.4
CAF_AAR_06	2021	26.10.2021	28.10.2021	2	0.3	1	2961	1480.5	1741.8
CAF_AAR_19	2021	02.11.2021	6.11.2021	4	2.08	4	2574	643.5	1340.6
CAF_AAR_14	2021	26.10.2021	29.10.2021	3	1.41	7	2591	863.0	1629.6
CAF_AAR_15	2021	26.10.2021	29.10.2021	3	1.5	3	3238	1079.3	2158.7
CAF_AAR_16	2021	2.11.2021	23.11.2021	21	19	6	4371	208.1	2185.5
CAF_AAR_12	2021	30.10.2021	6.11.2021	7	4.5	4	3171	453.0	1268.4
CAF_AAR_19	2022	30.10.2022	17.11.2022	17	16	2	3211	189.0	3211.0
CAF_AAR_06	2022	27.10.2022	14.11.2022	18	17	2	2969	164.4	1653

Note: Codes of individuals are defined in Table 1. Abbreviations: MS – migration start; ME – migration end; MD – migration duration; SD – total stopover duration; NS – number of stopovers; Dist – migration distance; MMS – mean migration speed; AFS – mean active-flight speed.

Breeding individuals tended to migrate for longer periods, as shown by a one-way ANOVA comparing breeding status groups ($F = 9.612$, $p = 0.0112$; $n = 21$), and also spent more time at stopovers ($F = 10.49$, $p = 0.0089$; $n = 21$). The total migration distance, however, did not differ significantly between breeding and non-breeding birds. Correlation analysis (Spearman r_s; $n = 21$) revealed a moderate positive association between migration duration and total distance ($r_s = 0.596$, $n = 21$, $p = 0.004$) and a strong negative correlation between migration duration and mean migration speed ($r_s = -0.972$, $n = 21$, $p < 0.001$). A positive relationship was also detected between migration duration and daily progression speed ($r_s = 0.483$, $n = 21$, $p = 0.027$). Overall, autumn migration exhibited substantial individual variability in strategy, reflecting flexible behavioural responses to environmental and physiological conditions. These results provide a quantitative basis for a more robust ecological interpretation of route selection and movement energetics of *Anser anser rubrirostris* along the CAF.

Autumn migration routes and stopovers

The autumn migration of *Anser anser rubrirostris* shows a high variability in routes and a heterogeneous distribution of stopover sites. The main flyway passes through Central Kazakhstan, from where individuals move south-southwest to their first major stopover in the Aral Sea bays and the deltaic lakes of the River Syr Darya. In total, eleven tracked individuals used this region as a staging area. From the Aral region, migration flows diverge into four main directions. Individuals wintering in southern Uzbekistan and southeastern Turkmenistan continue southeast along the River Amu Darya floodplain. Birds destined for central Turkmenistan follow a more direct southern route. Individuals wintering on inland waterbodies of northern and central Iran migrate southwest along the southeastern Caspian coast. A smaller proportion moves strictly west, crossing the Caspian Sea and following its western shoreline towards wintering grounds in Azerbaijan and northwestern Iran (Fig. 2).

During autumn migration, *Anser anser rubrirostris* make between one and eight stopovers, with durations ranging from one to 41 days. The mean number of recorded stopovers was 3.2 ± 2.1. In total, nine major stopover sites were identified across Kazakhstan, Uzbekistan, Turkmenistan, Russia (Dagestan), and Iraq. The stopover duration varied substantially among regions. Extended stays (> 16 days) occurred more frequently in areas with high food availability, such as Kizlyar Bay (Dagestan) and the River Irgiz valley in Kazakhstan (Vilkov, 2023; BirdLife International, 2024). In contrast, short stopovers (1–4 days) predominated on intermediate sites, such as the western Aral Sea (Kazakhstan) and Lake Hamrin (Iraq), which likely function as temporary resting sites (Salih et al., 2022). The highest concentration occurred in the

