Research and Conservation of Black-necked Cranes in Bhutan

Final project report

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Content

Black-necked Cranes in Bhutan

1. Importance of Bhutan for Black-necked Cranes

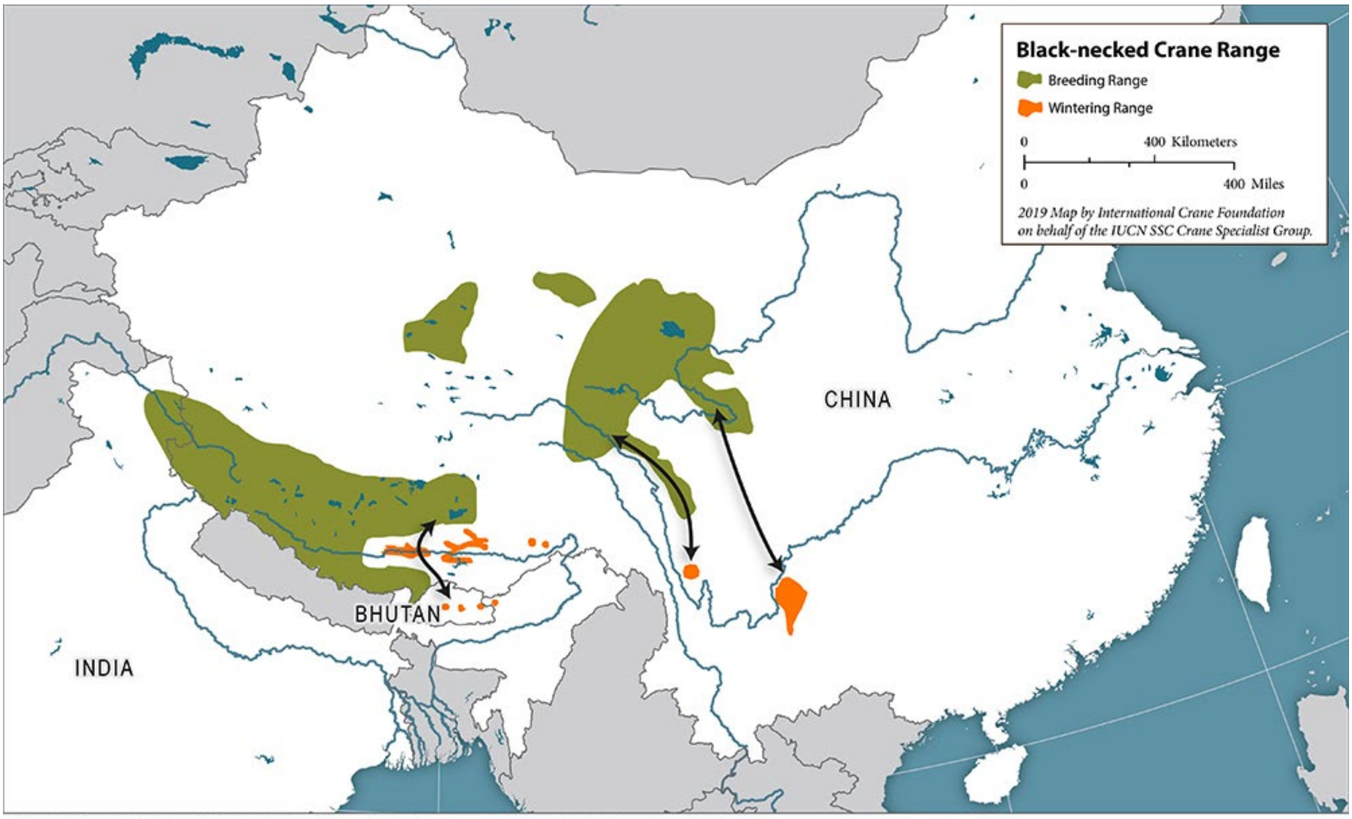
The Black-necked Crane (Grus nigricollis) is the only alpine crane species in the world. It's breeding range includes most parts of the Qinghai-Tibetan Plateau in western China, with a small breeding population occurring in adjacent Ladakh in India. Wintering grounds of Black-necked Cranes (BNC) include lower elevations of the Qinghai-Tibet and Yunnan-Guizhou Plateaus in China, as well as several hundred occurring in Bhutan and few individuals in northeast India (see Figure 1).

The entire population was estimated to 13,500 in 2020 (CMS, 2020). As the population has slightly increased since the last estimation, the status of Black-necked Cranes on the IUCN Red List was upgraded in 2020 from vulnerable to near-threatened.

The stability and growth of the population of this species stands in marked contrast to significant population declines for most waterbirds in Asia over the past two to three decades. It is partly the success of conservation activities in the past, but might be also caused by favourable conditions in summer and winter caused by global warming (ICF, 2023).

The positive population trend needs to be stabilized. Therefore, knowledge gaps about the species have to be closed. This study analysed wintering und migrating pattern of BNC wintering in Bhutan. So far this knowledge, especially about migrations routes and resting areas, was rare.

Figure 1: *Distribution of Black-necked Cranes in the world. Source: International Crane Foundation (ICF), 2017*



Mirande CM, Harris JT, editors. 2019. Crane Conservation Strategy. Baraboo, Wisconsin, USA: International Crane Foundation.

2. Wintering population in Bhutan

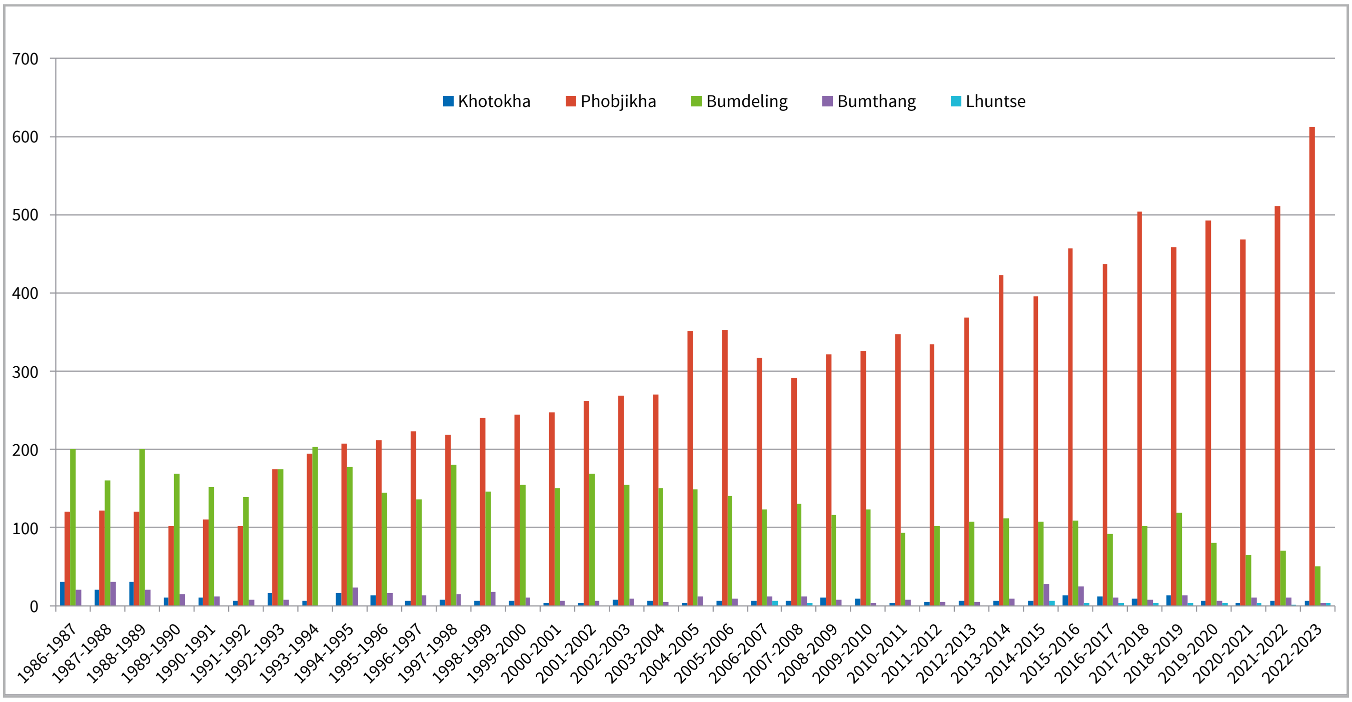
Black-necked Cranes spend the winters mainly in three populations: Eastern population (northeastern Yunnan and northwestern Guizhou Provinces), Central population (northwestern Yunnan) and Western population (south-central Tibet and Bhutan) (ICF, 2023). The western population is the largest of these three populations.

The wintering grounds in Tibet are located along the Lower and Middle Reaches of the Yarlung Tsangpo (Brahmaputra) River Basin. Here, the major wintering sites of Tibet are found in the Middle Yarlung Tsangpo Black-necked Cranes reserve, which was established in 1993 (ICF, 2023).

