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Satellite Telemetry Insights into the Winter Habitat Use and Movement Ecology of Common and Demoiselle Cranes

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Simple Summary: We studied the home ranges, movement, migration patterns, and habitat use of Common Cranes and Demoiselle Cranes using satellite telemetry. The average home ranges calculated in India were slightly greater than in their breeding areas. Common Crane-1 covered 12,982 km in 17 days to reach Russia. On the return journey, it covered a total distance of 14,873 km in 72 days. Common Crane-2 covered a total distance of 4500 km in 30 days to reach Kazakhstan. While returning to India, it covered 4922 km in 25 days. On the other hand, Demoiselle Crane-1 covered a total distance of 4968 km in 18 days during its northbound migration to Kazakhstan and 7394 km in 105 days to reach India. Demoiselle Crane-2 traveled a distance of 4310 km in 18 days to reach Kazakhstan and then made the return journey to India, covering a distance of 7757 km over a period of 128 days. Croplands and water bodies were the most important habitat variables influencing crane presence positively. The changing crop patterns from cereal grains to cotton, coupled with the shrinkage of water bodies within the study area, may raise concerns about their presence during winter in the near future.

Abstract: Using satellite telemetry, it is possible to track long-distance migrant birds with high accuracy and greater spatial coverage. However, prior to 2014, less than 1% of bird species in India had been monitored using this technology. Between January and February 2022, we deployed leg-mounted solar GPS/GSM satellite transmitters to Common Cranes and Demoiselle Cranes (two each) to study home ranges, movement, migration patterns, and habitat use. We used 95% kernels to define the total home range size and 50% kernels to delimit the core areas. The winter habitat use was assessed using Generalized Linear Models (GLM). The average home range of Common Cranes and Demoiselle Cranes was estimated as 161.22 ± 172.08 km^2 and 971.40 ± 1023.57 km^2, respectively. During migration, Common Crane-1 and Common Crane-2 traveled an average of 471.19 ± 442.42 and 176.97 ± 24.82 km per day, and Demoiselle Crane-1 and Demoiselle Crane-2 covered an average daily distance of 168.10 ± 203.77 and 192.97 ± 250.72 km, respectively. Water bodies and croplands were the most important habitat variables influencing crane presence positively. In recent years, the share of food grain crops within the study area has declined from 43% in 1994–1995 to 36% in 2014–2015, while the share of cotton crops has doubled from 11% to 20%, indicating a probable cause of concern in the near future.

Keywords: Central Asian Flyway; Gruidae; Gujarat; home ranges; migration

Citation: Ram, M.; Gadhavi, D.; Sahu, A.; Srivastava, N.; Rather, T.A.; Jhala, L.; Kapadi, P.; Vala, K.; Zala, Y.; Modi, V.; et al. Satellite Telemetry Insights into the Winter Habitat Use and Movement Ecology of Common and Demoiselle Cranes. *Birds* **2023**, *4*, 337–358. https://doi.org/10.3390/birds4040029

Academic Editor: Jukka Jokimäki

Received: 1 October 2023
Revised: 14 November 2023
Accepted: 21 November 2023
Published: 28 November 2023

1. Introduction

Common Cranes (*Grus grus*) and Demoiselle Cranes (*Anthropoides virgo*) have an extensive range with increasing population trends, due to which they are listed as Least Concern (LC) in the IUCN Red List of threatened species [1,2]. They are enlisted in Appendix II of the Convention on Migratory Species (CMS) and also in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [3,4]. Both the species are fully migratory, with the probable exception of isolated breeding populations east and south of the Black Sea, which may be resident, undertaking only local movements [5]. Like other crane species, the Common Crane and Demoiselle Crane are characterized as having a highly traditional pattern of wintering and staging areas, the latter being stopover points between breeding and wintering grounds where the birds remain for varying lengths of time to forage and sometimes also to avoid unfavorable weather conditions. The breeding habitat of Common Cranes is characterized by a variety of shallow wetlands, swampy forests, reedy marshes, and rice paddies [6]. Demoiselle Cranes typically prefer grassland habitats near streams, shallow lakes, and wetlands. They also frequent arid areas such as deserts with adequate water availability [7,8]. Habitat loss and habitat degradation are the main threats concerning both the species across their breeding and non-breeding ranges [9,10]. Collision with the overhead transmission lines in wintering ranges is frequent [10]. Hunting during migration in Afghanistan and Pakistan has also been reported to be a significant threat to Common and Demoiselle Cranes [10,11].

Among migratory birds, cranes have been widely studied using satellite telemetry across most of their range [12–16]. However, in India, the use of satellite telemetry to study birds is limited. Until 2014, less than 1% of the bird species (11 out of 1375) found in India had been monitored using satellite telemetry [17]. The use of satellite telemetry for migratory birds in the Indian sub-continent was limited to one study conducted in 1994, where three Common Cranes were deployed with satellite transmitters in Keoladeo National Park, Rajasthan, India [18].

Later on, the application of satellite telemetry to study the migration patterns of cranes in South Asia commenced at a much-needed pace. For example, between 1991 and 1992, 11 White-naped Cranes (*Grus vipio*) and five Hooded Cranes (*Grus monacha*) were studied using satellite telemetry [19] and 15 White-naped Cranes were later satellite tracked to determine their migration from Japanese breeding grounds in 1996 [20]. In 1998, satellite tracking determined the autumn migration routes of Red-crowned Cranes (*Grus japonensis*) in Japan [21]. Between 1998 and 1999, five more Red-crowned Cranes were satellite-tracked along the Amur River in the Russian Far East, which described important stopover areas for Red-crowned Cranes [22]. Similarly, Kanai et al. [12] tracked eleven Siberian Cranes (*Grus leucogeranus*) that wintered in Iran and reported the Qiqihar-Baicheng area, Aumannykan area, Shuangtaizi River delta, and Yellow River delta to be important stopover areas.

During their annual migration, cranes cover enormous distances. Cranes breeding in northern latitudes, such as in Kazakhstan and Russia, migrate across several countries by flying over deserts, lakes, and seas, and some fly over the tallest mountain ranges to reach their traditional wintering grounds in South Asia [12]. India is one of the important wintering grounds for Common and Demoiselle Cranes [23]. Studies have shown that cranes with breeding grounds located in Russia and central Kazakhstan migrate along the west Siberian flyway and in the lake systems of North Kazakhstan; after that, they cross several central Asian countries to the wintering grounds in eastern Iran and western India [24]. Cranes that winter in China use the East Asian Flyway across the Tibetan plateau through Mongolia to central and western China and Myanmar [25]. Out of the fifteen extant crane species found worldwide, four occur in India: Common Crane, Demoiselle Crane, Black-necked Crane (*Grus nigricollis*), and Sarus Crane (*Grus antigone*). Other than the Sarus Crane, which is the resident breeding crane species found in India [26], the Black-necked Crane's breeding range includes much of the Qinghai–Tibetan Plateau in western China, with a small breeding population in the adjacent Ladakh region in India [27]. The population of the Siberian Crane (*Leucogeranus leucogeranus*) that bred on the basin of the

Kunovat River, in the north of West Siberia, used to winter in north-western India [10]. They were last reported wintering in India in 2001–2002 [28].

