

Migration Patterns, Utilization Distribution, and Site Fidelity of Two GPS-tracked Hooded Cranes (*Grus monacha*)

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Abstract: Understanding how migratory birds move and use space throughout the annual cycle is essential for conserving their habitats. Although the population of the Hooded Crane (*Grus monacha*) is increasing, much of the population is concentrated in a limited number of key habitats, making the species vulnerable to habitat loss and functional degradation. This study characterized migration patterns, quantified space use at residency sites, and evaluated interannual site fidelity. All comparisons were interpreted descriptively. Two individuals were tracked for 412 and 726 days, yielding one and two complete migration cycles, respectively. Residency sites were identified using spatiotemporal clustering, utilization distributions were estimated using autocorrelated kernel density estimation, and site fidelity was assessed using home range overlap and habitat use similarity. Southward migration lasted 73-81 days and was longer than northward migration, which lasted 24-34 days. Home range and core area differed among residency site types, with the largest estimates observed at critical stopover sites, followed by breeding and wintering sites. High home range overlap (0.87-0.91) and habitat use similarity (0.80-0.97) indicated strong fidelity to breeding and wintering sites. These findings provide individual-level baseline information on the locations and spatial extent of habitats used throughout the annual cycle.

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Keywords: Hooded Crane, Migration pattern, Movement ecology, Site fidelity, Utilization distribution

Introduction

Long-distance migratory birds rely on geographically separated networks of breeding, stopover, and wintering sites throughout their annual cycles [1,2]. Environmental conditions encountered at any stage of the annual cycle can affect survival, reproduction, and subsequent migration, highlighting the need to understand movement patterns and habitat use across the entire annual cycle [3,4]. Recent advances in wildlife tracking technologies have greatly improved our ability to collect fine-scale spatiotemporal data over broad geographic ranges. In particular, GPS tracking devices are now widely used in movement ecology because they can remotely provide frequent, highly accurate location data, including from regions that are difficult to access through conventional field surveys [5]. These data have im-

proved our understanding of how individuals use space and adjust their movements across seasons and life stages, thereby providing essential information for population management and habitat conservation [6,7].

Within this broader context, migration patterns and utilization distributions (UDs) provide complementary perspectives on the spatial ecology of migratory birds. Analyses of migration routes, timing, and duration reveal how individuals move between seasonally distinct habitats, while the identification of residency sites and the duration of their use reveals where and when individuals remain for extended periods during the annual cycle [8,9]. At these residency sites, UD quantifies the relative intensity of an individual's space use and can be used to estimate home ranges and core areas, thereby providing insight into the overall extent of space use and the areas used most intensively [10,11]. Together, analyses of migration patterns and UD can identify locations where individuals may be exposed to threats and provide a spatial basis for conservation planning throughout the annual cycle [6,12,13].

Beyond identifying where migratory birds move and reside, repeated tracking across multiple annual cycles enables researchers to evaluate the consistency of spatial use. The tendency of individuals to revisit familiar areas, commonly referred to as site fidelity, is a widespread movement strategy [14]. Familiarity with the physical and social characteristics of an area can confer several fitness benefits, including more efficient resource acquisition [15,16], reduced movement costs [17,18], and improved reproductive performance [19]. These benefits may be particularly important at breeding and wintering sites, where access to predictable resources and suitable environmental conditions can directly influence survival and reproduction [20,21]. However, strong fidelity to a limited number of sites may also increase vulnerability to local habitat loss or degradation [22]. Site fidelity can be assessed by examining interannual consistency in spatial and habitat use, including home range overlap and habitat use similarity across successive annual cycles [23]. Quantifying these patterns can identify areas that are repeatedly used and clarify the extent to which individuals depend on particular sites, thereby supporting the prioritization of habitats for conservation.