Black-necked Cranes wintering in Bhutan are recorded at five sites: Phobjikha, Bumdeling, Khotokha, Bumthang and Lhuntse. Nowadays, about 500-600 cranes spend the winter in Bhutan. The wintering population has significantly increased since its first recording in winter 1986-1987. At that time, about 120 cranes were found during winter in Bhutan. The population is still slightly increasing year by year as shown in Figure 2. In winter 2022-23 612 cranes stayed in Bhutan (RSPN, 2023b).

Very few cranes, belonging to the western population, winter in India. The wintering ground is located in Pangchen valley (Tawang) and Sangti valley (West Kameng) in Arunachal Pradesh (ICF, 2023).

Figure 2: Development of the BNC wintering population in Bhutan sorted by wintering sites. Source: RSPN, 2023b



3. Phobjikha valley, the most important wintering site

The increasing population of wintering cranes in Bhutan is the result from an increase in the wintering population in Phobjikha valley. All other wintering grounds in Bhutan show a negative population trend. In winter 2022-23 only 51 were recorded in Bumdeling, seven in Khotokha, four in Bumthang and three in Lhuntse. Therewith, Phobhjikha is the most important wintering site for BNC in Bhutan. Figure 3 shows the number of cranes wintering in Phobjikha valley from 1986-87 to 2022-23 as well as the relevance of Phobjikha for the entire wintering population in Bhutan. In winter 2022-23 90.4 % of all cranes wintering in Bhutan stayed in Phobjikha valley.

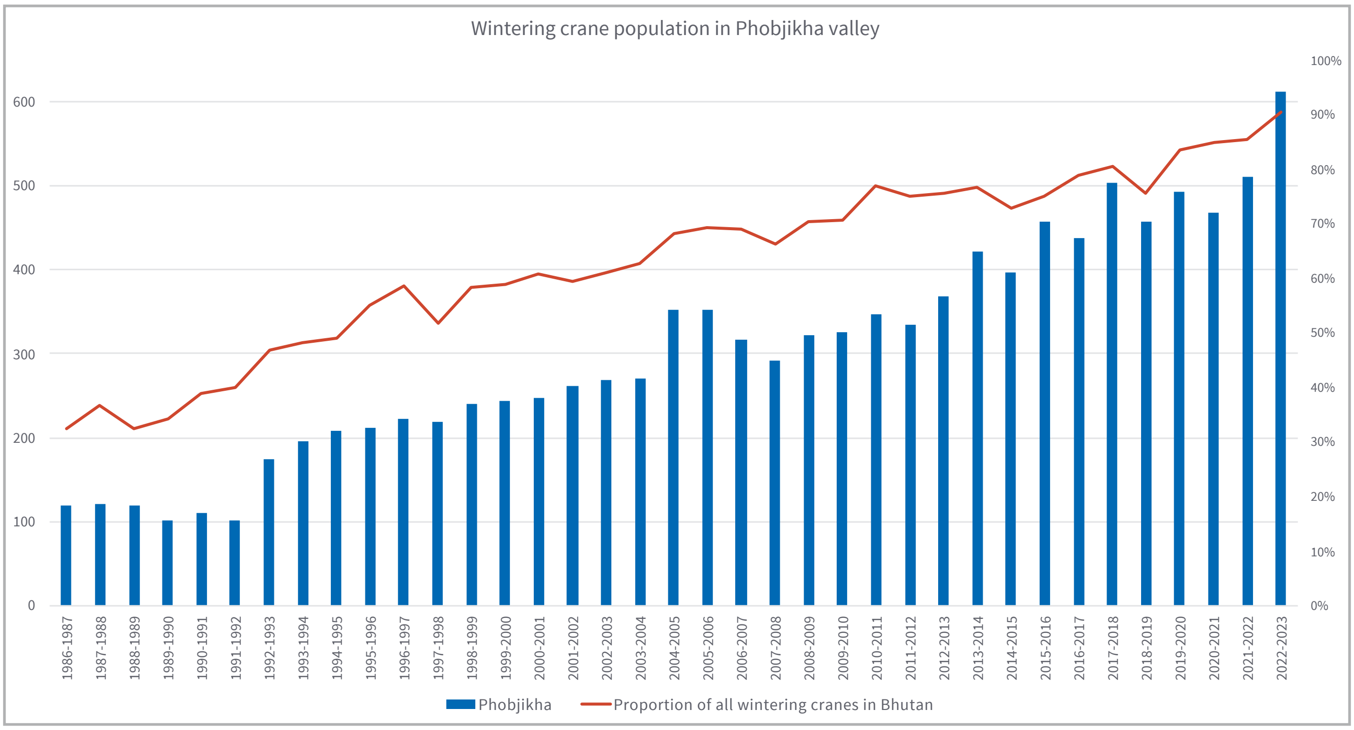


Figure 3: *Total number of cranes wintering in Phobjikha and its proportion of all cranes wintering in Bhutan from 1986–87 to 2022–23. Source: RSPN, 2023b*

The project

1. Background

The Black-necked Crane (Grus nigricollis) holds a remarkable position in the ecological realm as the sole alpine crane species in the world. Moreover, it carries tremendous cultural significance in the Himalayan region. Since 1979, the species has been listed in Appendices I and II of the Convention on Migratory Species (CMS). Substantial efforts have been made to conserve Black-necked Cranes in China, India, and Bhutan through successful collaborations between government agencies and civil society organizations (CMS, 2020). The recent discovery of Black-necked Crane individuals in Nepal is an important addition to the knowledge of the international conservationist community (RSPN, 2023a; ICF, 2023). At the international level, conservation activities are largely influenced by the IUCN SSC Crane Specialist Group and the International Crane Foundation (ICF). ICF plays a significant role in supporting Black-necked Crane conservation partners and strengthening networks, including the Chinese-based Black-necked Crane Network. Since 1996, ICF has also been involved in supporting Crane conservation activities in Bhutan.

Since 1987, the Royal Society for the Protection of Nature (RSPN) has been implementing a Black-necked Crane conservation program in Bhutan. Starting in 2011, the Ugyen Wangchuck Institute for Conservation and Environment Research (UWICER) has been conducting annual movement studies on BNCs with support from the Max Planck Institute for Animal Behavior. However, there is still insufficient knowledge regarding the flyways of these specific wintering cranes in Bhutan. In order to address this gap and contribute to existing conservation efforts, the Royal Society for the Protection of Nature (RSPN), NABU International - Foundation for Nature (NABU International), and Crane Conservation Germany (CCG) jointly implemented a research and conservation project for BNCs in Bhutan. The project ran from 2018 to 2023 and was funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection (BMUV). The project collaborated with the ongoing activities of UWICER in the field of data utilization. Within this project, migration patterns, habitat use, population structure, and threats of Grus nigricollis were studied with the aim of developing a national conservation program in Bhutan. Furthermore, it was part of the project team's effort to be in close cooperation with other actors in BNC research and conservation. This culminated in the facilitation of an International Black-necked Crane Conservation Network Meeting in the fall of 2022 in Thimphu, Bhutan.

2. Objectives

Overall, this project aimed to contribute to maintaining a stable or increasing population of Black-necked Cranes. It complements ongoing research and conservation activities. From a research perspective the project specifically aimed to gain more information on the species migratory pattern (e.g. flyways, resting sites, distances, altitudes, speed) and behavioral pattern in the wintering grounds (e.g. habitat use, home-range and roosting sites) of BNCs in Bhutan and make data available for future conservation activities. Gained information was used to formulate recommendations for future conservation activities. Furthermore, data management capacities of crane conservationists in Bhutan was enhanced by conducting two coaching workshops. Additionally, exchange and cooperation between crane conservationists between range states was promoted by the implementation of an international workshop.

3. Methods

a) Data gathering and field trips

Between 18th January and 2nd February 2019 Dr. Günter Nowald and Anne Kettner, two members of Crane Conservation Germany (CCG), travelled to Bhutan for the first field trip within the project. Together with Jigme Tshering, the project coordinator of the Royal Society for Protection of Nature (RSPN), and his colleagues they travelled to the Phobjikha valley, the major overwintering site of Black-necked Cranes in Bhutan. Approximately one year later (09th to 24th January 2020) Dr. Günter Nowald travelled again to Bhutan together with his colleague Xavier Chauby. Together with Jigme Tshering and RSPN staff they conducted the second field trip of the project in Phobhijka valley. Afterwards they travelled to Bumthang valley for a short survey.