Cranes wintering in Gujarat have been studied only recently. A previous telemetry study of Common Cranes in northwestern India (Rajasthan) documented the western route used for spring migration [23]. A recent satellite tracking of the Common Crane in Kutch, Gujarat, showed that they used the same western route across central Asian countries to reach Kazakhstan [29]. Pierre and Higuchi [30] delineated the migration routes of more than 11 species of birds in Asia, including the Common and Demoiselle Crane. They found intra and inter-species variations in distances covered by crane species wintering in Asia. However, the precise estimation of breeding and non-breeding home ranges, daily movement patterns between migration and non-migration seasons, stopover areas, and migration duration are still unknown for cranes wintering in western India, particularly Gujarat. Thus, the purpose of this study was to (1) estimate home ranges within breeding and non-breeding areas, (2) identify important stopover sites along the migration flyway, (3) assess the daily movement patterns between migration and non-migration season, (4) understand important habitat variables influencing crane occurrence within the study area, and (5) reveal spatiotemporal migration patterns. Based on the above objectives, we hypothesized that daily and monthly distances covered by cranes would increase in migration season, the breeding home ranges would be smaller than wintering home ranges, and that cranes would establish home ranges in preferred habitats with the presence of water bodies.

2. Materials and Methods

2.1. Study Area

Common Cranes and Demoiselle Cranes were tagged around Kaj wetland (Nanavada area), a designated Important Bird Area (IBA) site with A1, A4i IBA criteria [31]. Kaj wetland is situated around 10 km east of Kodinar town, in the Gir-Somnath district, which forms part of a much larger landscape known as the Asiatic Lion Landscape (ALL). ALL is a multiple land-use area located within the southwestern part of Saurashtra, Gujarat, India (Figure 1). It consists of five protected areas, namely, Gir National Park, Gir Wildlife Sanctuary, Paniya Wildlife Sanctuary, Mitiyala Wildlife Sanctuary, and Girnar Wildlife Sanctuary. These protected areas span 2058 sq. km (1879.13 sq. km Gir PAs + 178.87 sq. km Girnar Wildlife Sanctuary). The landscape is composed of nine districts, including Junagadh, Gir-Somnath, Amreli, Bhavnagar, Botad, Porbandar, Jamnagar, Rajkot, and Surendranagar, constituting 53 talukas covering a whole expanse of ~30,000 sq. km. This landscape represents a typical semi-arid biogeographical zone [32]. The area is characterized by three seasons: dry and hot summer (March–June), monsoon (July–October), and a primarily dry winter (November–February). Kaj wetland is an important IBA that supports thousands of waterfowl in winter and other threatened ecological communities, due to which it was proposed as a Ramsar Site [33]. The maximum depth of the water is 2 m; the maximum water level occurs during July and August and the minimum level occurs during March [31]. The water from the lake is utilized by the farmers of the surrounding villages for agriculture from October onwards. The wetland has a moderate vegetation cover, with reed (*Typha* spp.) and sedges (*Cyperus* spp.) being typical emergent vegetation [31]. Scattered shrubs of Indian jujube *Ziziphus* and caper shrubs (*Capparis* spp.) occur in the lake's surrounding areas, interspersed with sparse Vilayati babul *Prosopis juliflora* thickets. Agriculture is the main occupation of the surrounding villages, and cotton (*Gossypium* spp.), groundnut (*Arachis hypogea*), sugarcane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), and maize (*Zea mays*) are the major crops grown [31].