The Hooded Crane (*Grus monacha*) is classified as Vulnerable on the IUCN Red List [24]. It breeds primarily in the Russian Far East and northeastern China and winters in southern Japan, southern Korea, and the Yangtze River basin of China [9,25-27]. The global population is currently estimated at approximately 19,300 individuals [28]. Although the population has increased in recent decades [24], a large proportion of individuals remains concentrated in a limited number of key habitats, making habitat loss and functional degradation major threats to the species [29]. Consequently, identifying the migration routes connecting breeding, stopover, and wintering areas, as well as the key residency sites that are used repeatedly, is essential for the long-term conservation of Hooded Cranes [29]. A previous study on Hooded Cranes wintering in South Korea examined late-winter habitat use and home ranges in Suncheon Bay and identified northward migration routes and stopover sites leading to the breeding grounds [26]. The two individuals analyzed in the present study were also included in the previous study. However, the present study extends that work by incorporating southward migration to characterize complete annual migration cycles, identifying residency sites throughout the annual cycle, quantifying their spatial extent, and evaluating interannual site fidelity based on home range overlap and habitat use similarity. These aspects of annual-cycle movement ecology remain poorly understood for Hooded Cranes wintering in South Korea.

Accordingly, this study aimed to (1) characterize complete annual migration cycles and compare northward and southward migration patterns; (2) identify breeding, wintering, and stopover sites and quantify residency duration, home range size, and core area at each site; and (3) evaluate site fidelity by examining interannual home range overlap and similarity in habitat use. The findings provide essential baseline information for the effective conservation and management of the Hooded Crane.

Results

Complete annual migration cycles were recorded for both individuals. One complete annual cycle was recorded for Grus 2302, comprising one northward and one southward migration, while two complete cycles were recorded for Grus 2303 (Table 1;

Table 1. Migration timing and duration of two GPS-tracked Hooded Cranes (*Grus monacha*)

Tracker ID	Migration	Departure date	Arrival date	Duration (days)
Grus 2302	Northward_2023	2023-03-25	2023-04-28	34
	Southward_2023	2023-08-26	2023-11-07	73
Grus 2303	Northward_2023	2023-03-25	2023-04-18	24
	Southward_2023	2023-08-22	2023-11-11	81
	Northward_2024	2024-03-22	2024-04-16	25
	Southward_2024	2024-08-18	2024-11-06	80

Fig. 1). The northward and southward migrations of Grus 2302 lasted 34 and 73 days, respectively. For Grus 2303, the two northward migrations lasted 24 and 25 days, while the two southward migrations lasted 81 and 80 days (Table 1).

T-DBSCAN identified 24 residency clusters across the two individuals: 11 for Grus 2302 and 13 for Grus 2303 (Table 2; Fig. 1). The clusters identified for Grus 2302 included two wintering clusters, one breeding cluster, one critical stopover cluster, and seven stopover clusters. Among clusters with complete arrival and departure records, residency duration was 136 days at the wintering site, 120 days at the breeding site, and 27 days at the critical stopover site. The mean residency duration across the stopover sites was 8.1 days. The clusters identified for Grus 2303 comprised three wintering clusters, two breeding clusters, seven critical stopover clusters, and one stopover cluster. Residency duration was 132 days for the complete wintering period, averaged 125 days across breeding sites and 25.6 days across critical stopover sites, and was 3 days at the stopover site.

For Grus 2302, home range and core area sizes were 7.55 and 1.41 km² in wintering cluster 1 and 6.75 and 1.03 km² in wintering cluster 11, respectively. The corresponding estimates were 14.21 and 3.19 km² in breeding cluster 5 and 20.26 and 4.41 km² in critical stopover cluster 8. For Grus 2303, home range and core area sizes were 9.56 and 1.96 km² in wintering cluster 1, 5.06 and 0.86 km² in wintering cluster 8, and 11.62 and 1.63 km² in wintering cluster 13, respectively. At the breeding sites, the corresponding estimates were 16.41 and 3.39 km² in cluster 3 and 14.11 and 2.59 km² in cluster 10. Across the seven critical