The following project activities were implemented during these two field trips:

- Capture and marking of Black-necked Cranes with coloured-rings and/or GPS-tags.
- Mapping of cranes for analyzing habitat use and identifying threats
- Synchronous counting to document population size in Phobhjikha valley
- Workshop to train RSPN staff in GPS analysis (2019) and crane marking methods (2020)

In total eight Black-necked Cranes were caught in 2019 (3) and 2020 (5) at the roost-site by using different passive trap techniques. The details are descripted in the field trip reports (Nowald et al. 2020, Kettner et al. 2019). All cranes were marked with coloured rings as recommended by the European Crane Working Group (Nowald, 2010. Whereas the colour combination in Europe consists of in total six plastic rings, for Bhutan a colour combination of just four rings was chosen, because the population of BNC is

Figure 4: *Group picture during the first field trip – from left to right: Chimmi Dorji, Tenzin Nima, Jigme Tshering, Anne Kettner, Günter Nowald, Annalena Lohaus, Bishnu Maya Rai, Pema Wango, Chimi Dorji, Santa Gajmer. Photo: G. Nowald*

much smaller and therewith the number of marked individuals. The colour combination of BNC consists of two rings on the left leg, which shows the country code (Bhutan: Yellow-Red) and two rings on the right leg to identify the individual. Six of eight cranes were additionally equipped with a GPS-tag produced by the German company e-obs (Type: Bird Solar UMTS 42 g). The GPS data was used for analysing migration and wintering pattern as described in the next section.

Table 1:
Overview of all BNCs that were marked in Phobjikha valley within this project with GPS-tag and/or coloured rings. Y: Yellow, R: Red, Bu: Blue, G: Green, W: White, Br: Brown, Bk: Black

Tag ID	Crane name	Age	Ring detail	Date	Ringer
6602	Annea guentera	Adult	YR-RBu	26.01.2019	S. Sherub
6603	WangC	Immature	RY-GW	25.01.2019	G. Nowald, A. Kettner, J. Tshering
6604	Sonamw	Adult	RY-BuW	25.01.2019	G. Nowald, A. Kettner, J. Tshering
7118	Kinley	Adult	YR-RY	15.01.2020	G. Nowald, X. Chauby, J. Tshering
7117	Tsheyphell	Adult	YR-RG	16.01.2020	G. Nowald, X. Chauby, J. Tshering
7116	Nameless	Adult	YR-RW	20.01.2020	G. Nowald, X. Chauby, J. Tshering
x	x	Adult	YR-BrW	20.01.2020	G. Nowald, X. Chauby, J. Tshering
x	x	Adult	YR-BuBk	20.01.2020	G. Nowald, X. Chauby, J. Tshering

In addition to the marked cranes from Phobjikha valley, Sherub working for the Ugyen Wangchuck Institute for Conservation & Environmental Research in Bhutan, tagged three BNC in Bumdeling valley in commission of RSPN. He used a different type of ring, but the same GPS-tag. The GPS data was included in the GPS-analysis conducted within this project.

Tag ID	Crane name	Dand ID	Ring Col	Date	Ringer
6606	Karma	90 RL	Blue LL	28.02.2019	S. Sherub
6607	Samten	59 RL	Green LL	27.02.2019	S. Sherub
6608	Dorji	57 RL	Red LL	26.02.2019	S. Sherub

Table 2:
BNCs that were marked in Bumdeling valley and included in the data analysis of this project.

All captured cranes were measured and weighted. Karma, a crane living in captivity at the crane visitor centre in Phobjikha, was also measured and weighted during the first field trip. The results of all measurements can be found on page 16.

b) Data analysis

Each of the nine GPS-tags recorded the height and the coordinates (vertical and horizontal reference system: WGS84) at specific points in time. Those data points were transferred to and could be downloaded from the online platform Movebank (www.movebank.org). The analysis was done with GIS software (ArcMap, ArcGIS Pro or QGIS) as well as the software Microsoft Excel.

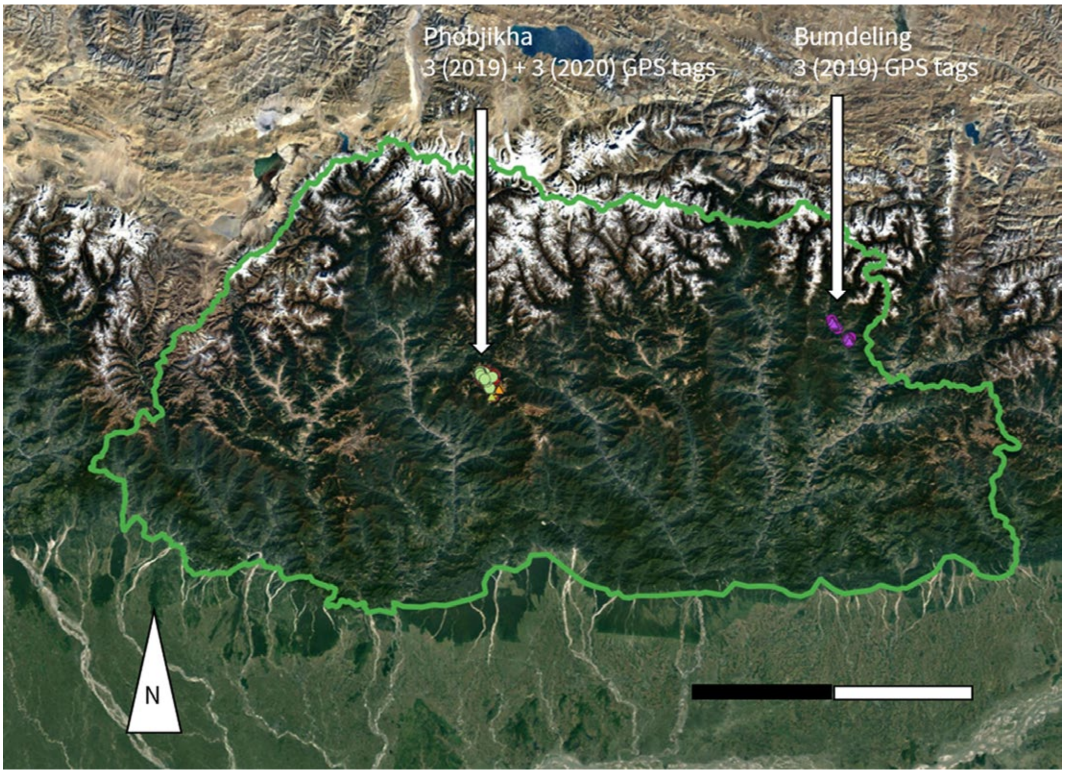


Figure 5: *Number, year and location of all nine GPS-tags in Bhutan included in this study. Map: Google Satellite*

Migration

The data collected between the date of tagging and the first migratory movement were excluded from further analysis, because it did not cover a complete winter seasons and the behavior might be influenced by the tagging itself.

For every tagged crane the analysis of migration pattern included all data points were a migratory movement was recognizable. This movement is confined by GPS point clusters at both ends of the migratory route, either within the wintering area or within the summering/ breeding area, more precisely by the last respectively the first point, at which the crane was definitely still or not yet flying.

The analyzation of migration patterns included the identification of resting areas on the migratory route. Those areas are constituted of the non-flying points, which lie, usually spatially clustered, between the single stages of a migratory movement. So, at first, the identification of the non-flying points had to be conducted. Therefore, for every single data point the ground height in reference to the EGM96 Geoid had to be extracted from a Digital Elevation Model (De Ferranti, 2014) with the ArcGIS–tool 'Extract values to points'. In addition, the height data from the GPS-tags had to be transformed to the same reference system. By doing so, the difference between the positional and the ground height could be calculated for every single GPS point. Due to inaccuracy of positional heights for each GPS point the tags recorded an estimation value, showing the possible deviation from recorded to actual height. This estimation value and also an additional value, resulting from the inaccuracy of the Digital Elevation Model (+/- 30,64 m, Mukul et al., 2017) as well as from the calculation method used by ArcGIS to transform the height data from one vertical reference system to another (+/- 1), were used to calculate the minimal possible flying altitude for each data point. The non-flying points are those points, where the minimal possible flying altitude is below zero.

The spatially clustered non-flying points constitute the resting areas, single or few non-flying points, at which a crane was not staying overnight, are still part of the adjoining migratory stage. The single resting areas should only be connected by one flight route within the same migration, otherwise the respective crane was flying back and forth between two areas, which therefore are regarded as one single resting area. From now on the resting areas at which a crane was only staying for a night are labelled as **stopover areas**, the ones where it stayed for several nights are labelled as **resting areas**. The locations of the single areas were determined at the respective roost with the most data points. **Roost sites** in general were identified on the basis of spatially dense clusters of points within an area, which were recorded during the night and which are located in or near wetlands.

The analyzation of migration patterns also included the calculation of **statistical values for the migratory movements**. After the resting and stopover areas were identified, the single stages of a migratory movement, i.e. consecutive flying-points (minimal possible altitude > 0) lying between those areas, could be identified. The differences in time and space between those points were used to calculate several statistical values for each crane and migratory movement. To calculate the **distance** between two points, linking lines were created with the ArcGIS–tool 'XY to Line' and the geodesic length of those lines were calculated with the ArcGIS–tool 'Add geometry attributes'.