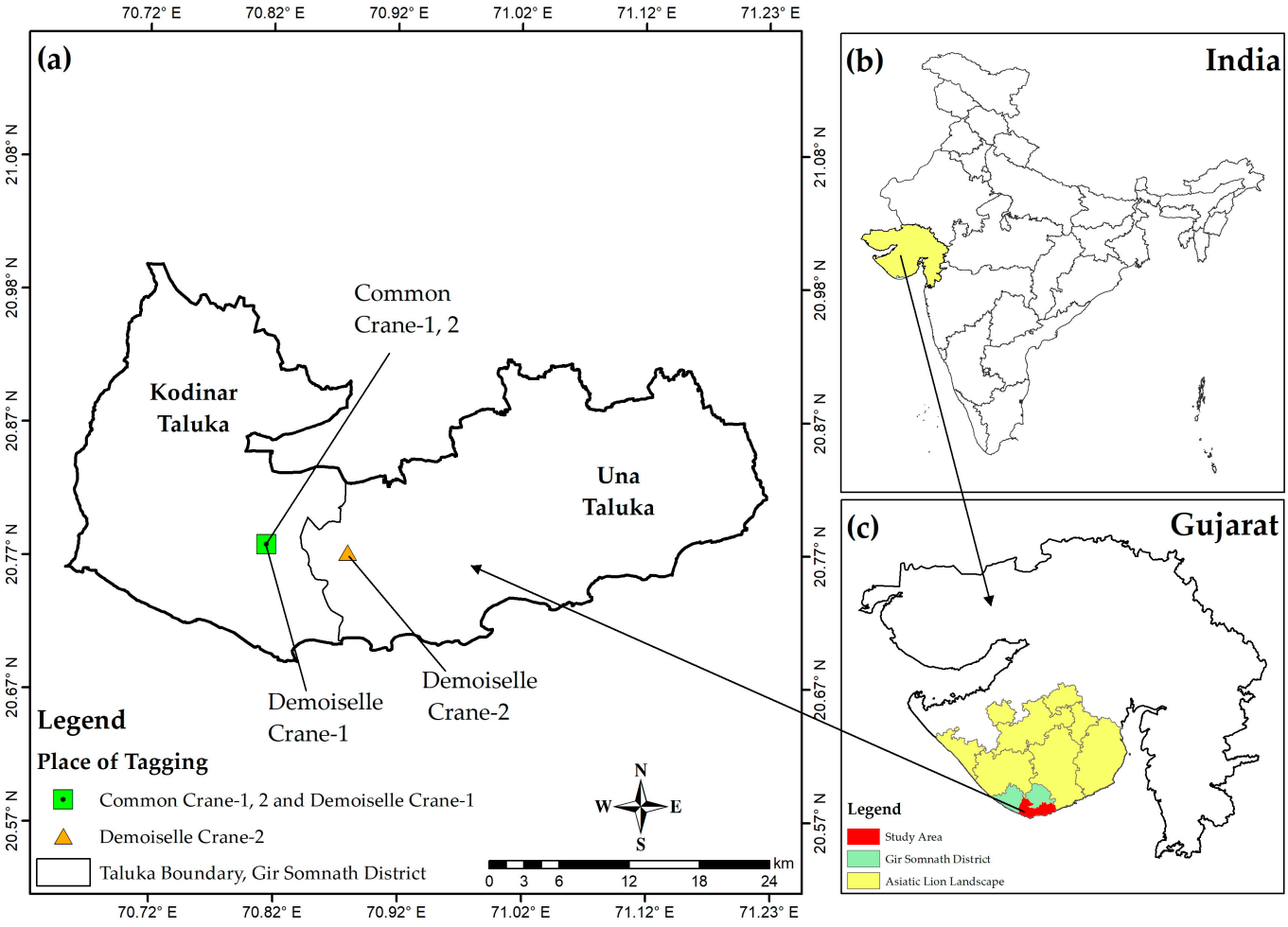

Figure 1. Location of study area. Panel (**a**) shows the location of the Kodinar and Una taluka in Gir-Somnath district, panel (**b**) shows the location of Gujarat, India, and panel (**c**) shows the location of Asiatic Lion Landscape situated in southwestern Gujarat.

2.2. Reconnaissance, Capture, and Tagging

Before capturing the cranes, we monitored the sites around the water bodies within the study area. These water bodies are traditionally known to harbor the annual winter congregation of cranes. We selected Kaj wetland (Nanavada area) due to the large congregation of cranes. We laid noose traps in shallow water and around the banks of the wetland, where the regular movement of targeted birds was observed. The noose traps consisted of an anchor line and monofilament fishing line; nooses were attached to the anchor line. All the precautions were taken to cause minimum disturbance to the birds. Captured birds were handled with care and kept in specially designed bird bags, and their heads were covered to minimize the capture stress, if needed. All birds (two Common Cranes and two Demoiselle Cranes) were deployed with leg-mounted solar GPS/GSM satellite transmitters with European Laser-Signed Advanced (ELSA) color rings (two rings below the transmitter in each bird). All the transmitters (Ornitela, UAB, Vilnius, Lithuania) weighed 19 g each and used a GSM network (cellular phone) to transmit data. Common Crane-1 and Demoiselle Crane-1 were captured and tagged on the 26 and 31 January 2022 and Common Crane-2 and Demoiselle Crane-2 were captured and tagged on the 4 and 7 February 2022, respectively. The photographic details showing the complete process of reconnaissance, capture, deployment of transmitters, color sequence of ELSA rings, release of the tagged cranes, and other associated information are available in Supplementary Information S1.

The tagging devices were programmed to record GPS coordinates at 30 min intervals and transmit the collected data every half an hour, resulting in 48 location points per 24 h. These signals were transmitted through the GSM network. The movements were monitored remotely through satellite-transmitted data at the Gir Hi-Tech Monitoring Unit in Sasan-Gir.

2.3. Home Range Estimation

We estimated home ranges using Kernel Density Estimators (KDE) with the R package adehabitatHR [34] in R [35]. We used 95% kernels (95% KDE) to define the total home range size and 50% kernels (50% KDE) to delimit the core areas or most intensively used areas. Reference bandwidth 'href' was used as a smoothing parameter for all home range estimations [36,37]. We calculated five home range polygons for Common Crane-1 and Common Crane-2. Three home ranges were calculated in the non-breeding range in Gujarat, India, and two in the breeding range (Kazakhstan and Russia) for Common Crane-1. For Common Crane-2, three home ranges were calculated in the non-breeding range (Gujarat, India) and two in its breeding range in Kazakhstan. Similarly, we calculated five home range polygons for Demoiselle Crane-1 and four for Demoiselle Crane-2. Two of the home ranges for Demoiselle Crane-1 were in Gujarat and one was in Rajasthan, while the rest were in Kazakhstan. For Demoiselle Crane-2, out of four home range polygons, three were in India and one was in Kazakhstan.

2.4. Habitat Use

We investigated habitat use by cranes within their home ranges using Generalized Linear Models (GLM). We used crane presence–absence as the dependent variable and we used habitat variables within their home ranges as explanatory variables. We created a circular buffer of a 250 m radius around each presence location and generated twice the number of pseudo-absence locations using ArcGIS 10.8.1 (ESRI, Redlands, CA, USA). Each pseudo-absence location from within the 250 m buffers around each presence location was removed to avoid pseudo-replication. Spatial filtering of 300 m was applied to the presence location data using the SDM toolbox [38] in ArcGIS 10.8.1 (ESRI, Redlands, CA, USA). In the final step, we removed additional pseudo-absence locations. We retained an equal subset of pseudo-absence locations as the spatially filtered presence locations to counteract the problems arising from unbalanced prevalence [39]. We obtained a land use land cover map of the study area from the Bhaskaracharya National Institute for Space Applications and Geo-Informatics (BISAG, Gujarat, India). We reclassified each habitat category on a continuous scale using the reclassify tool in ArcGIS. We used focal statistics and extracted values to the points within the radius of 250 m of each presence-absence point of cranes. All of the analysis was conducted in R statistical program language [35]. We used the minimum Akaike Information Criterion (AIC) for the model selection [40,41]. We calculated misclassification error, model specificity, model sensitivity, and Area Under the Curve (AUC) as the indices of model accuracy (Supplementary Information S2).

2.5. Movement and Migration

We calculated the monthly and daily movement patterns of Common Cranes and Demoiselle Cranes using the Tracking Analyst tool in ArcGIS. We segregated the location fixes of cranes into months and calculated the distance traveled across all months. We calculated overall distances traveled, which included both migration and non-migration seasons. To compare the distances traveled during migration and non-migration seasons, we accordingly segregated the location fixes into migration and non-migration seasons. The spring migration season was marked when the apparent directional movement towards the north from India was observed in cranes. Likewise, the directional movement southwards from their breeding grounds towards India was marked as their winter migration.

3. Results

We obtained a total of 67,384 location fixes with an average of 16,846 ± 3213.25 fixes for each individual crane and retained a total of 67,129 location fixes after removing the fixes with no coordinates. Out of 67,129 location fixes retained, we used a total number of 54,814 (81%) location fixes for home range estimation with an average number of 13,703.50 ± 3156.90 location fixes for each individual crane.