Barsakelmes State Nature Reserve (Aral Sea, Kazakhstan), where up to eleven tracked individuals stopped over in different years, with a maximum stay of 41 days. At most other sites, only one or two individuals were recorded, indicating considerable individual variability in route selection. Individual cases illustrate the complexity of stopover strategies. For instance, individual CAF_AAR_15 made an additional sixteen-day stopover in Kizlyar Bay before continuing to winter at Lake Urmia (north-western Iran). Another bird (CAF_AAR_16, 2021) departed south-west after its pre-migratory staging, crossed the Caspian Sea, and stopped for fourteen days in the River Volga Delta (River Bakhtemir) before proceeding to Lake Hamrin (Iraq). Overall, the autumn migration of *Anser anser rubrirostris* constitutes a complex spatio-temporal system, encompassing both long-term staging sites and short-term intermediate stopovers. These findings underscore the high conservation importance of wetlands along the CAF and emphasise the need for further investigation into the environmental and individual factors shaping migration strategies in this species.

Wintering sites

The wintering grounds of *Anser anser rubrirostris* from Northern Kazakhstan cover a broad geographic range, extending from the Caspian lowlands to the Mesopotamian Marshes. Most of the identified wintering areas have previously been recognised as critical for waterfowl (Riazi & Mirarmandhi, 2008; Al-Emarah & Abou-Turab, 2022), underlining their high conservation importance and the need for continued monitoring across the region.

Spring migration parameters

The spring migration of *Anser anser rubrirostris* begins in mid-February and continues until late April. The mean duration of spring migration was 34.2 ± 11.4 days (n = 13), substantially longer than in autumn. During this period, individuals covered an average distance of 3253 ± 453 km (n = 13). The mean daily migration speed, calculated as total distance divided by total migration duration, was 98.3 ± 24.4 km day^{-1}. Because individuals spent most of the migration period at stopover sites, stopover duration accounted for the majority of total migration time and averaged 33.0 ± 10.3 days. The number of stopovers ranged from one to seven, with a mean of 4.3 ± 1.9. The average straightness index of migratory trajectories was 0.79 ± 0.09, indicating moderately complex routes. The mean speed of active flight (i.e. excluding stopover time) was highly variable due to the short windows of directed movement, ranging from 742 km day^{-1} to 3534 km day^{-1}, with a mean of 1887 ± 1070 km day^{-1} (Table 3). Correlation analysis (Spearman's r_s, n = 13) revealed no significant relationship between migration duration and total distance (r_s = 0.07, p = 0.82), reflecting substantial individual variation in movement strategies. In contrast, migration duration was strongly and negatively correlated with mean travel speed (r_s = -0.81, p = 0.0007). A moderate, non-significant negative trend was also observed between migration duration and the number of stopovers (r_s = -0.35, p = 0.25). Overall, spring migration is longer and behaviourally more complex than autumn migration, with its parameters shaped primarily by the number and duration of stopovers. These findings emphasise the critical importance of staging habitats for the successful completion of spring migration.

Spring migration routes and stopover sites

The spring migration of *Anser anser rubrirostris* exhibited a high variability in routes and a heterogeneous distribution of stopover sites, although the overall spatial pattern broadly followed the same flyway as in autumn (Fig. 3). Individuals made between one and seven stopovers, each lasting from one day to 51 days, with a mean of 3.2 ± 2.1 stopovers per journey. In total, ten key stopover sites were used across Kazakhstan, Uzbekistan, and Turkmenistan. Stopover duration differed markedly among regions: individuals remained substantially longer (12–27 days) at resource-rich areas such as the Barsakelmes State Nature Reserve (Aral Sea, Kazakhstan) and Lake Aydarkul (Uzbekistan), whereas only short pauses (1–4 days) occurred at intermediate sites including Lake Kernay (Turkmenistan) and Lake Sudochye (Uzbekistan), which likely functioned as temporary resting points. As in autumn, the highest concentration of individuals occurred at the Barsakelmes State Nature Reserve, where six tagged individuals stopped in different years for periods of 12–27 days. On most other sites, only one or two birds staged, underscoring the strong individual variation in route choice and the behavioural flexibility characteristic of this population.