To gain values for a whole migratory movement the single migratory stages had to be connected by lines linking the last data point of a preceding and the first data point of a following migratory stage, thus bridging the resting- and stopover areas to create a coherent migratory route between the wintering and the summering/breeding area. Most of the later presented statistical values refer to the whole migratory route, i.e. for all associated migratory stages and connecting lines, only for the value of **average spee**d ('Ø km/h') the migratory stages without the connecting lines between them where considered.

Three different categories of heights were calculated. The value 'Δ ground level start to end' is the difference in ground height between the first and the last data point, i.e. between the first starting- and the last landing-point of a migratory route. The category 'max. Δ ground level from start' is the overcome ground height during migration, i.e. the height difference between the first starting-point and the most elevated data-point of a migratory route. The value 'max. flight level over MSL' is the maximal achieved height over the mean sea level (i.e. over the EGM96 Geoid, without considering the possible deviation of each positional height) during a migratory route.

Behavior and habitat use

Not only the migration pattern but also home-range, roost sites and habitat use during wintering were analysed.

To determine the wintering areas for all cranes and seasons, single seasonal home-ranges had to be calculated on the basis of non-flying GPS-fixes, which lie between the last data point of the preceding and the first data point of the following migratory route. In each possible case, for those data points three home-range categories were calculated by using two different methods to create an encompassing polygon and by encompassing either all (one method) or 95 % of them (both methods). The first method, the **minimum convex polygon (MCP)**, was to create a ‘convex hull’ around all (100 %) and around 95 % of data points with the GIS-tool ‘Minimum Bounding Geometry’.

The second method was to execute a ‘Kernel-Density-Estimation’ (KDE) (ArcGIS-tool) and to convert the resulting raster in a raster with integer values with the ArcGIS-tool ‘Int (Spatial Analyst Tool)’ to subsequently extract its cell values for each of the associated data points with the ArcGIS-tool ‘Extract Values to Points’. The cell value of the data point, which constitute the 95 %-margin was then used as a decisive value to attribute for each cell, if it is part of the home-range which encompasses 95 % of the data points or not. Finally, this attribute was used to convert the raster dataset to polygons (tool: ‘Raster to Polygon’) and subsequently, the polygon which comprises the data-points outside the 95 % home-range were excluded from further calculations. For all of the created encompassing polygons the geodesic areas and thus the home-range sizes were calculated with the tool: ‘Calculate Geometry Attributes’.

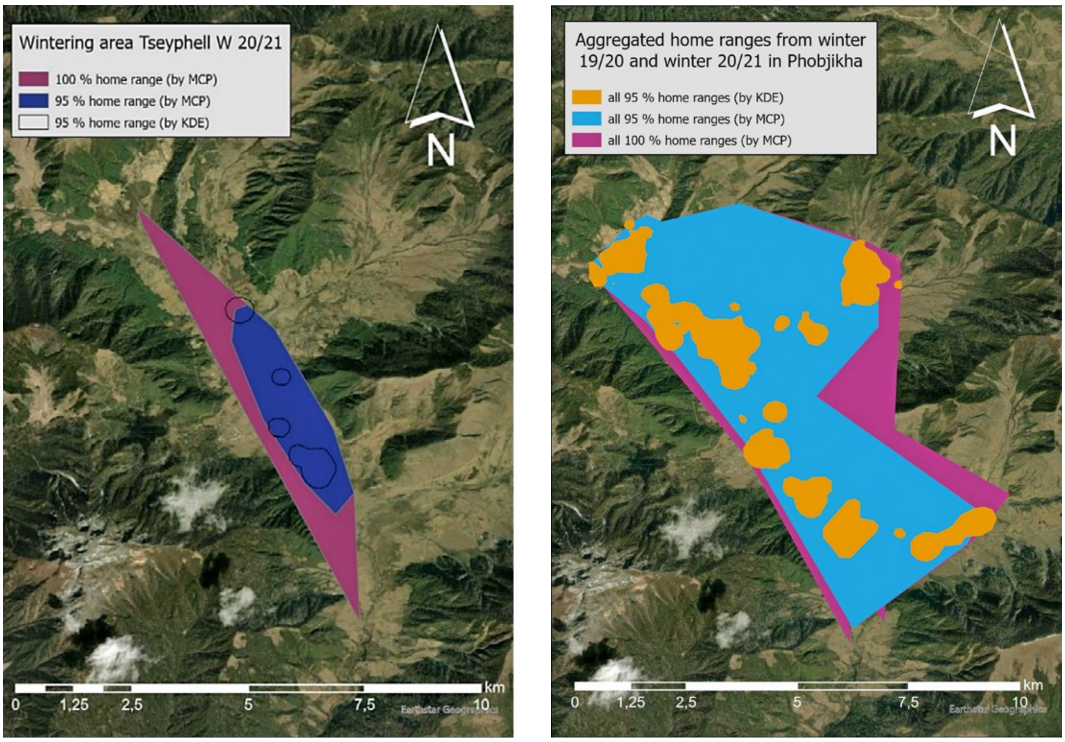


Figure 6: ▸ *(Aggregated) Home-range calculated with three different methods. Map: Earthstar Geographics*

For each of the three home-range methods all associated seasonal home-ranges within Phobjikha Valley were merged (ArcGIS tool ‘Merge’) and aggregated (ArcGIS tool ‘Aggregate Polygons’, with the smallest possible aggregation distance for all of the three home-range methods and also with an aggregation distance of 1 km and a minimum hole size of 1 hectare for the 95 % - home-range based on KDE) to compare the resulting areas and to conclude the best method to gain coherent areas, in which protection measures would have the largest effect. The best method to gain coherent and effective protection areas was finally conducted also for Bumdeling valley resulting in an **aggregated home-range** for the valley.

Within the single seasonal home-ranges, the roosts were determined and analysed. Therefore, for each of the associated data points it was determined, if it was recorded during the day, the night or during a transitional time span. Those time spans were defined by the local time of sunrise and sunset (at Thimphu for Phobjikha valley and at Tashi Yangtse for Bumdeling valley; source: www.sunrise-and-sunset.com). A transitional time span was required because of the variation of times for sunrise and sunset throughout the winter period, which for this purpose was determined from 15th of November to 15th of March. With this new attribute, all nightly data points (see Figure 7) of all single seasonal home-ranges could be selected to identify and to determine the borders of the single roosts and therewith to allocate each nightly data point to one of the identified roosts.

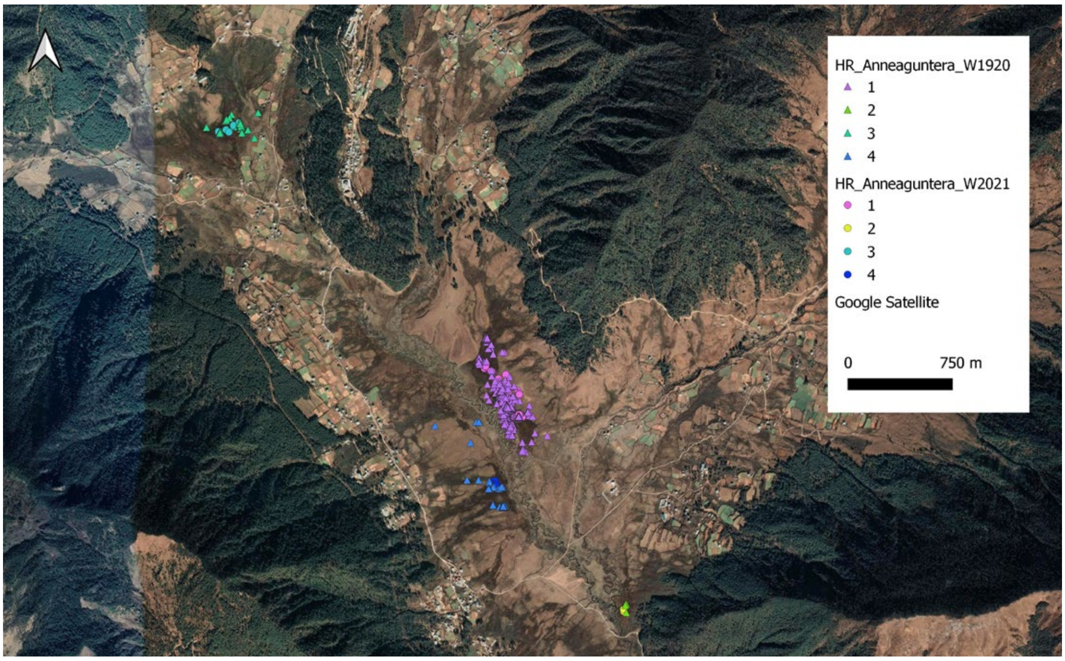


Figure 7: *Night data of crane "Anneaguntera" in two winter seasons. Once the nightly GPS points are extracted, roost sites can be identified. Map: Google Satellite*

By doing so it was possible to count the number of nights completely spent at each roost and also the number of nights in which a crane moved during the night to another roost. If roosts were shifted, sometimes even repeatedly during one night, the roost a crane started from and the roost it arrived at were also noted. Because most tags were switched off between 7:00 pm and 4:00 am to save energy, the exact time of the movement remains unknown. However, with the noted data it was possible to assess the susceptibility of the single roosts.