3.1. Home Range Estimations

The average home range and core area of Common Cranes (including breeding and non-breeding home ranges) were estimated as 161.22 ± 172.08 km^2 (mean ± SD) and 24.17 ± 23.88 km^2, (mean ± SD) respectively (Table 1). Home ranges and core areas are expressed as 95% and 50% kernels.

Table 1. Details of home range estimations (km^2) of Common Cranes in breeding [b] and non-breeding [nb] ranges.

ID	Timeline	Site	95% KDE	50% KDE
Common Crane-1	January to March 2022	Gujarat, India [nb]	53.83	6.05
	April to August 2022	Russia [b]	76.33	7.28
	August to October 2022	Kazakhstan [b]	54.58	10.31
	October 2022 to January 2023	Gujarat, India [nb]	46.89	7.22
	January to February 2023	Gujarat, India [nb]	602.64	71.17
Common Crane-2	February to March 2022	Gujarat, India [nb]	83.21	7.77
	May 2022	Kazakhstan [b]	226.28	41.43
	June 2022	Kazakhstan [b]	265.13	57.79
	October to December 2022	Gujarat, India [nb]	113.02	18.33
	December 2022 to February 2023	Gujarat, India [nb]	90.78	13.93
Average	-	-	161.22	24.17

For Common Crane-1, the most extensive home range was estimated as 602.64 km^2 and the smallest was estimated as 46.89 km^2 (Table 1). The average home range size of Common Crane-1 was estimated as 166.76 ± 243.91 km^2 and the core area was estimated as 20.40 ± 28.42 km^2. We calculated five home range polygons for Common Crane-1 and Common Crane-2, respectively.

For Common Crane-2, the most extensive home range was calculated as 265.13 km^2, while the smallest was calculated as 83.21 km^2 (Table 1). The average home range and core area of Common Crane-2 were 155.68 ± 84.03 km^2 and 27.95 ± 20.97 km^2, respectively. For Common Crane-2, three home range polygons were calculated in the non-breeding range (Gujarat, India) and two were calculated in its breeding range in Kazakhstan (Supplementary Information S3).

The average home range and core area of Demoiselle Cranes (including breeding and non-breeding home ranges) were estimated as 971.40 ± 1023.57 km^2 and 140.57 ± 174.16 km^2, respectively (Table 2). The largest (1939.73 km^2) as well as the smallest (109.61 km^2) home ranges for Demoiselle Crane-1 were estimated in Kazakhstan (Table 2).

The average home range and core area of Demoiselle Crane-1 were estimated as 834.06 ± 780.73 km^2 and 115.97 ± 141.65 km^2, respectively. The average home range size and core area of Demoiselle Crane-2 were calculated as 1143.07 ± 1382.17 km^2 and 171.73 ± 277.66 km^2, respectively. We calculated four home range polygons for Demoiselle Crane-2; three were calculated in India and one in Kazakhstan (Supplementary Information S3).

Table 2. Details of home range estimations (km^2) of Demoiselle Cranes in breeding [b] and non-breeding ranges [nb].

ID	Timeline	Site	95% KDE	50% KDE
Demoiselle Crane-1	February to March 2022	Gujarat, India [nb]	700.68	49.38
	April to July 2022	Kazakhstan [b]	109.61	13.21
	August to September 2022	Kazakhstan [b]	1939.73	343.39
	September to November 2022	Rajasthan, India [nb]	143.43	9.93
	November 2022 to February 2023	Gujarat, India [nb]	1276.88	163.95
Demoiselle crane-2	February to March 2022	Gujarat, India [nb]	1451.34	171.33
	April to July 2022	Kazakhstan [b]	54.87	4.22
	August to October 2022	Rajasthan, India [nb]	92.94	17.64
	October 2022 to February 2023	Gujarat, India [nb]	2973.16	493.73
Average	-	-	971.40	140.75

3.2. Movement Patterns

Common Crane-1 covered an average of 2682.51 ± 3852.44 km per month (in both migration and non-migration seasons), while the daily average distance covered was 89.77 ± 123.63 km (Table 3). Common Crane-2 covered a relatively smaller monthly distance than Common Crane-1 (Table 3). Overall, the largest monthly distance was covered by Common Crane-1 (Table 3).

Table 3. Overall monthly and daily distances (km) traveled by Common Cranes and Demoiselle Cranes.

ID	Minimum Monthly	Maximum Monthly	Monthly Average	Minimum Daily	Maximum Daily	Daily Average
Common Crane-1	37.58	13,482.19	2682.51 ± 3852.44	6.80	434.90	89.77 ± 123.63
Common Crane-2	171.96	4542.84	1233.04 ± 1493.79	5.73	150.02	41.11 ± 48.53
Demoiselle Crane-1	300.80	4146.36	1555.86 ± 1250.01	10.02	138.21	52.42 ± 40.28
Demoiselle Crane-2	215.13	5485.86	1534.69 ± 1479.85	6.93	176.96	52.42 ± 46.57

Interestingly, there was not much difference in the distances covered by Demoiselle Crane-1 and Demoiselle Crane-2 (Table 3).

The non-migration season lasted 296 days for Common Crane-1 and 320 days for Common Crane-2. During this period, Common Crane-1 covered an average distance of 746.09 ± 729.01 km every month and an average daily distance of 31.13 ± 22.87 km (Table 4). Common Crane-2 covered an average of 550.54 ± 331.85 km per month and 20.44 ± 9.30 km per day during the non-migration season (Table 4).

Demoiselle Crane-1 covered a monthly distance of 714.79 ± 452.22 km and a daily distance of 31.63 ± 12.19 km during the non-migration season (Table 5). Demoiselle Crane-2 covered a monthly distance of 875.90 ± 782.25 km and a daily distance of 35.01 ± 27.99 km (Table 5).

Table 4. Details of monthly and daily distances (km) traveled by Common Cranes during the non-migration season.

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Common Crane-1	5	January 2022	137.58	7.52
	28	February 2022	724.33	25.87
	24	March 2022	608.14	25.34
	20	April 2022	330.55	16.53
	31	May 2022	2713.85	87.54
	30	June 2022	204.16	6.81
	31	July 2022	565.13	18.23
	13	August 2022	392.11	30.16
	6	October 2022	189.66	31.61
	30	November 2022	659.43	21.98
	31	December 2022	618.64	19.96
	31	January 2023	1745.82	56.32
	16	February 2023	909.79	56.86
Average		-	746.09 ± 729.01	31.13 ± 22.87
Common Crane-2	24	February 2022	495.89	20.66
	31	March 2022	724.31	23.36
	31	May 2022	861.18	27.78
	30	June 2022	171.96	5.73
	31	July 2022	1063.45	34.30
	31	August 2022	408.63	13.18
	27	September 2022	484.47	17.94
	7	October 2022	166.48	23.78
	30	November 2022	493.54	16.45
	31	December 2022	1144.20	36.90
	31	January 2023	391.77	12.63
	16	February 2023	200.64	12.54
Average	-	-	550.54 ± 331.85	20.44 ± 9.30

Table 5. Details of monthly and daily distances (km) traveled by Demoiselle Cranes during the non-migration season.