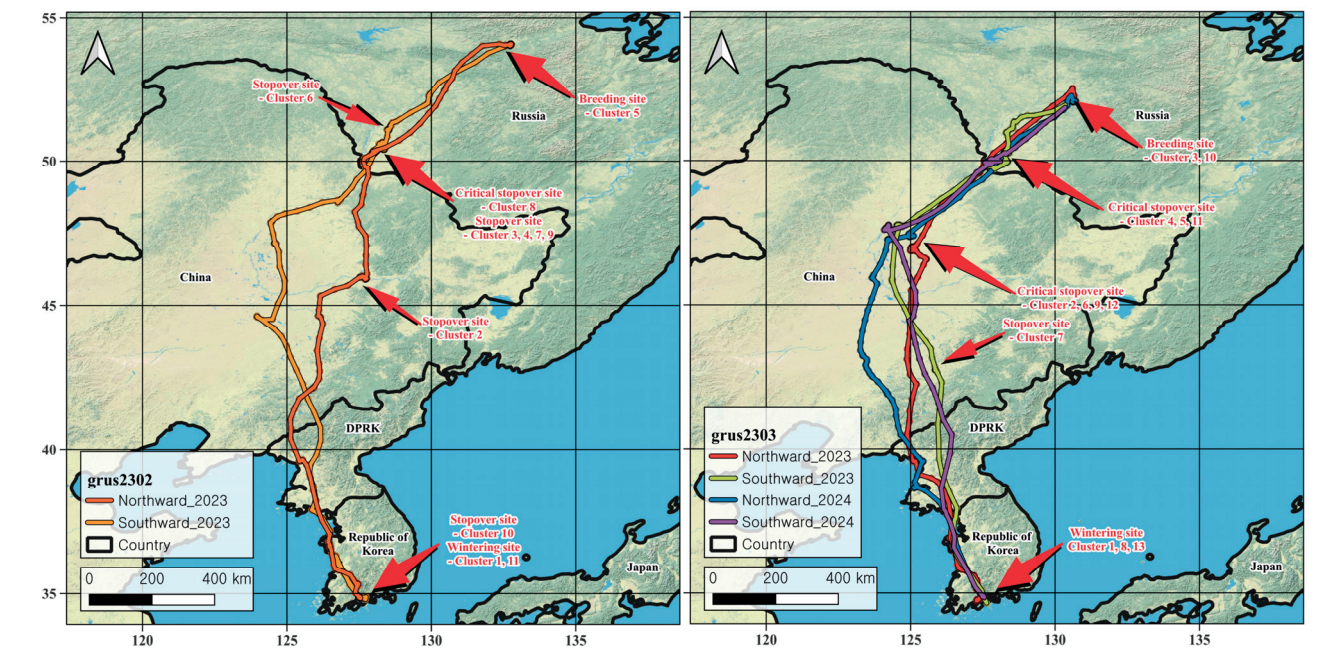


Fig. 1. Migration routes and residency clusters identified using T-DBSCAN for two GPS-tracked Hooded Cranes (*Grus monacha*). The left and right panels show the migration trajectories of individuals Grus 2302 and Grus 2303, respectively. Colored lines indicate northward and southward migration routes for each tracking year, as indicated in the panel legends. Red arrows point to spatial clusters identified using T-DBSCAN and classified as breeding, wintering, critical stopover, or stopover sites.

Table 2. Characteristics of clusters identified using T-DBSCAN from tracking data of two GPS-tracked Hooded Cranes (*G. monacha*)