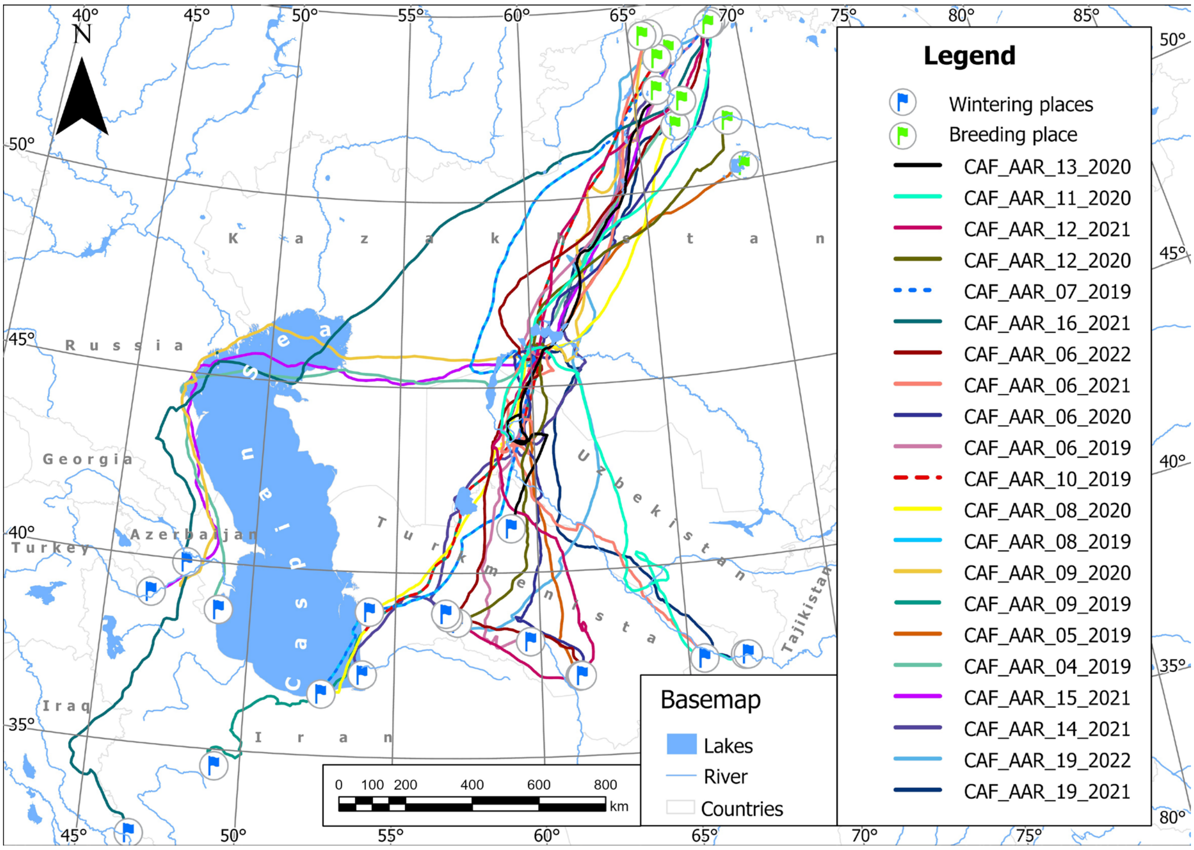

Fig. 2. Autumn migration routes of *Anser anser rubrirostris* based on satellite telemetry (2019–2022).

Table 3. Detailed spring migration parameters of *Anser anser rubrirostris* based on GPS/GSM telemetry along the CAF (2019–2023)

ID	Year	MS	ME	MD (d)	SD (d)	NS	Dist (km)	MMS ($km\ d^{-1}$)	AFS ($km\ d^{-1}$)
CAF_AAR_05	2020	08.02.2020	31.03.2020	53	51	6	3301	62.3	1650.5
CAF_AAR_06	2020	20.02.2020	26.03.2020	36	35	3	2952	82.0	2952.0
CAF_AAR_07	2020	29.02.2020	29.03.2020	30	27	5	3202	106.7	1067.3
CAF_AAR_08	2020	29.02.2020	29.03.2020	30	27	5	3167	105.6	1055.7
CAF_AAR_09	2020	14.03.2020	17.04.2020	32	30	3	4134	129.2	2067.0
CAF_AAR_13	2021	29.03.2021	29.04.2021	31	27.5	7	3534	114.0	1009.7
CAF_AAR_06	2021	08.03.2021	06.04.2021	29	28	2	2817	97.1	2817.0
CAF_AAR_12	2021	19.03.2021	11.04.2021	23	22	6	3110	135.2	3110.0
CAF_AAR_06	2022	12.03.2022	08.04.2022	27	24	5	2226	82.4	742.0
CAF_AAR_12	2022	19.02.2022	11.04.2022	52	50	3	3370	64.8	1685.0
CAF_AAR_13	2022	19.03.2022	17.04.2022	30	29	7	3534	117.8	3534.0
CAF_AAR_06	2023	23.02.2023	24.03.2023	29	28	3	3320	114.5	3320.0
CAF_AAR_19	2023	19.02.2023	13.04.2023	53	50	1	3626	68.4	1208.7