A further analysation of the wintering areas included the examination of the use of different habitats while foraging in those areas. Therefore, all data points associated with the single home-ranges were attributed with the land cover by joining the data-point-layers spatially (Arc-GIS-Tool: "Add Spatial Join") with a land-cover-polygon-layer provided by the RSPN (see FRMD 2017). Furthermore, each point was also attributed with one of the following daytime categories according to the local time at which they were recorded: "morning" (6:00 am until < 10:00 am), "midday" (10:00 am until < 2:00 pm), "afternoon" (2:00 pm until 6:00 pm) or „x" (> 6:00 pm until < 6:00 am). From this newly attributed data points only those which were consecutive and from the same crane and season were used to calculate the single time spans a crane were staying within the same daytime- and the same land-cover-category (those within the daytime-category "X" were excluded). Finally, for each of the wintering areas separately as well as combined those time spans were summed by calculating for each daytime-category the amount of time spent in the different land-cover-categories.

New insights about Black-necked Cranes

1. Size and weight of BNCs

12 Black-necked Cranes were measured within this study (see Table 3). One was an immature bird, the others were fully grown. In January, approximately in the middle of their wintering period in Bhutan, the weight of the cranes (n=11) was on average 6.40 kg. Out of nine measured cranes the tarsus was on average 25.47 cm. Out of four measured cranes, their wing was on average 63.03 cm. The average length of the beak measured on seven cranes (Figure 8) was on average 12.37 cm. The head of five measured cranes was on average 20.94 cm. The differences in sample size is a result of animal welfare. If a crane was very excited and nervous, the capture team decided to stop measurements and quickly release the bird.

Tag No.	Age	Weight netto (Kg)	Tarsus (CM)	Wing (CM)	Beak (CM)	Head (CM)	Sex
6602	Adult	6.3	24.0	62.0	12.2	x	female
6603	Immature	6.08	26.1	61.5	x	x	male
6604	Adult	5.97	24.1	61.0	x	x	female
6606	Adult	6.86	x	x	x	x	male
6607	Adult	6.46	x	x	x	x	female
6608	Adult	5.3	x	x	x	x	female
KARMA	Adult	6.82	26.9	66.1	12.75	x	male
7118	Adult	6.5	24.9	x	11.98	20.1	x
7117	Adult	6.2	26	x	12.254	20.7	x
7116	Adult	6.01	23	x	12.08	20.3	x
x	Adult	6.67	28.2	x	12.32	21.9	x
x	Adult	6.52	26	x	12.997	21.7	x

Table 3: *Values of all measurements of BNCs in this project as well as some calculations below.*

Out of seven cranes the sex was analysed by a blood or feather sample. Unfortunately, the sample size is too small for serious statistics. However, when comparing mean and median values of male and female individuals, male tend to be heavier, have longer legs and wings, as well as longer beaks than female ones (see Table 4). These differences in size and weight are known from other cranes species as well, e.g. Eurasian Cranes (Miikkulainen, 1999).

Sex	Value	Weight netto (Kg)	Tarsus (CM)	Wing (CM)	Beak (CM)	Head (CM)
All	Mean	6.31	25.47	63.03	12.37	20.94
	Median	6.38	26.00	62.00	12.25	20.70
	n	12	9	4	7	5
Male	Mean	6.59	26.50	66.10	12.75	x
	Median	6.82	26.50	66.10	12.75	x
	n	3	2	2	1	0
Female	Mean	6.01	24.05	61.50	12.20	x
	Median	6.135	24.05	61.50	12.20	x
	n	4	2	2	1	0

Table 4: *Size and weight of female and male BNCs.*

Figure 8: *Günter Nowald (CCG) is measuring the length of the beak of crane "Karma" in January 2019. Photo: Anne Kettner.*

2. Migration pattern between Bhutan and breeding sites

Because one of the tags (crane “Sonamw”) stopped recording after the first spring migration, instead of 30 only 27 single migrations were completed from winter of 2018-19 to the winter of 2020-21. Only 23 of them were sufficiently recorded and thus could be analysed fully as described, whereas at least two could be used to identify resting- and stopover areas. From winter to summer of 2020-21 eight additional single migrations were completed and six of them were sufficiently recorded to identify resting and stopover areas, for those the determination of statistical values would have been too time consuming considering the projects timeframe.

The results of the migrations pattern are divided into four sections: migration route; altitude, speed and distance; duration of migration; as well as resting sites.

a) Migration routes

The migration routes of six tagged cranes in Phobjikha and three tagged cranes in Bumdeling are illustrated in Figure 9. Obviously, migration routes of cranes from Phobjikha (cranes “Anneaguntera”, “Tseyphell”, “Nameless”, “Wangchen”, “Kinley” and “Sonamw”) and cranes from Bumdeling (“Samten”, “Karma” and “Dorji”) are different. After starting migration, the cranes from Phobjikha as well as those from Bumdeling fly northwest towards the Greater Himalayan mountain chain. Here they cross the mountains at different locations and end up in different breeding grounds.

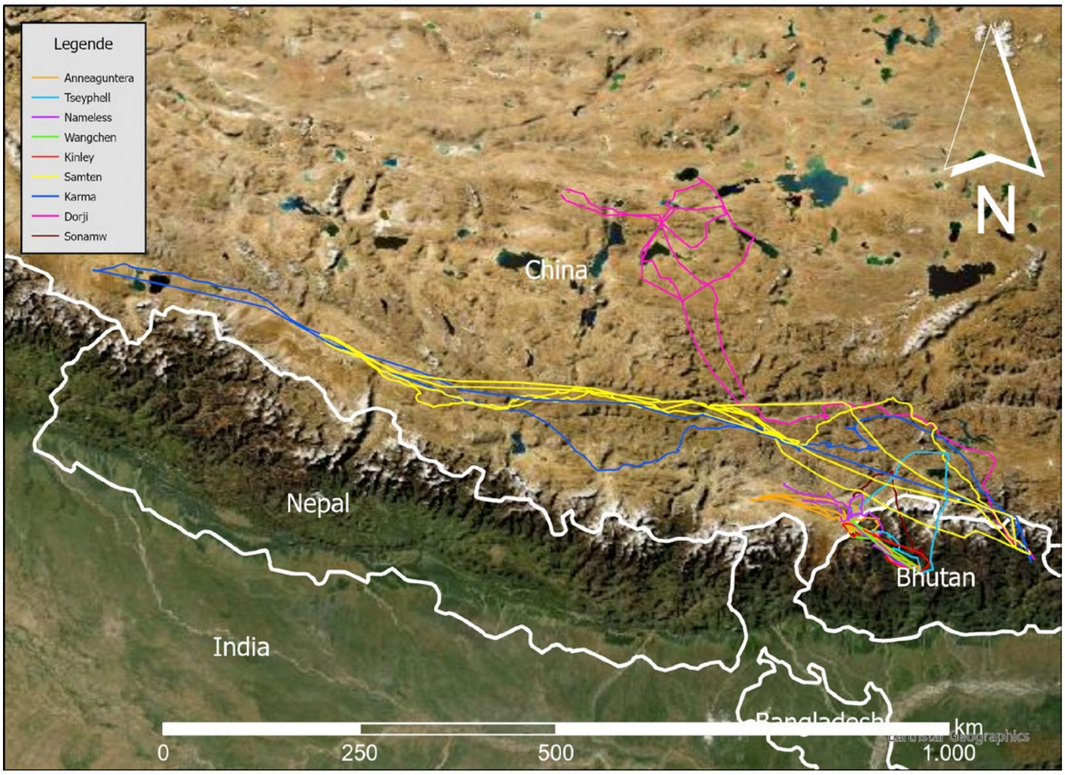


Figure 9: *All migration routes from cranes tagged in Phobjikha and Bumdeling valley included in this study.*
Map: Earthstar Geographics

Whereas the cranes migrating from Phobhjika have almost reached their summer destination after crossing the Greater Himalayas and fly on for just about 200 km, the cranes migrating from Bumdeling continue to fly almost parallel to the Greater Himalayan mountain chain and the border between Nepal and China for on average of 1.000 km. At the beginning they fly northwest until they reach the Yarlung Tsangpo (Brahmaputra) river.

From here they follow the riverbed upstream in western direction. The locations of the summer destinations from Bumdeling cranes vary much more than the destinations of cranes from Phobjikha.

Both of those basic migration flyways were occasionally overlapped by few individuals. However, in our study cranes from Phobjikha and Bumdeling have never stopped at the same site. Therefore, the stopover and resting-sites of cranes from Phobjikha differ from those of cranes from Bumdeling.

The following two figures illustrate spring and autumn migration of cranes from Phobjikha and Bumdeling.