Tracker ID	Cluster No.	Habitat	Region	Arrival date	Departure date	Duration (days)	AKDE 95% (km ²)	AKDE 50% (km ²)
Grus 2302	1	Wintering	Suncheon Bay wetland, South Korea	2023-02-05 ^a	2023-03-25	–	7.55	1.41
	2	Stopover	Songhua River wetland, China	2023-04-04	2023-04-14	10	–	–
	3	Stopover	Ivanovka River floodplain, Russia	2023-04-15	2023-04-22	7	–	–
	4	Stopover	Ivanovka River floodplain, Russia	2023-04-22	2023-04-26	4	–	–
	5	Breeding	Tuguro-Chumikansky wetland, Russia	2023-04-28	2023-08-26	120	14.21	3.19
	6	Stopover	Ukrainka agricultural area, Russia	2023-08-28	2023-09-08	11	–	–
	7	Stopover	Ivanovka River floodplain, Russia	2023-09-08	2023-09-14	6	–	–
	8	Critical Stopover	Ivanovka River floodplain, Russia	2023-09-15	2023-10-12	27	20.26	4.41
	9	Stopover	Ivanovka River floodplain, Russia	2023-10-12	2023-10-22	10	–	–
	10	Stopover	Yulchon reclaimed land, South Korea	2023-10-29	2023-11-07	9	–	–
	11	Wintering	Suncheon Bay wetland, South Korea	2023-11-07	2024-03-22	136	6.75	1.03
Grus 2303	1	Wintering	Suncheon–Goheung wetlands, South Korea	2023-02-05 ^a	2023-03-25	–	9.56	1.96
	2	Critical Stopover	Zhaodong–Anda agricultural area, China	2023-03-31	2023-04-16	16	193.53	55.51
	3	Breeding	Amur–Zeya Plain wetland, Russia	2023-04-18	2023-08-22	126	16.41	3.39
	4	Critical Stopover	Manchzhurka River floodplain, Russia	2023-08-25	2023-09-11	17	244.44	54.67
	5	Critical Stopover	Tambovsky agricultural area, Russia	2023-09-11	2023-09-30	19	39.87	8.14
	6	Critical Stopover	Fuyu wetland, China	2023-10-02	2023-11-06	35	27.52	5.38
	7	Stopover	Meihekou agricultural area, China	2023-11-07	2023-11-10	3	–	–
	8	Wintering	Suncheon Bay wetland, South Korea	2023-11-11	2024-03-22	132	5.06	0.86
	9	Critical Stopover	Lindian wetland, China	2024-03-28	2024-04-13	16	145.79	32.89
	10	Breeding	Amur–Zeya Plain wetland, Russia	2024-04-16	2024-08-18	124	14.11	2.59
	11	Critical Stopover	Gilchin River floodplain, Russia	2024-08-19	2024-10-08	50	137.4	33.14
	12	Critical Stopover	Nen River floodplain, China	2024-10-09	2024-11-04	26	98.87	25.5
	13	Wintering	Suncheon Bay wetland, South Korea	2024-11-06	2025-01-30 ^b	–	11.62	1.63

^a GPS logger attachment date.^b Tracking end date.

stopover sites, home range and core area sizes ranged from 27.52 to 244.44 km² and from 5.38 to 55.51 km², respectively (Table 2).

For Grus 2302, home range overlap and habitat use similarity between wintering clusters 1 and 11 were 0.90 and 0.96, respectively. For Grus 2303, the corresponding values were 0.87 and 0.80 between wintering clusters 8 and 13, and 0.91 and 0.97 between breeding clusters 3 and 10 (Fig. 2).

Discussion

The two tracked Hooded Cranes completed northward migration in 24–34 days, while southward migration lasted substantially longer, ranging from 73 to 81 days. The longer southward migrations were associated with the use of more stopover sites and longer residency at several of these sites, indicating that stopover behavior was a major contributor to the seasonal difference