Note: Codes of individuals are defined in Table 1. Abbreviations: MS – migration start; ME – migration end; MD – migration duration; SD – total stopover duration; NS – number of stopovers; Dist – migration distance; MMS – mean migration speed; AFS – mean active-flight speed.

Seasonal comparisons confirmed these patterns quantitatively. The Mann–Whitney U test applied to six key migration parameters ($n_1 = 13$ spring, $n_2 = 21$ autumn) showed that spring migration was significantly longer than autumn migration ($U = 20$, $Z = -4.13$, $p < 0.001$, $r = 0.71$), and stopover duration was likewise longer in spring ($U = 21$, $Z = -4.09$, $p < 0.001$, $r = 0.70$). The number of stopovers showed a weaker and non-significant seasonal trend ($U = 82$, $Z = -1.93$, $p = 0.054$, $r = 0.33$). Migration speed was markedly lower during spring ($U = 18$, $Z = -4.20$, $p < 0.001$, $r = 0.72$), and the same pattern occurred for daily travel speed ($U = 18$, $Z = -4.20$, $p < 0.001$, $r = 0.72$). In contrast, no significant seasonal differences were detected for the total migration distance ($U = 129$, $Z = -0.27$, $p = 0.79$, $r = 0.05$) or route straightness. Taken together, these results demonstrate that spring migration is characterised by substantially longer durations and reduced movement rates, driven primarily by extended stopovers, while overall distances travelled and the geometric structure of routes remain broadly consistent between seasons.

Pre-migratory stopover sites and their role in the conservation of Anser anser rubrirostris

Satellite telemetry data collected between 2019 and 2022 identified nineteen stopover sites used by *Anser anser rubrirostris* along the CAF during both autumn and spring migrations (Fig. 4). Among these, only three sites (16.7%) are found within Protected Areas, including state nature reserves and Important Bird Areas, while the remaining 15 sites (83.3%) are outside any formal protection framework (Table 4).