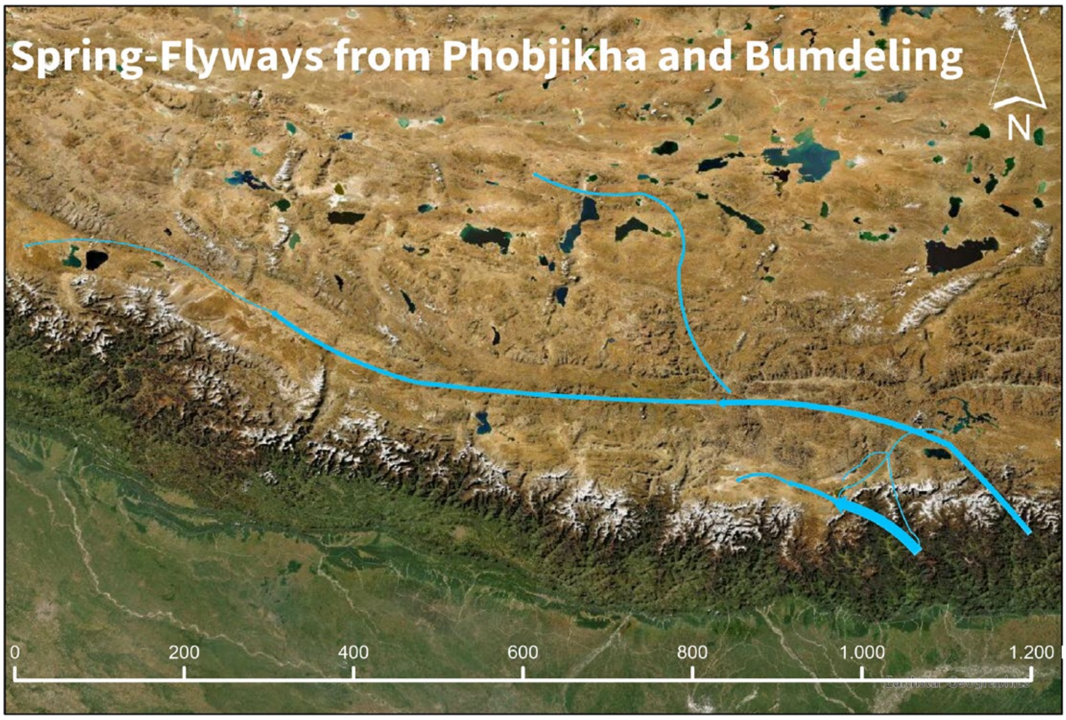


Figure 10: Simplified migration routes from the wintering sites in Bhutan to the breeding sites in China. Map: Earthstar Geographics

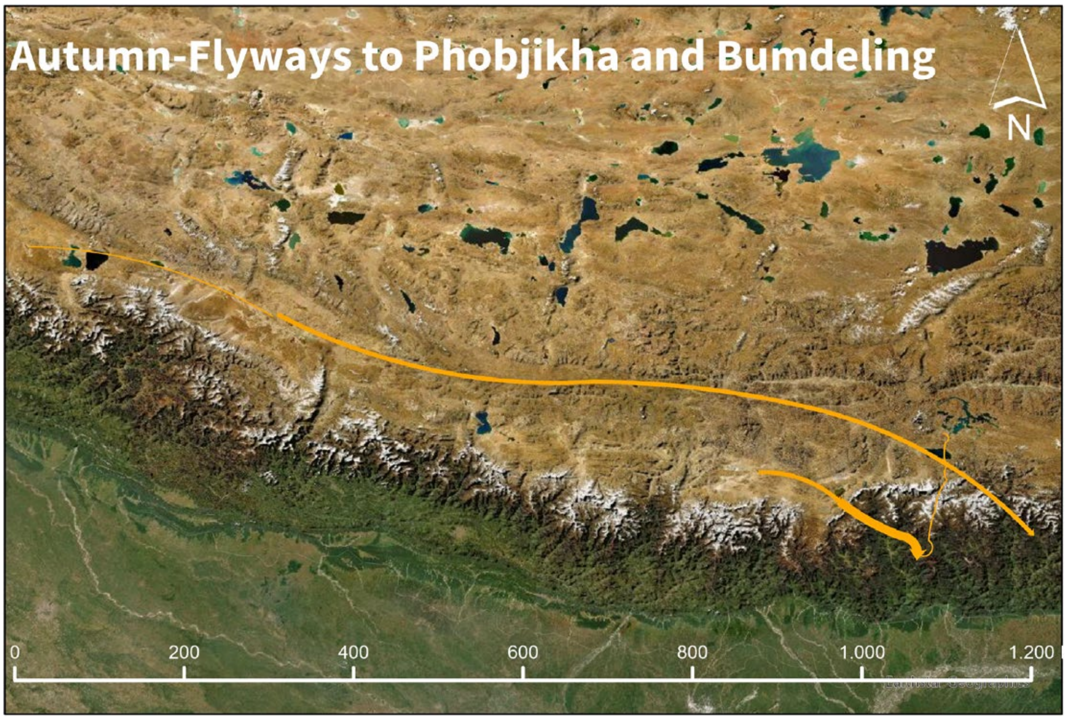


Figure 11: Simplified migration routes from the breeding sites in China to the wintering sites in Bhutan. Map: Earthstar Geographics

The difference between the two maps is a flyway branching of the Bumdeling migration route in spring. Here, crane "Dorji" left the main migration route towards the central Qinghai-Tibet Plateau in spring of 2019 and stayed there until the end of winter 20/21 while wintering in the proximity of the city of Xigaze. Afterwards, unfortunately it did not send sufficiently GPS-data. Due to the small sample size of tagged individuals in Bumdeling, it remains unclear, whether that is an exceptional flyway or not.

Another exceptional flyway was found by one of the cranes tagged in Phobjikha valley ("Nameless"). In every recorded year it left the summering/breeding area in the Qinghai-Tibetan Plateau during or after spring migration and flew to India (see Figure 12). There it stayed between a few days to some weeks (2020: 14th May – 17th June, 2021: 17th – 21st April, 2022: 19th – 20th April) almost in the same place. The reason for this excursion remains unclear.

Figure 12: *Spring migration of crane "Nameless" in 2020 from Bhutan to China (purple line) and movements during summer including a trip to India. Map: Earthstar Geographics*

b) Altitude, speed and distance of migration

The average distance between wintering grounds in Bhutan and breeding sites in Tibet, calculated out of 23 single migrations, was 500 km. The average distance covered by the Phobjikha cranes (15 migrations) was hereby much smaller – 199 km – than the distance flown by the cranes from Bumdeling (8 migrations) – 1,065 km. The migration route from the wintering site in Phobjikha is thus shorter than the migration route from the wintering site in Bumdeling as shown in Table 5.

Migration time	Wintering site	Ø Stop-overs	Duration (d)	Length (km)	Ø km/h	Max flight level (over MSL)
Spring	Phobjikha	1.0	5	202	33	6,084
Spring	Bumdeling	6.2	54	1,075	30	7,293
Autumn	Phobjikha	0.6	2	196	44	6,246
Autumn	Bumdeling	3.7	64	1,049	24	6,926
All	Phobjikha	0.8	3	199	38	6,160
All	Bumdeling	5.3	57	1,065	28	7,155
All	**Both**	**2.4**	**22**	**500**	**35**	**6,506**

Table 5: *Comparison of average values for spring and autumn migrations from Phobjkha and Bumdeling.*

On average cranes needed 22 days, flying on average 35 km/h, to complete their migration. Therewith, they fly slower than Eurasian cranes during their migration. They fly on average 44 km/h on the Western European Flyway, which contains less and smaller mountains that the flyway of cranes wintering in Bhutan. However, when comparing the maximum speed, BNCs are found to be faster: 139 km/h (Eurasian cranes: 133 km/h) (Sommermann, 2019).

Cranes wintering in Phobjikha needed on average just three days to complete their migration, whereas cranes wintering in Bumdeling needed on average 28 days (see Table 5).

Furthermore, the average speed of the migrating cranes differs between cranes from the two wintering grounds in Bhutan. Phobjikha cranes flew on average 10 km/h faster (38 km/h) than Bumdeling cranes (28 km/h). The average speed of all cranes and migrations is illustrated in Figure 13.