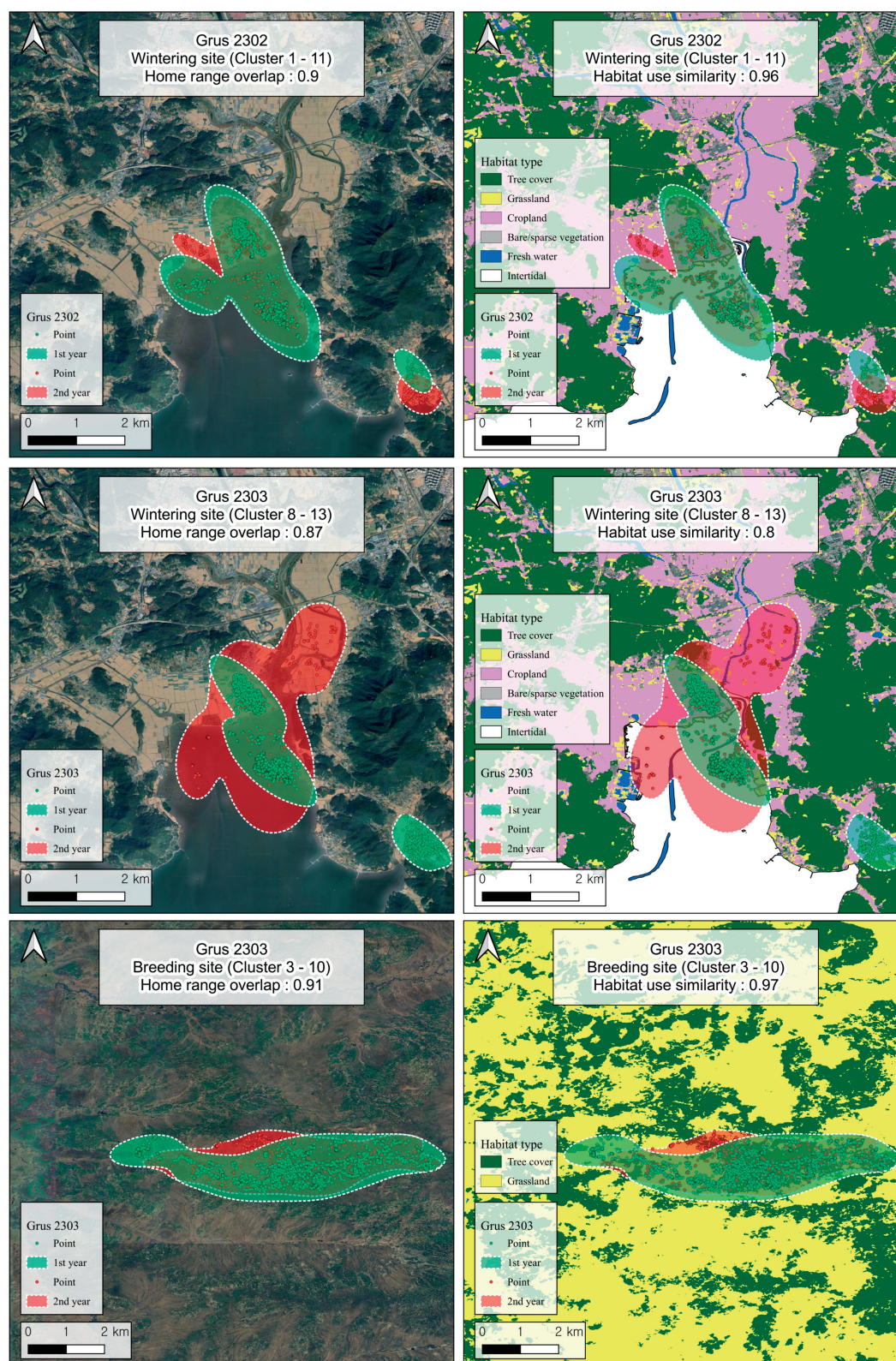


Fig. 2. Interannual home range overlap and habitat use similarity at breeding and wintering sites of two GPS-tracked Hooded Cranes (*Grus monacha*). Green points and polygons represent GPS locations and 95% AKDE home ranges during the first year, while red points and polygons represent those during the second year. Panels on the left show the spatial overlap between annual home ranges, and panels on the right show the corresponding habitat distributions used to calculate habitat use similarity. From top to bottom, the rows show the wintering site of Grus 2302 (clusters 1 and 11), the wintering site of Grus 2303 (clusters 8 and 13), and the breeding site of Grus 2303 (clusters 3 and 10). Home range overlap values were 0.9, 0.87, and 0.91, respectively, and the corresponding habitat use similarity values were 0.96, 0.8, and 0.97.

in migration duration. Similar patterns have been reported in several crane species. For example, adult Hooded Cranes wintering in Izumi, Japan, required an average of 44.3 days for northward migration and 54.0 days for southward migration [9]. Likewise, Common Cranes (*Grus grus*) and Whooping Cranes (*Grus americana*) exhibited longer southward than northward migrations [30-32].

The shorter northward migrations observed in our study may reflect stronger time constraints associated with arrival at the breeding grounds. Earlier arrival can improve access to high-quality breeding territories and provide more time for nesting and replacement breeding attempts, thereby potentially increasing reproductive success [33,34]. In contrast, birds generally experience weaker time constraints during southward migration because they do not face an immediate breeding deadline, allowing them to spend more time resting and replenishing energy reserves at stopover sites [35,36]. Moreover, individuals may begin southward migration in poor condition after breeding, further increasing their reliance on stopover sites for recovery and refueling [31,37]. Consequently, the prolonged southward migrations observed in the tracked Hooded Cranes likely resulted from weaker time constraints and greater reliance on stopover sites for energy replenishment.