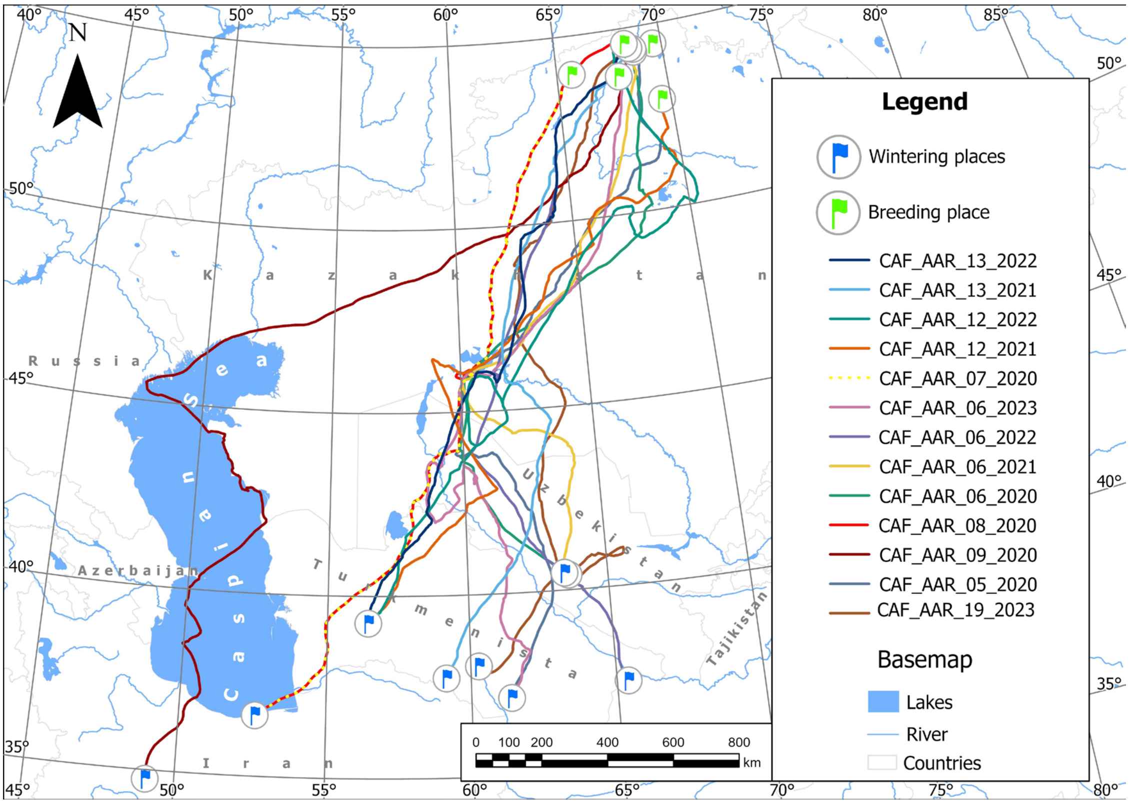

Fig. 3. Spring migration routes of *Anser anser rubrirostris* based on satellite telemetry, 2020–2023.

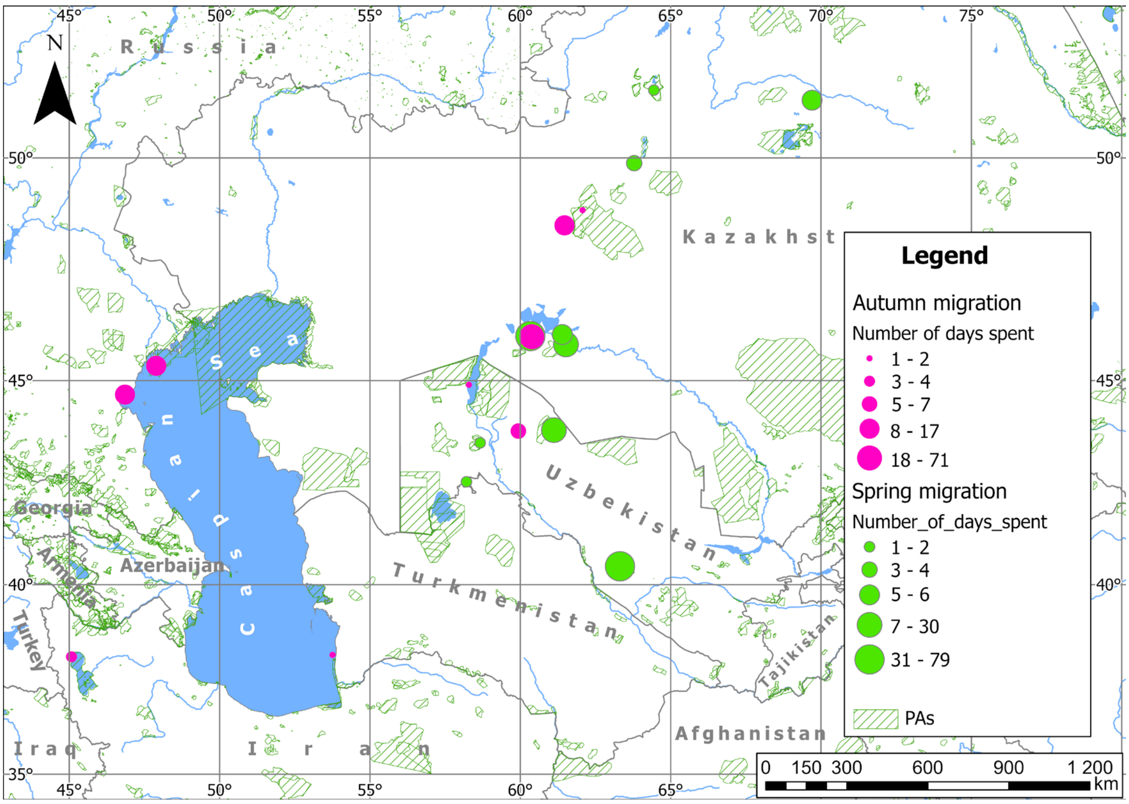

Fig. 4. Spring and autumn stopover sites of *Anser anser rubrirostris* along the CAF, 2019–2023.