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Demoiselle Crane-1	28	February 2022	1145.93	40.93
	24	March 2022	1069.25	44.55
	16	April 2022	441.14	27.57
	31	May 2022	1264.98	40.81
	30	June 2022	300.80	10.03
	31	July 2022	312.15	10.07
	7	August	207.67	29.67
	7	November 2022	251.14	35.88

Table 5. *Cont.*

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Demoiselle Crane-1	31	December 2022	951.33	30.69
	31	January 2023	1392.16	44.91
	16	February 2023	526.22	32.89
Average	-	-	714.79 ± 452.22	31.63 ± 12.19
Demoiselle Crane-2	21	February 2022	867.02	41.29
	24	March 2022	421.83	17.58
	17	April 2022	159.82	9.40
	31	May 2022	215.13	6.94
	30	June 2022	241.68	8.06
	31	July 2022	1006.02	32.45
	24	August 2022	1898.81	79.12
	31	January 2023	2373.59	76.57
	16	February 2023	699.26	43.70
Average	-	-	875.90 ± 782.25	35.01 ± 27.99

During migration, both Common Cranes and Demoiselle Cranes traveled overwhelming distances (monthly and daily) compared to the distances traveled in non-migration seasons (Tables 6 and 7).

Table 6. Details of monthly and daily distances (km) traveled by Common Cranes during migration season.

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Common Crane-1	7	March 2022	6454.44	1075.74
	10	April 2022	6527.75	625.77
	17	August 2022	819.5	48.20
	30	September 2022	761.58	25.38
	24	October 2022	13,292.76	553.86
Average		-	5571.20 ± 5172.73	471.19 ± 442.42
Common Crane-2	30	April 2022	4500.76	150.02
	3	September 2022	545.91	181.97
	22	October 2022	4376.36	198.92
Average		-	3141 ± 2248.28	176.97 ± 24.82

Table 7. Details of monthly and daily distances (km) traveled by Demoiselle Cranes during migration season.

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Demoiselle Crane-1	5	March 2022	2848.15	569.63
	13	April 2022	2120.73	163.13
	23	August 2022	1215.22	52.83
	30	September 2022	4146.36	138.21

Table 7. *Cont.*

ID	Number of Days	Timeline	Monthly Distance	Daily Distance
Demoiselle Crane-1	31	October 2022	779.09	25.13
	21	November 2022	1253.88	59.70
Average			2060.57 ± 1263.48	168.10 ± 203.77
Demoiselle Crane-2	6	March 2022	3090.17	515.02
	12	April 2022	1219.84	101.65
	6	August 2022	3587.05	597.84
	30	September 2022	732.76	24.42
	31	October 2022	1134.21	36.58
	30	November 2022	931.58	31.05
	31	December 2022	1372.18	44.26
Average			1723.97 ± 1130.90	192.97 ± 250.72

3.3. Migration Patterns

3.3.1. Common Crane-1

Common Crane-1 started migrating from Gujarat, India, on the 25 March 2022 (Figure 2). The migration lasted 17 days (the 25 March to the 10 April), crossing Pakistan, Afghanistan, Iran, Turkmenistan, Uzbekistan, and Kazakhstan to reach Russia (see Supplementary Information S4 for details). It covered a total distance of 12,982 km during its migration to Russia, with the largest distance covered in April. It covered a daily distance of 864.25 ± 299.08 km during migration and flew at an average altitude of 475.39 ± 564.87 m above Mean Sea Level (MSL). It rested at stopovers located in Pakistan, Afghanistan, Turkmenistan, and Kazakhstan (Supplementary Information S5). The return migration started on the 14 August 2022. The winter migration lasted for 71 days, during which Common Crane-1 traveled a total of 14,873 km in 71 days by covering a daily average distance of 209.15 ± 298.74 km and flew at an average elevation of 252.76 ± 323.83 m above MSL. While returning, the stopovers were located in the same countries, with the addition of Uzbekistan (Supplementary Information S5).

3.3.2. Common Crane-2

Common Crane-2 started its migration on the 1 April 2022 (Figure 3). Common Crane-2 covered a total distance of 4500 km in about 30 days while migrating from India to Kazakhstan. It covered an average daily distance of 150.02 ± 145.22 km and flew at an average elevation of 286.39 ± 578.55 m above MSL. Stopovers were located in Pakistan, Afghanistan, Iran, Turkmenistan, Uzbekistan, and Kazakhstan (Supplementary Information S4). On its return migration towards India, Common Crane-2 started moving southwards between the 28 and 29 September 2022. It crossed into India on the 10 October 2022. While in Gujarat, it made several stopovers in Kutch, Jamnagar, Rajkot, Junagadh, and Porbandar before settling in southern Gujarat (Figure 3). While returning, it covered a total distance of 4922 km in 25 days by covering an average daily distance of 864.25 ± 299.08 km and flying at an average elevation of 305.27 ± 512.01 m above MSL. While returning, the stopovers were made in Kazakhstan, Turkmenistan, Afghanistan, Pakistan, and India (Supplementary Information S5).

Figure 2. Migration route of Common Crane-1. Solid red line shows the northbound migration route towards Russia and the dashed red line shows the southbound migration route towards India. The yellow dots indicate the stopover locations used by Common Crane-1.

3.3.3. Demoiselle Crane-1

Demoiselle Crane-1 started migrating on the 26 March 2022 by traveling towards Pakistan (Figure 4). Demoiselle Crane-1 covered a total distance of 4968 km in 18 days and traveled an average daily distance of 366.38 ± 287.43 to reach Kazakhstan from India. It flew at an average elevation of 744.75 ± 685.26 m above MSL. It avoided crossing over all three deserts along its route, such as the Registan desert in Afghanistan, the Karakum desert in Turkmenistan, and the Kyzylum desert in Uzbekistan (Supplementary Information S4). It rested at stopovers located in Pakistan, Uzbekistan, and Kazakhstan (Supplementary Information S5).

Figure 3. Migration route of Common Crane-2. Solid purple line shows the northbound migration route towards Kazakhstan and the dashed purple line shows the southbound migration route towards India. The yellow dots indicate the stopover locations used by Common Crane-2.