The two tracked Hooded Cranes also exhibited a consistent pattern in the spatial extent of their major residency sites. Mean home ranges and core areas were smallest at wintering sites, ranging from 7.15 to 8.75 km² and 1.22 to 1.48 km², respectively. Home ranges and core areas at breeding sites were moderately larger, ranging from 14.21 to 15.26 km² and 2.99 to 3.19 km², respectively. In contrast, the largest and most variable estimates occurred at critical stopover sites, where mean home ranges ranged from 20.26 to 126.77 km² and core areas ranged from 4.41 to 30.75 km². Direct comparisons of home range sizes among breeding, stopover, and wintering sites are scarce in crane species. Moreover, published estimates are not directly comparable because previous studies have differed in species, sampling design, and home range estimators. Differences in home range and core area size among residency site types may reflect variation in resource distribution and predictability, disturbance levels, and stage-specific behavioral constraints [38-40]. Predictable resources and low disturbance may promote compact space use, repeated disturbance may increase movement distances, and breeding activities may constrain individuals to remain near nesting areas.

The large and variable home ranges observed at critical stopover sites may partly reflect repeated disturbance within foraging landscapes. At a Hooded Crane stopover site, foraging habitats consisted primarily of croplands and grasslands, and the stopover period generally coincided with cultivation and harvest seasons [41]. Agricultural activities and other forms of human disturbance frequently interrupted foraging and caused flushing distances of approximately 600 m in response to motor noise and over 700 m in response to whistles and shouts [42]. Such disturbances may displace cranes from otherwise suitable foraging patches and force them to seek safer feeding sites, thereby contributing to the large and variable home ranges observed at the critical stopover sites in our study. In contrast, the particularly small home ranges and core areas at the wintering sites may reflect the predictable availability of food and relatively low levels of human disturbance in Suncheon Bay. Hooded Cranes consistently concentrated in protected agricultural fields where rice seed was provided under Suncheon Bay's Payment for Ecosystem Services (PES) program, and human access was restricted [43]. Together, predictable food availability and restricted human access may have reduced the need for extensive foraging movements and promoted repeated use of the same feeding and resting areas, thereby contributing to the compact wintering ranges observed in both individuals. Breeding site home ranges and core areas were intermediate in size between those of wintering and critical stopover sites. During the breeding season, incubation, chick rearing, and territory maintenance may constrain cranes to remain near nesting areas even when more profitable feeding opportunities are available elsewhere [39]. According to central place foraging theory, breeding birds must repeatedly return to a fixed nesting site to incubate eggs or provision offspring, thereby limiting the distance and duration of their foraging movements [44]. For example, incubating Whooping Cranes continued to use wetlands within their breeding territories despite lower foraging efficiency, suggesting that they accepted reduced feeding returns to remain close to their nests [45]. The intermediate breeding ranges observed in our study may therefore reflect a balance between acquiring sufficient food and maintaining proximity to nesting and brood-rearing areas.

The tracked Hooded Cranes exhibited high interannual home range overlap (0.87-0.91) and habitat use similarity (0.80-0.97), indicating strong spatial and habitat use fidelity at breeding and wintering sites. For *Grus* 2303, the wintering site comparison

included a partial record for cluster 13 because tracking ended before the completion of the wintering period. Compared with Grus 2302, the slightly lower home range overlap (0.87) and habitat use similarity (0.80) observed for Grus 2303 may reflect both this incomplete tracking record and some degree of individual flexibility in spatial and habitat use within the wintering area. Similar patterns of high interannual site fidelity have been documented in other crane species [30,46,47]. For example, Sandhill Cranes (*Antigone canadensis*) tracked over two to four consecutive breeding seasons exhibited strong breeding-site fidelity, with a mean distance of 0.79 ± 1.40 km between breeding ranges in successive years [48]. Likewise, Whooping Cranes showed a mean overlap of 68% between winter home ranges in consecutive years [49]. Repeated use of familiar breeding and wintering areas may reduce the costs of movement, territory establishment, and resource location by allowing individuals to capitalize on prior knowledge of productive foraging areas and secure roosting sites, while also facilitating the maintenance of established social associations [47,50,51]. Nevertheless, strong site fidelity can also lead to maladaptive outcomes when environmental conditions change rapidly [22]. Continued use of historically used sites despite declining habitat suitability may expose individuals to fidelity-induced ecological traps, potentially reducing individual fitness and population resilience [52]. Accordingly, the strong site fidelity observed in the tracked Hooded Cranes highlights the importance of maintaining the spatial extent, habitat composition, and ecological quality of traditionally used breeding and wintering sites.