Table 4. Distribution of *Anser anser rubrirostris* stopover sites along the CAF (2019–2022), with protection status and mean stopover duration

Country	Total stopovers	Protected stopovers	Unprotected stopovers	Mean stopover duration (days)
Kazakhstan	9	2	7	18.5
Uzbekistan	4	0	4	20.3
Turkmenistan	2	0	2	1.0
Russia	2	1	1	15.0
Iraq	1	0	1	4.0
Total	18	3	15	12.8

Mean stopover duration differed between categories, averaging 16.4 ± 8.7 days at protected areas, with a maximum of 41 days (Barsakelmes State Nature Reserve, Kazakhstan), and 7.9 ± 12.5 days at unprotected areas, with a maximum of 51 days (Lake Karakir, Uzbekistan). Major stopover nodes included the Barsakelmes State Nature Reserve (Aral Sea, Kazakhstan), used by up to 11 individuals with a maximum stay of 41 days, and Kizlyar Bay (Dagestan, Russia), where birds remained for up to sixteen days. In the Naurzum State Nature Reserve (Kazakhstan), a brief but ecologically important two-day stopover took place, highlighting the value of steppe Protected Areas in supporting migration.

Unprotected wetlands displayed a high individual variability in use. On Lake Jiltyrbas (Uzbekistan), five individuals stayed for 1–22 days, while one goose remained on Lake Karakir (Uzbekistan) for 51 days, demonstrating the potential importance of these unprotected sites. Overall, more than 70% of stopovers took place outside protected areas, including inland wetlands of Central Asia (Aydarkol, Sudochie, Jiltyrbas) and the Caspian coastal zones (Turkmenistan, Russia). Such reliance on unprotected sites underscores the importance of integrating local management practice with international conservation frameworks, as demonstrated for migratory waterfowl in Kazakhstan (Jones et al., 2022). Such patterns expose the migrating population to significant anthropogenic pressures, including agricultural expansion, water extraction, hunting, and wetland degradation. Although *Anser anser rubrirostris* populations in Europe remain stable or increasing, and the species is commonly regarded as a game bird, the situation in Central Asia and Russia differs markedly. Several local populations have already disappeared (southern Kazakhstan, southeastern Russia), while the Western Siberian population shows clear signs of decline (Erokhov, 2003). Thus, the CAF represents a critical bottleneck for the conservation of this population. The existing network of protected areas-including Barsakelmes State Nature Reserve, Naurzum State Nature Reserve, and Kizlyar Bay-provides only partial coverage, underlining the urgent need to expand the regional system of protected wetlands and enhance international cooperation to secure sustainable conservation of migratory waterbirds along the CAF.

Discussion

This study presents the first detailed description of the migratory strategies of the Western Siberian population of *Anser anser rubrirostris* along the CAF based on satellite telemetry. The migration system of the Western Siberian *Anser anser rubrirostris* population should also be interpreted in the context of long-term faunal and environmental dynamics of the region. Palaeoecological studies indicate that the composition and spatial structure of vertebrate fauna in Western Siberia have undergone substantial changes throughout the Holocene in response to climatic fluctuations, hydrological shifts, and landscape transformations, with wetland ecosystems being particularly sensitive to these processes (Gashev et al., 2017).

In Europe, several *Anser anser* populations have shortened their migration distances because of agricultural expansion and milder winter conditions (Fox & Leafloor, 2018; Nilsson et al., 2022). Increasingly, Central European populations remain in Europe during winter rather than migrating to southern Europe or North Africa (Podhrázský et al., 2017). Scandinavian populations of *Anser anser* show a combination of leapfrog migration and partial residency (Nilsson et al., 2022). Recent satellite-tracking studies have further demonstrated that European *Anser anser* may follow different flyways and exhibit distinct migration strategies depending on breeding location, including differences in migration timing, migration distance, and stopover behaviour (Piironen, 2023). Icelandic populations continue to perform long-distance migrations to the British Isles, following well-defined routes, centred around a few key protected staging sites (Swann et al., 2005).