When returning, Demoiselle Crane-1 started its southward migration on the 8 August 2022. The return migration route was similar to the northbound migration, avoiding all major deserts (Figure 4). While returning, it covered a total distance of 7394 km in 105 days to reach India. It covered an average daily distance of 68.97 ± 48.51 km and flew at an average elevation of 404.04 ± 366.69 m above MSL, and rested at stopovers located in Kazakhstan, Uzbekistan, and India (Supplementary Information S5).

Figure 4. Migration route of Demoiselle Crane-1. Solid green line shows the northbound migration route towards Kazakhstan and the dashed green line shows the southbound migration route towards India. The yellow dots indicate the stopover locations used by Demoiselle Crane-1.

3.3.4. Demoiselle Crane-2

The northward migration undertaken by Demoiselle Crane-2 was apparent on the 25 March 2022, and it took a similar route to that of Demoiselle Crane-1 (Figure 5). Demoiselle Crane-2 covered a total distance of 4310 km in 18 days to reach Kazakhstan. The average daily distance covered during migration from India to Kazakhstan was estimated as 308.34 ± 292.30 km, and it flew at an average elevation of 338.60 ± 679.46 m above MSL. Like Demoiselle Crane-1, it avoided major deserts in Afghanistan, Uzbekistan, and Turkmenistan and rested at stopovers in Uzbekistan and Kazakhstan (Supplementary Information S5).

Figure 5. Migration route of Demoiselle Crane-2. Solid yellow line shows the northbound migration route towards Kazakhstan and dashed yellow line shows the southbound migration route towards India. The grey dots indicate the stopover locations used by Demoiselle Crane-2.

The return southward migration started on the 25 August 2022. It covered a total distance of 7757 km in 128 days by covering a daily average distance of 146.83 ± 252.22 while migrating from Kazakhstan to Gujarat, flying at an average elevation of 183.82 ± 359.50 m above MSL. Interestingly, during its return southward migration, it crossed the Kyzlum and Karakum deserts it had avoided crossing while on its northward migration and made stopovers in Kazakhstan, Uzbekistan, Turkmenistan, Afghanistan, and Pakistan (Supplementary Information S4). After crossing to India, it settled in Rajasthan for about two months before traveling to its wintering areas in Gujarat (Supplementary Information S5).

3.4. Habitat Use

During its stay in India, Common Crane-1 stayed between Porbandar and Gir-Somnath sites, with occasional movements between these sites. Thus, we investigated habitat use separately for Porbandar and Gir-Somnath due to the high variation in landscape composition between these two. Similarly, Common Crane-2 stayed in Bhavnagar and Gir-Somnath and, thus, habitat use was also investigated separately for each site. Demoiselle Crane-1 stayed mostly in Porbandar during its stay in India, and Demoiselle Crane-2 stayed for about 17 days at Kutch but mostly in Porbandar. Thus, like Common Cranes, the habitat use of Demoiselle Cranes was also investigated for each site separately. Supplementary Information S6 further shows the occurrence locations of both Common and Demoiselle Cranes as plotted on the land use land cover map of the study area.

3.4.1. Habitat Use of Common Crane-1

We extracted and used eight habitat variables for Common Crane-1 at Gir-Somnath (Supplementary Information S7). The best model predicting the occurrences based on the minimum Akaike Information Criterion (AIC) included only three habitat variables including croplands, water bodies, and open scrub (Supplementary Information S7). All three habitat variables positively influenced the presence of Common Crane-1 in the Gir-Somnath landscape (Supplementary Information S8). For Porbandar, we used six habitat variables: built-up areas, croplands, forested areas, open-scrub habitats, human settlements, and water bodies (Supplementary Information S7). Among the selected variables, only croplands, water bodies, and open-scrub habitats significantly influenced the presence of Common Crane-1 (Supplementary Information S8).

3.4.2. Habitat Use of Common Crane-2

For Common Crane-2, we used five habitat variables to analyze its habitat use in Bhavnagar. The model best predicting the occurrence included only croplands and water bodies, which influenced the crane's presence positively (Supplementary Information S7 and S8). In Gir-Somnath, we used the same set of variables for Common Crane-2 and found that the best habitat use model included only cropland and open-scrub habitats (Supplementary Information S7). However, the second-best ranked model also included water bodies. These habitat variables were positively associated with Common Crane-2′s presence (Supplementary Information S8).

3.4.3. Habitat Use of Demoiselle Crane-1

Demoiselle Crane-1 stayed mostly at Porbandar during its winter stay in India. We used a total of seven habitat variables to assess its habitat use. The variables used were built-up areas, croplands, forest areas, open-scrub habitats, saltpans, human settlements, and water bodies. Among these, the best-suited habitat use model included only croplands and water bodies (Supplementary Information S7). These variables positively influenced the presence of Demoiselle Crane-1 at Porbandar (Supplementary Information S8).

3.4.4. Habitat Use of Demoiselle Crane-2

Other than Porbandar, Demoiselle Crane-2 also stayed for some days at Kutch, where it used mainly croplands and water bodies. Habitat use at Kutch was evaluated using a set of five habitat variables: croplands, water bodies, human settlements, *Prosopis* scrubs, and open-scrub habitats. As expected, water bodies and croplands positively influenced its presence at Kutch (Supplementary Information S8). Porbandar's best-suited habitat use model included four variables: forest land, open scrub, human settlements, and croplands (Supplementary Information S7). Forest land and human settlements were negatively associated with Demoiselle Crane-2, while croplands and open-scrub habitats were positively associated with its presence (Supplementary Information S8). The model that included water bodies was not significant, see discussion for further details (Supplementary Information S7).

4. Discussion

4.1. Home Ranges

The home range of cranes typically varies depending on several factors, such as food availability, breeding season, habitat conditions, and weather conditions [42]. Common Cranes are migratory birds that breed in the temperate regions of Europe and Asia during the summer months and move to warmer regions during the winter. During the breeding season, their home range can be as small as a few hectares, and they tend to remain within a specific territory [7]. However, during the non-breeding season, their home range can be much more extensive, and they may travel several hundred kilometers to find suitable feeding and roosting sites [7].

Our hypothesis was proven to hold true that overall home ranges in wintering grounds during the non-breeding season were more extensive than the respective home ranges in breeding grounds. A study conducted in Germany used GPS telemetry to track the movements of Common Cranes during the non-breeding season and found that their average home range varied from 50 to 400 km^2 [43]. We observed similar patterns of home range size in India during the non-breeding season for both Common and Demoiselle Cranes. A similar study conducted in south-central Sweden used satellite tracking to estimate the home range of Common Cranes (n = 11) during the breeding season and found that, on average, their home range was relatively small, 250 $\pm$ 47.8 ha (mean $\pm$ SE) [44]. In Germany, the smallest home range of Common Cranes in the breeding season was estimated as 70 ha, while the largest was estimated as 132 ha [43,45], and, in Spain, average winter territories were estimated as 70 ha [46]. However, the home ranges were estimated for the family group, and only 2% of the families were present within the study area [46]. Thus, our results concur with these studies that home ranges are on average smaller in breeding areas than in non-breeding areas.