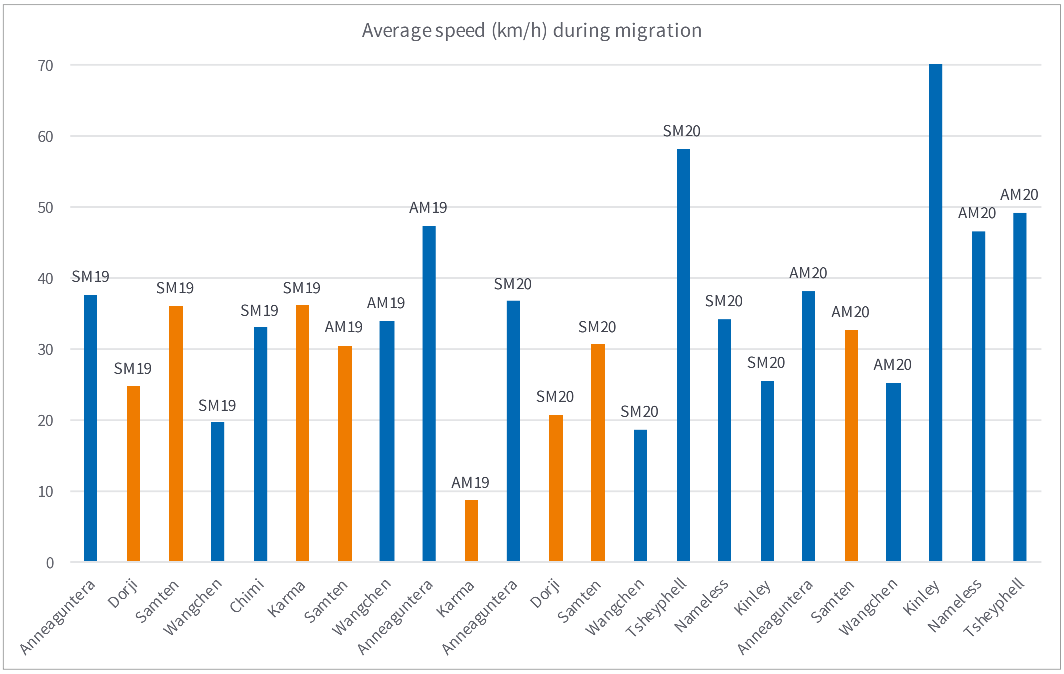


Figure 13: *Average speed by crane (name) and season (SM: spring migration, AM: autumn migration). Blue: cranes wintering in Phobjikha, orange: cranes wintering in Bumdeling.*

The reason for this large difference is the altitude reached by the cranes during migration. The maximum flight level over mean sea level (MSL) varies between 4,572 m to 7,099 m (6,160 m on average) for cranes migrating from/to Phobjikha valley and 6,796 m to 7,441 m (7,155 m on average) for cranes migrating from/to Bumdeling (see Figure 14).

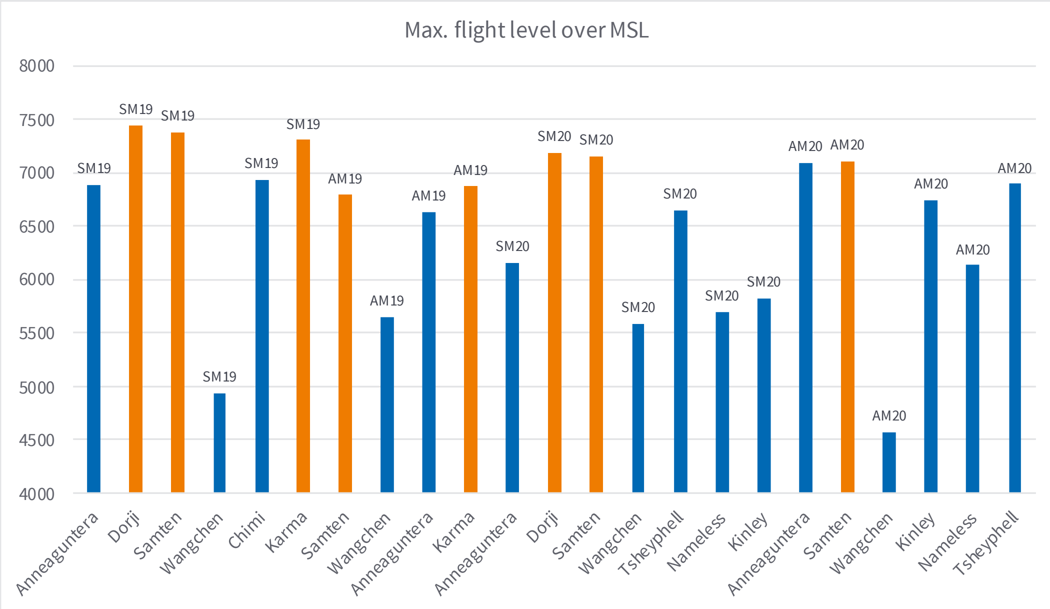


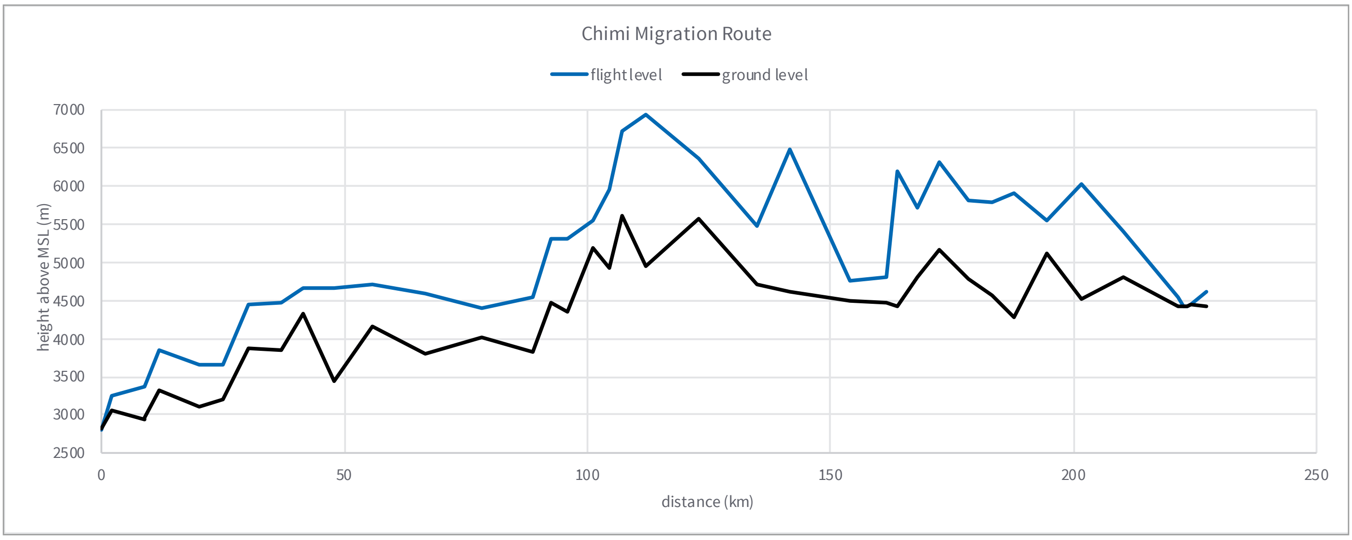
Figure 14: *Maximum flight level by crane (name) and season (SM: spring migration, AM: autumn migration). Blue: cranes wintering in Phobjikha, orange: cranes wintering in Bumdeling.*

Thus, cranes wintering in Bumdeling fly on average about 1 km higher than cranes wintering in Phobjikha, and therefore need more time for thermal circling, which results in a lower average speed. Cranes wintering in Bumdeling need to overcome higher mountain ranges, but at the same time need to start spring migration at a lower point, because Bumdeling is located at about 1,900 m altitude and Phobjikha at about 2,900 m.

That means that during spring migration - depending on the migration route of the individual - cranes from Bumdeling need to overcome significant larger altitudes than cranes from Phobjikha. For example, in spring 2019 the maximum mountain height (max. height above geoid of all GPS-fixes) was 6,939 m on the migration from Phobjikha and 7,378 m on the migration from Bumdeling. In sum, cranes from Bumdeling therewith had to overcome maximal 1,439 m more than cranes from Phobjikha. This difference is illustrated by Figure 15 and Figure 16. These figures exemplarily show flight altitude and ground altitude during spring migration 2019 of two cranes, one from Phobjikha (“Chimi”) and one Bumdeling valley (“Dorji”).

The migration of "Dorji" is longer (distance), shows at various points higher altitudes (flight level) and more mountain chains (ground level). Moreover, "Dorji" had to start migration (at least in spring) at a lower point (ground level).