The movements of the two tracked individuals illustrate the importance of considering habitats used throughout the full annual cycle when developing conservation strategies for Hooded Cranes. Migratory crane populations rely on a network of geographically separated habitats, and the degradation of key stopover sites can disrupt migratory connectivity and ultimately reduce migration success [53]. The extensive and variable home ranges observed at critical stopover sites highlight the importance of maintaining sufficient habitat availability and minimizing human disturbance during migration. The compact home ranges observed at the wintering sites in Suncheon Bay suggest that the continued provision of predictable food resources through the PES program, together with restricted human access, may help maintain suitable feeding and resting habitats. Furthermore, the strong interannual fidelity observed at breeding and wintering sites indicates that habitat loss or functional degradation of traditionally used areas could repeatedly affect the same individuals across years. Although based on two individuals, these results provide baseline information that may help inform coordinated conservation efforts along the migratory pathway across South Korea, China, and Russia.

This study was based on only two individuals captured at the same wintering site. The number of complete annual cycles differed between them; therefore, the observed migration patterns, space use, and site fidelity may not fully represent those of the broader Hooded Crane population. To date, published GPS-tracking studies in South Korea have involved only five Hooded Cranes [26], indicating the scarcity of long-term movement data for this species. Future studies should therefore track a larger number of individuals from multiple wintering sites over several consecutive years to better quantify individual and interannual variation and establish more representative population-level patterns of migration, space use, and site fidelity.

Materials and Methods

On February 4, 2023, five adult Hooded Cranes were captured in a rice field in Suncheon Bay using a cannon net. After capture, birds were placed individually into bags and immediately transported to the closest handling station. Following the methods [54], each bird was weighed, after which a solar-powered GPS logger (WT-300, Koeco Inc., Daejeon, Korea) weighing less than 5% of the bird's body mass was mounted as a backpack using a Teflon ribbon harness to minimize potential negative effects. GPS loggers were attached to all five individuals; however, only two individuals, Grus 2302 and Grus 2303, provided sufficient long-term tracking data for the analyses conducted in this study. The sex of the tagged Hooded Cranes was not determined because no blood or feather samples were collected for molecular sex identification. The procedures for capturing, handling, and tagging the birds complied with applicable national laws and relevant guidelines and regulations. Before fieldwork, animal ethics training

in “Ethical Handling of Animals and Related Laws” was completed (KoEco Certificate No. 2023-001). GPS loggers were programmed to record locations at 1-h intervals. Individual Grus 2302 was tracked for 412 days, and individual Grus 2303 was tracked for 726 days. To improve positional accuracy, GPS locations with dilution of precision (DOP) values > 5 were excluded from the analysis [55,56]. The final dataset used for analysis included only latitude, longitude, and timestamp information.

Residency sites were identified using the Time Density-Based Spatial Clustering of Applications with Noise (T-DBSCAN) algorithm. This clustering approach incorporates both spatial density and temporal continuity and has been shown to effectively identify stopover sites from satellite-tracking data [57]. Following Erdenechimeg et al. (2023) [30], residency sites were defined as spatial clusters in which an individual remained for at least two consecutive days (48 h). Accordingly, the minimum number of locations required to form a cluster (minPts) was set to 48 based on the 1-h GPS sampling interval, and the minimum cluster duration (minTenure) was set to 48 h. The maximum allowable lag in the sequential order of locations (maxLag) was set to 100. Epsilon (eps) was estimated separately for each individual from the elbow of a smoothed k-nearest neighbor distance curve, with a lower bound of 1,000 m. After identifying residency clusters, each cluster was classified as a breeding, stopover, critical stopover, or wintering site using temporal and spatial criteria. Breeding sites were defined as locations where an individual remained for at least one month within the species’ breeding range during the breeding season and exhibited spatially concentrated movements consistent with breeding-stage residency. Wintering sites were defined as the residency cluster with the longest duration among the southernmost clusters recorded within the species’ wintering range during the winter season. Stopover sites were defined as residency clusters that were used temporarily during migration and did not meet the criteria for breeding or wintering sites. Stopover sites occupied for at least 14 consecutive days were further classified as critical stopover sites [30,32]. All site classifications were verified by visual inspection. All clustering analyses were performed using the “tdbscan” function in the tdbscan package [58].