4.2. Movement and Migration

Demoiselle Cranes and Common Cranes travel thousands of kilometers each year, stopping at various wetlands and grasslands during their migration [7,47]. Some studies have shown that Common Cranes that breed in northern Europe are short-to-medium-distance migrants wintering in southern Europe, northern Africa, and the Middle East [48,49]. However, some from northern Europe are known to migrate as far as Ethiopia [49]. In southern Europe, there are short-distance migrants and residents [50,51].

The migration routes and stopover sites of Common Cranes are more well-studied in Europe [48,52,53] than in Asia. Mostly, migratory birds wintering in the Indian subcontinent are reported to fly over the Himalayas during migration [54]. Similarly, Demoiselle Cranes have been reported to fly across the Himalayas during migration [55]. However, the exact migration routes and stopovers used during such migration remain unknown. In this study, we observed that Common Cranes and Demoiselle Cranes use the Central Asian Flyway (CAF) [56] to winter in western India. Here, we identify the long-distance route of Common Cranes and Demoiselle Cranes across Pakistan, Afghanistan, Iran, Turkmenistan, Uzbekistan, and Kazakhstan up to Russia. Previous telemetry studies of Common Cranes in Rajasthan, northwestern India, also documented the same CAF flyway used for spring migration [23]. A recent satellite tracking of the Common Crane in Kutch showed that the Common Crane used the same flyway across the same countries to reach Kazakhstan [29]. Pierre and Higuchi [30] delineated the migration routes of more than 11 species of birds in Asia, including Common and Demoiselle Cranes. They found intra and inter-species variations in distances covered by crane species wintering in Asia.

We observed that daily and monthly distances increased with migration, as hypothesized. Higuchi et al. [23] found that Common Cranes covered a total migration distance of over 4000 km in 30 days (towards breeding sites). Our results also show that Common Crane-2 covered almost the same distance in the same time while migrating towards Kazakhstan and then back to India. During their northward migration, the detected number of resting stopovers for Common Crane-1 and Common Crane-2 were 11 and 12, respectively.

Demoiselle Crane-1 and Demoiselle Crane-2 made 12 and 7 resting stopovers, respectively, during their northbound migration. The number of stopovers is comparable with those observed in earlier telemetry studies of Common Cranes across the same migratory route [23]. The number of stopovers varies with species, weather conditions, and accumulated fat reserves. Studies have found that Red-crowned Cranes were able to undertake longer flight durations with fewer stopovers [22], and White-naped Cranes were able to complete their migration with as few as one stopover [20]. Among cranes, Siberian Cranes have been found to make more stopovers than any other crane species tracked [9].

Generally, cranes are known to undertake longer flight durations between stopovers and usually stay for shorter periods at stopover locations [30]. We found inter-species variation in the number of days cranes migrated from breeding areas to India. We found that Common Cranes and Demoiselle Cranes took an average of 23.5 and 18 days, respectively, for their northbound migration from India, while, on their return, the number of days increased to 48.5 and 116 days, respectively. Studies have shown that Common Cranes use time and energy to have a minimum energy utilization strategy during autumn migration [57]. The number and selection of days during migration are highly related to weather conditions, which has been well demonstrated in cranes [58]. Satellite telemetry studies provide helpful information on the wintering sites and stopover sites migratory birds use. Our work mainly shows more than 40 administrative areas (districts) in seven countries as crucial to Common Cranes and Demoiselle Cranes during migration (Supplementary Information S5). Prolonged satellite telemetry studies of Common Cranes and Demoiselle Cranes in India would provide more information about migration patterns, flyways, stopover locations, and threats that the cranes may face during migration.

4.3. Habitat Use

The spatial distribution and habitat use of wildlife species can help determine conservation priority areas for better management. This is particularly true for long-distance migratory birds, where conservation efforts often require international collaboration and efforts. Our results indicate that water bodies, croplands, and, to some extent, open-scrub habitats were the most important determining factors affecting the cranes' presence positively. Our hypothesis that home ranges were expected to be in habitats with water bodies also holds true, with only one exception where the model including water bodies was not statistically significant.

In our study area, Demoiselle Cranes preferred a more comprehensive range of habitat types, including marshes, freshwater lakes rivers [59], cultivated fields and rice stubble [7,9], sandy riverbeds, the flat and open margins of seasonal pans and farm ponds [7], and hot desert (if water is readily available) [7–10]. Our results agree with these studies that habitat types with water and croplands are among the most-used habitats by Demoiselle Cranes. In this study, Demoiselle Cranes showed a preference for water bodies and croplands, except at Porbandar, where they were found to use water bodies; however, the habitat model was not significant. This may have been due to the high proportion of pseudo-absence locations in water bodies.

Similarly, Common Cranes prefer a variety of shallow wetlands, including high-altitude treeless bogs, often with some quantity of stagnant water; swampy forests; reedy marshes; and rice paddies [6]. Our results also indicate that water bodies and croplands are essential in determining habitat factors in their non-breeding range. Common Cranes are reported to be similar in their foraging habits to the Sandhill Crane (*Grus canadensis*), consuming a bulk of plant materials such as roots, rhizomes, tubers, stems, leaves, fruits, and seeds [7]. Croplands provide an easy supply of food to Common and Demoiselle Cranes during the winter season. A similar study conducted in China during the winter congregation also found that Black-necked Cranes and Common Cranes were detected more frequently in farmlands and avoided grasslands [60]. Water bodies are optimal foraging habitats for cranes because of the ready supply of consumable food resources and their difficult access for humans [61]. Likewise, croplands are highly utilized by most

crane species across their wintering grounds in Asia [61] and are regarded as vital foraging habitats during winter.

In recent years, traditional low-intensity agricultural practices have changed to modern mechanized practices to meet ever-increasing demands arising from human population growth, leading to a change in cropping patterns [62]. In the present study area (Gujarat), 54% of the land is utilized for agriculture, accounting for the 12.8 million hectares of cropped area in Gujarat [63]. Cotton (*Gossypium* spp.), groundnut (*Arachis hypogea*), castor (*Ricinus communis*), rice (*Oryza sativa*), wheat (*Triticum aestivum*), bajra (*Pennisetum glaucum*), and maize (*Zea mays*) are the major crops grown in Gujarat. However, it has been found that agriculture has shifted from food grains to cotton production [63]. Overall, the share of food grains has declined from 43% in 1994–1995 to 36% in 2014–2015, while the share of cotton doubled from 11% to 20% within the same period [63].