In contrast, the Western Siberian population continues to undertake long-distance migrations exceeding 3000 km, with mean durations of 17 days in autumn and 35 days in spring. The number of stopovers remains relatively high (mean 3–4; range 1–8) and shows substantial individual variation (1–51 days per stopover). These findings indicate a strong dependence on a network of multiple staging wetlands distributed along the CAF, many of which currently lack any form of protection. It should also be noted that migration parameters may differ between breeding individuals and birds that do not participate in reproduction or that undertake moult migration. In several *Anser* species, individuals that fail to breed or immature birds may perform additional movements to specialised moulting areas, which can substantially increase the total migration distance and alter migration timing. Such patterns have been documented in satellite-tracking studies of *Anser* species, where non-breeding individuals undertake moult migrations that significantly extend their annual migration distance and modify the temporal structure of migration (Piironen, 2023). Consequently, part of the variability observed in migration duration, stopover number, and route configuration in the present study may reflect differences in breeding status among tracked individuals.

Telemetry studies in East Asia have shown links between breeding areas in Mongolia and northeastern China and wintering grounds in the River Yangtze basin (Li et al., 2020). These populations rely mainly on large floodplains and river valleys, which continue to provide relatively stable conditions for migrating waterfowl. In contrast, the CAF consists primarily of endorheic lakes (Aral Sea, Aydarkul, Tengiz, Karakir) and semi-arid wetlands, which are highly vulnerable to hydrological fluctuations, irrigation, and water overuse (Berezovikov, 2014; Wetlands International, 2015). The unpredictable availability of such habitats likely explains the high variability in migratory behaviour recorded in this study. To place the migration characteristics of the Western Siberian population into a broader geographic context, migration parameters were compared with those reported for other major populations of *Anser anser* across Eurasia. Table 5 summarises key migration metrics derived from satellite telemetry studies conducted in different regions. Comparative analysis indicates that the Western Siberian population performs one of the longest and most complex migrations within the species' range, characterised by longer migration distances and more frequent stopovers compared with most European and East Asian populations. The low straightness index of routes further reflects the fragmented nature and ecological instability of habitats across Central Asia.

While *Anser anser* populations in Europe remain stable or increasing, where the species is managed as a game bird, the Western Siberian population shows clear signs of decline (Erokhov, 2003; Rozenfeld & Dmitriev, 2016; Rozenfeld, 2019). In southern Kazakhstan and southeastern Russia, several local populations have already disappeared. Telemetry data obtained in the present study also confirmed the presence of direct anthropogenic impact, with at least seven tagged individuals lost in Iran, Uzbekistan, Iraq, and Russia.

Analysis of stopover distribution revealed that over 70% of the sites occur outside protected areas. Long stopovers were recorded both within state nature reserves (e.g. Barsakelmes State Nature Reserve – up to 41 days, Naurzum State Nature Reserve – two days) and in unprotected wetlands (e.g. Karakir – up to 51 days, Jiltyrbas – up to 22 days). This dependence on unprotected habitats, combined with wetland degradation driven by irrigation, agriculture, and water extraction, poses serious threats to the sustainability of the migration system. Therefore, priority conservation actions should focus on expanding the network of Protected Areas to include key unprotected wetlands such as Karakir, Jiltyrbas, and Aydarkul, strengthening international co-operation among Kazakhstan, Uzbekistan, Turkmenistan, Iran, and Russia to ensure co-ordinated conservation efforts along the CAF, and implementing stricter hunting regulations, particularly in wintering regions, to reduce direct mortality. Implementation of these measures would help safeguard critical stopover habitats and stabilise the Western Siberian population of *Anser anser rubrirostris*, thereby contributing to the long-term resilience of migratory waterbird populations along the CAF.