Arrival date was defined as the date of the first GPS fix recorded within a residency site, whereas departure date was defined as the date of the first GPS fix recorded after the individual left the site. Residency duration was calculated as the elapsed time between arrival and departure. When either the arrival or departure date could not be determined because tracking began or ended while the individual occupied a residency site, residency duration was not calculated. Migration duration was calculated as the elapsed time between departure from a breeding or wintering site and arrival at the subsequent wintering or breeding site, respectively.

When estimating home ranges and core areas using tracking devices, it is essential to account for autocorrelation in the data [59]. Conventional kernel density estimation (KDE) does not account for this autocorrelation and may produce biased estimates, often underestimating home range and core area sizes [60,61]. In contrast, autocorrelated KDE (AKDE) explicitly accounts for autocorrelation in tracking data, minimizing biases associated with inconsistent tracking time lags [59,60]. It is therefore appropriate for movement behavior studies. Home ranges and core areas were estimated separately for each breeding, wintering, and critical stopover site in each year. Stopover sites were excluded from home range estimation because their short residency periods were unlikely to provide sufficient temporal coverage for reliable estimation of utilization distribution [59]. Home ranges were defined as the 95% utilization distribution contour and core areas as the 50% contour [62,63]. All home range and core area estimations were performed using the “akde” function in the ctmm package [64].

To assess site fidelity, home range overlap and habitat use similarity were quantified. These analyses were conducted using home range estimates from either two consecutive breeding seasons or two consecutive wintering seasons. Home range overlap between annual 95% AKDE home ranges was quantified using Bhattacharyya’s affinity [65]. Bhattacharyya’s affinity quantifies the similarity between two utilization distributions and ranges from 0, indicating no overlap, to 1, indicating identical utilization distributions, making it well suited for evaluating probabilistic home range overlap [66]. Habitat use was quantified by assigning each GPS location within each 95% home range to a land cover type using the ESA WorldCover 10 m 2021 v2 dataset [67]. For locations within South Korea, the WorldCover dataset was supplemented with river and tidal flat maps provided by the Ministry of Oceans and Fisheries, Republic of Korea. Because the WorldCover “permanent water bodies” class does not distinguish intertidal flats from other aquatic environments, these supplementary data were used to identify intertidal areas more explicitly, particularly

at major wintering sites such as Suncheon Bay. The resulting dataset comprised seven land cover types: tree cover, cropland, grassland, bare/sparse vegetation, herbaceous wetland, freshwater, and intertidal areas. Interannual habitat use similarity between consecutive breeding or wintering seasons was quantified using the Bray–Curtis similarity index [68]. Bray–Curtis dissimilarity was subtracted from 1 to obtain habitat use similarity values ranging from 0, indicating complete compositional dissimilarity, to 1, indicating identical habitat use composition [8]. Home range overlap was calculated using the overlap function in the ctmm package [64], and Bray–Curtis dissimilarity was calculated using the “vegdist” function in the vegan package [69]. All analyses were conducted using R software (version 4.4.2; R Foundation for Statistical Computing, Vienna, Austria).

Data Availability: All data are available in the main text or in the Supplementary Information.

Author Contributions: D.H.C., S.M.J., and S.W.L. conceived and designed the study; D.H.C. collected the data; D.H.C. and S.M.J. performed the analysis; D.H.C. drafted the original manuscript; S.W.L. administered the project; H.C.S. supervised the study and reviewed and revised the manuscript. All authors approved the final manuscript.

Notes: The authors declare no conflict of interest

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Additional Information:

Supplementary information The online version contains supplementary material available at <https://doi.org/10.5338/KJEA.2026.45.15>

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