Furthermore, the share of oil seeds such as castor and groundnut declined from 27.1% to 23.9% during the same period [63]. Cranes in Eurasia and Africa have coexisted with agriculture and have adapted to traditional low-intensity agriculture, consuming waste grains and crops and feeding in rice paddies. Croplands provide predictable and high-energy food resources that are particularly important during the long-distance migration often undertaken by cranes. A systematic review of crane interactions with agriculture indicated that crops constitute an important component of their diet, with maize and wheat being consumed more frequently [62]. It has been argued that the degree to which cranes can adapt to the changing cropping pattern and use cereal grains as food may explain their population responses [62].

5. Shortcomings

Our study was limited by the smaller sample size, which explains the large variation observed in the home range sizes and movement patterns. In the future, such studies should incorporate factors such as the age, gender, and sexual status of the birds to account for the variation observed in home range sizes, besides increasing the sample size. Thus, the results of this study may vary with increased sample sizes. Other than the small sample size, a quantification of the potential threats such as rising cotton farming within the study area was not carried out in the field. A more comprehensive approach in the future may provide new insights into the ecology of migrating cranes in India.

6. Conservation Implications

As reported in previous studies mentioned above, wetlands and croplands are essential indicators of crane presence in Gujarat, India. These habitats are continuously being modified, such as by the changing crop patterns from cereal grains to cotton in Gujarat, which raises serious concerns about crane presence during winter in the near future. The presence of overhead power lines in the wetlands with crane presence within the study area poses a major electrocution risk due to collision. In recent times, one of the important concerns about their conservation has been the management of the water bodies along their migration flyways. The Common and Demoiselle Cranes that winter in Gujarat use the Central Asian Flyway by following the southwestern route and making stopovers around water bodies and croplands, which requires international cooperation for better management. This route includes countries where hunting during migration has been reported to be frequent and thus requires cross-border cooperation to ensure a safe pathway. Frequent collisions with utility lines in developed and wintering countries require international efforts and cooperation to safeguard cranes across their breeding and non-breeding ranges.

7. Conclusions

In conclusion, this study provides new insights into crane ecology using satellite telemetry in India. We found seasonal variations in home ranges between the breeding and non-breeding ranges of Common and Demoiselle Cranes, with larger home ranges in non-breeding ranges. Both these species traveled enormous distances between their

breeding and non-breeding grounds using the Central Asian Flyway. Water bodies and croplands were the most important habitat predictors of their presence in India. We identified stopover sites along their migration flyway that indicate the importance of conserving the water bodies among the range countries. We conclude that favorable crops, adequate water bodies, long-term monitoring using satellite tracking, and international collaboration among a range of countries of the Central Asian Flyway are important aspects of crane conservation.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/birds4040029/s1: Supplementary Information S1: Details of satellite tagging of Common Cranes and Demoiselle Cranes carried out in Gir-Somnath landscape, Gujarat, India Supplementary Information S2: Model validation matrix of the fine-scale habitat selection model (GLM) of Common Cranes and Demoiselle Cranes during their winter stay in Gujarat, India.; Supplementary Information S3: Home range polygons of Common Cranes and Demoiselle Cranes described in breeding (Russia and Kazakhstan) and non-breeding ranges (Gujarat, India); Supplementary Information S4: Detailed description of the migration route, and stopover locations used by Common and Demoiselle Cranes; Supplementary Information S5: Details of stopover locations used by Common Cranes and Demoiselle Cranes during migration; Supplementary Information S6: Presence locations of Common Cranes (1&2) and Demoiselle Cranes (1&2) plotted on the land use land cover map of the study area; Supplementary Information S7: Details of fine-scale habitat use of Common Cranes and Demoiselle Cranes as determined using generalized linear models; Supplementary Information S8: Partial dependence plots showing the marginal effect of selected habitat variables on the predicted occurrence of Common Cranes and Demoiselle Cranes.

Author Contributions: Conceptualization: M.R., A.S., N.S. and D.G.; Methodology: M.R., A.S., D.G. and T.A.R.; Formal acquisition, analysis, and investigation: M.R., A.S., D.G., T.A.R., Y.Z. and L.J.; Field implementation, capturing of birds, and deployment of transmitters: M.R., D.G., D.J., V.M., A.P., P.K., K.V., S.B. and D.D.; Writing—original draft preparation: M.R., D.G., T.A.R. and V.M.; Writing—review and editing: M.R., D.G., T.A.R., V.M., Y.Z. and L.J.; Development of maps: Y.Z., V.M., T.A.R., D.G. and M.R.; Resources: M.R. and D.G.; Supervision: M.R., A.S. and N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was undertaken by the Wildlife Division, Sasan-Gir, Gujarat Forest Department, and is one of the works of the concerned division. Therefore, the work was conducted as per the fund received under different heads for conducting such work.

Institutional Review Board Statement: All scientific research activities involved in this study were carried out after obtaining due permission from the competent authority [Chief Wildlife Warden, Gujarat state, Gandhinagar, India, (letter no: WLP/T.28/A/3242/2021-22, dated 26 August 2021)]. All experimental methods and works were carried out in accordance with relevant guidelines and regulations suggested by the Principal Chief Conservator of Forests (Wildlife) and Chief Wildlife Warden, Gujarat Forest Department, Government of Gujarat. Technical experts, experienced bird trappers and handlers, and qualified and experienced veterinarians carried out the tagging work.

Data Availability Statement: All data generated or analyzed during the mentioned period for this study are included in this published article and in the supplementary materials.

Acknowledgments: The authors would like to thank the Principal Chief Conservator of Forests and Head of Forest Force (PCCF&HoFF), Gujarat State, for their help and support. The field support extended by DCF Gir (West) Division and its field staff is duly acknowledged. We are grateful to our technical expert, Ivar Ojaste from Estonia, who provided valuable input about ringing and transmitter deployment techniques for cranes. We also acknowledge the technical support extended by the staff at The Corbett Foundation. We especially thank Kedar Gore from The Corbett Foundation for his constant support and encouragement. We are thankful to the Government of Gujarat and the Gujarat Forest Department for permission and for supporting this important study. We also acknowledge the support of the staff at the Wildlife Division, Sasan-Gir, and personnel at the Gir Hi-Tech Monitoring Unit, Sasan-Gir, for helping in monitoring the crane radio-telemetry project.

Conflicts of Interest: The authors have no competing interests to declare relevant to this article's content. The authors also declare that the territorial descriptions on maps are according to Google Imagery, and we remain neutral concerning the country boundaries depicted.

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