Table 5. Comparison of satellite-derived migration parameters of *Anser anser* across major populations and flyways

Population/Region	Migration distance (km)	Migration duration (days)	Number of stopovers	Route straightness index	Trend
Western Siberia – CAF (this study)	3171–3253	17 (autumn), 35 (spring)	1–8 (average: 3–4)	0.77–0.78	Decline, fragmentation
Central Europe (Podhrázský et al., 2017)	500–1500	7–15	1–2	0.85–0.90	Shortened migrations, stable/increasing
Scandinavia (Nilsson et al., 2022)	1000–2500	10–20	2–3	0.80–0.88	Partial residency, leapfrog migration
Iceland – UK/Ireland (Swann et al., 2005)	1500–2000	10–20	1–2	> 0.85	Stable
East Asia (Li et al., 2020)	2000–3000	20–30	2–4	0.80–0.86	Stable/increasing

Conclusions

This study delivers the first detailed account of the Western Siberian *Anser anser rubrirostris* migration along the CAF, using high-resolution telemetry. The analysis clarifies how individuals navigate a fragmented landscape of wetlands and follow routes that differ widely in distance, timing, and stopover behaviour. Seasonal contrasts show that spring migration demands longer travel and prolonged stopovers, while autumn migration proceeds more rapidly, despite similar overall distances. This population uses a network of 19 stopover sites, yet most of these wetlands lack formal protection and experience increasing human pressure. This pattern places the population at considerable risk, as many sites face hydrological alteration, agricultural expansion, and unregulated hunting. The consistent use of a few ecologically rich staging areas demonstrates their pivotal role in maintaining the annual migration cycle. The findings call for co-ordinated conservation actions along the entire flyway. Conservation agencies and regional partners need to strengthen protection of priority wetlands, incorporate key unprotected sites into international frameworks, and regulate hunting more rigorously in wintering areas. Such measures will support the long-term viability of the Western Siberian *Anser anser rubrirostris* population and help maintain ecological integrity across the CAF.

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МИГРАЦИОННЫЕ ПУТИ *ANSER ANSER RUBRIROSTRIS* (ANSERIFORMES) ВДОЛЬ ЦЕНТРАЛЬНО-АЗИАТСКОГО МИГРАЦИОННОГО ПУТИ ПО ДАННЫМ GPS/GSM-ТЕЛЕМЕТРИИ

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Anser anser rubrirostris является одним из широко распространенных таксонов водоплавающих птиц Евразии, однако его популяции, мигрирующие через Центральную Азию, в последние десятилетия испытывают выраженное сокращение численности. В период с 2019 по 2022 гг. с использованием GPS/GSM-телеметрии были отслежены 20 взрослых особей, гнездящихся на территории Северного Казахстана. В результате получены данные по 34 завершенным миграционным маршрутам от 15 особей, включая 21 осенний и 13 весенних маршрутов. В ходе миграции птицы использовали от одного до восьми пунктов остановки за сезон, при этом продолжительность остановок варьировала от одного до 51 дня. Средняя протяженность миграции составила 3289 ± 895 км осенью и 3253 ± 453 км весной. Средняя скорость миграции была выше в осенний период (132.4 ± 35.6 км·сут$^{-1}$), чем весной (98.3 ± 24.4 км·сут$^{-1}$), тогда как прямолинейность маршрутов оставалась сходной между сезонами (0.77–0.78). Всего вдоль Центрально-Азиатского миграционного пути выявлено 19 ключевых пунктов остановки, из которых лишь 26.3 % расположены в пределах особо охраняемых природных территорий. Большинство остановок (73.7 %) приходилось на неохраняемые водно-болотные угодья, включая важные участки в Узбекистане (Джилтырбас, Каракир, Айдаркуль), Казахстане (пойма р. Сырдарья), а также в прикаспийских районах Туркменистана и России. Наиболее продолжительные остановки отмечены в Барсакельмесском государственном природном заповеднике (Казахстан, до 41 дня) и на оз. Каракир (Узбекистан, до 51 дня). Полученные данные представляют первую телеметрическую количественную оценку миграционной экологии и использования пунктов остановки западносибирской популяцией *Anser anser rubrirostris* вдоль Центрально-Азиатского миграционного пути и подчеркивают ее высокую зависимость от неохраняемых водно-болотных угодий, что указывает на необходимость усиления природоохранных мер на уровне всего миграционного пути.

Ключевые слова: водно-болотные угодья, пункты остановки, связность местообитаний, сезонные перемещения, спутниковая телеметрия, Центральная Азия, экология миграций