Figure 15:
Altitude of ground-level and flight by "Chimi", a crane wintering in Phobjikha, during spring migration 2019



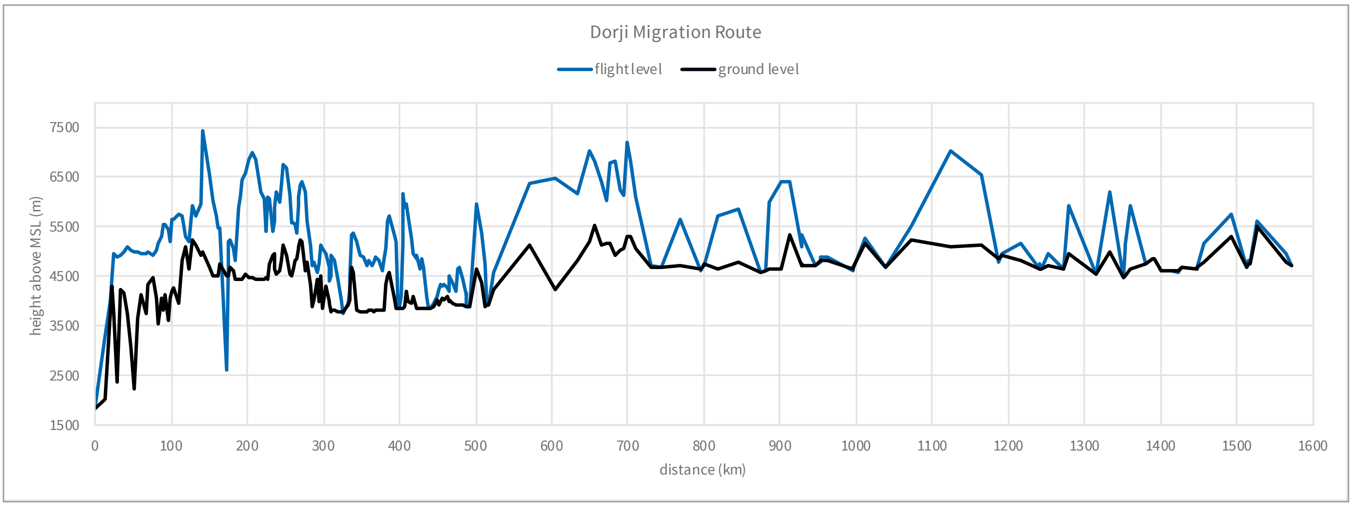


Figure 16:
Altitude of ground-level and flight by "Dorji", a crane wintering in Bumdeling, during spring migration 2019

The average altitude of breeding sites is almost the same for cranes wintering in Phobjikha (4,465 m) and Bumdeling (4,569 m). That means, during autumn migration they start from almost the same altitude. Nevertheless, Bumdeling cranes need to overfligh more and higher mountain ranges and end up in a deeper wintering valley.

Therewith, it is demonstrated that the migration of cranes wintering in Bumdeling is much more energy consumptive than the migration from Phobjikha. Among others (in particular habitat quality within the wintering site) that could be one reason explaining the increase of the wintering population in Phobjikha, while the population in Bumdeling and other wintering sites in Bhutan decrease.

c) Duration of migration

On average cranes wintering in Phobjikha need just one stop to complete their spring migration and less than one stop (0.6) to complete their autumn migration. Cranes wintering in Bumdeling take on average 6.2 stops for spring migration and 3.7 stops for autumn migration (see Table 5). Obviously, Bumdeling cranes need to stop more often, due to the larger horizontal and vertical distance they need to fly. To complete their migration, cranes wintering in Bumdeling therefore need on average 54 days (spring) and 64 days (autumn). In contrast, cranes wintering in Phobjikha need on average 5 days for spring migration and 2 days for autumn migration (see Table 5).

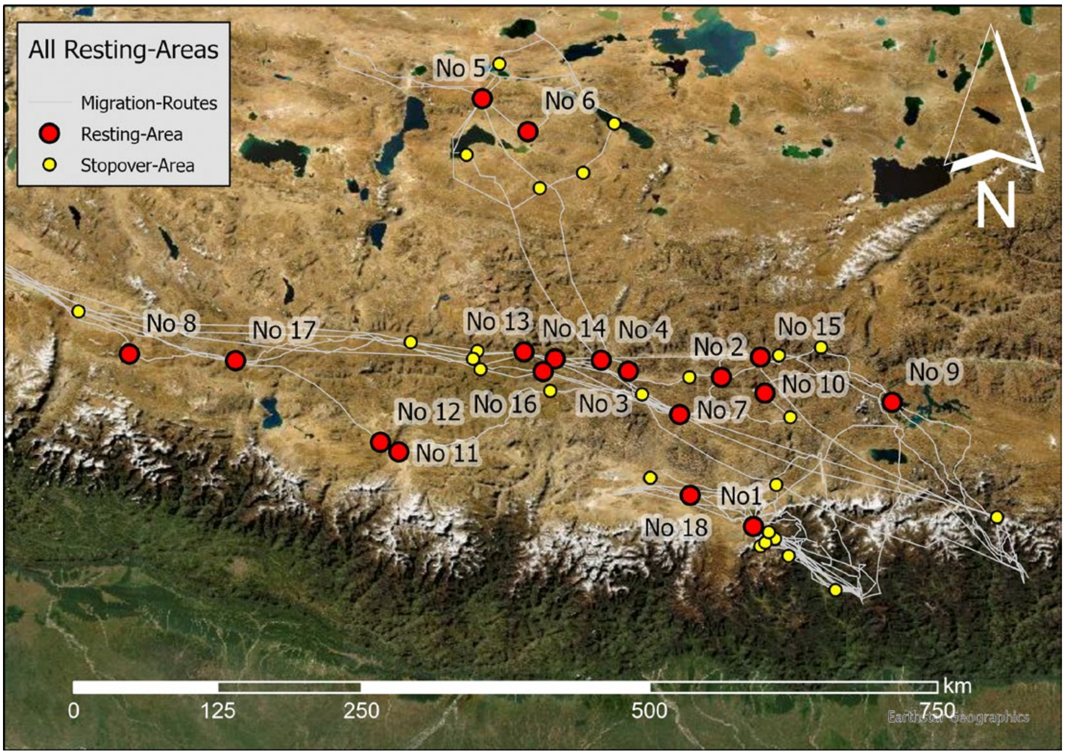
Although Bumdeling cranes stop less often in autumn, the migration takes longer, showing that they take longer rests during autumn migration. In spring, sexual mature cranes are advantaged, if arriving early in the breeding territories, because they can occupy the territory first and defend it against others. In autumn, there is no need for such a rush, unless food availability is low. That can explain, why spring migration of cranes wintering in Bumdeling, takes less time compared to autumn migration.

However, this is not true for Phobjikha cranes. Spring migration takes them on average five and autumn migration just two days (see Table 5). That is probably because they have to fly only about 200 km (horizontal distance) and thus, just stop in case of unsuitable conditions to cross the Greater Himalayan mountains.

d) Resting sites

For the identification of resting sites 31 migrations by all nine tagged cranes were sufficiently recorded. In total 44 resting areas were identified. At 18 of these resting areas the associated cranes stayed for more than one night, those are labelled as resting areas, whereas the 26 areas, at which a crane only stayed for one night, are labelled as stopover areas.

Figure 17: All resting- and stopover areas that were identified during migration between Bhutan and China. Map: Earthstar Geographics



All identified resting and stopover areas are depicted in Figure 17 and listed in the appendix. Due to their relevance for crane migration the resting areas were labelled with a number. The exact location of each resting area was determined by the respective roosting site, which had the largest amount of GPS points. The resting areas are listed in Table 6.

Table 6:
All identified resting areas; (S): summering area for the respective crane, SM: spring migration, AM: autumn migration, DD: decimal degrees

Label	Cranes	Seasons (2019-21)	Longitude (DD)	Latitude (DD)
No1	Anneaguntera, Chimi (S), Wangchen (S), Nameless, Tsheyphell, Kinley (S)	SM19, AM19, SM20, AM20, SM21	89,342515	28,018325
No 2	Dorji	SM19	89,094795	29,180814
No 3	Dorji	SM19	88,367836	29,230353
No 4	Dorji, Karma	SM19, AM20, SM21	88,156192	29,315263
No 5	Dorji	SM19, SM20	87,229785	31,355208
No 6	Dorji	SM19	87,585014	31,099529
No 7	Samten	SM19, AM19, SM20, AM20, SM21	88,77063	28,889746
No 8	Samten	SM19, SM21	84,476223	29,364929
No 9	Karma	SM19	90,426228	28,985818
No 10	Karma	SM19	89,431752	29,05916
No 11	Karma	SM19	86,577068	28,598703
No 12	Karma	SM19, SM21	86,434175	28,675814
No 13	Samten	AM19, AM20	87,5546566	29,3790057
No 14	Samten	AM19, AM20	87,7958613	29,3256125
No 15	Samten	AM19	89,400261	29,3397234
No 16	Karma	AM19, AM20	87,7046147	29,2271355
No 17	Samten	SM20, SM21	85,3039395	29,3109359
No 18	Nameless	SM21	88,8516633	28,2631202

From 18 identified resting areas ten were visited during more than one migration, and only two were also visited by more than one crane (resting area No. 1 & 4). No single resting area was located in Bhutan.

From 26 identified stopover areas none was visited during more than one migration and only one by more than one crane. Six stopover areas were located in Bhutan, all on the southern flyway, i.e. the flyway from or towards Phobjikha valley, and all were visited during spring migration before reaching the first resting area (No. 1). The locations of those areas, mostly near the highest mountain ridge to be crossed before reaching the Tibetan Plateau (see Figure 18), indicates that the respective cranes had to stop and wait for better flight conditions to cross the mountain ridge, probably because of strong headwind.

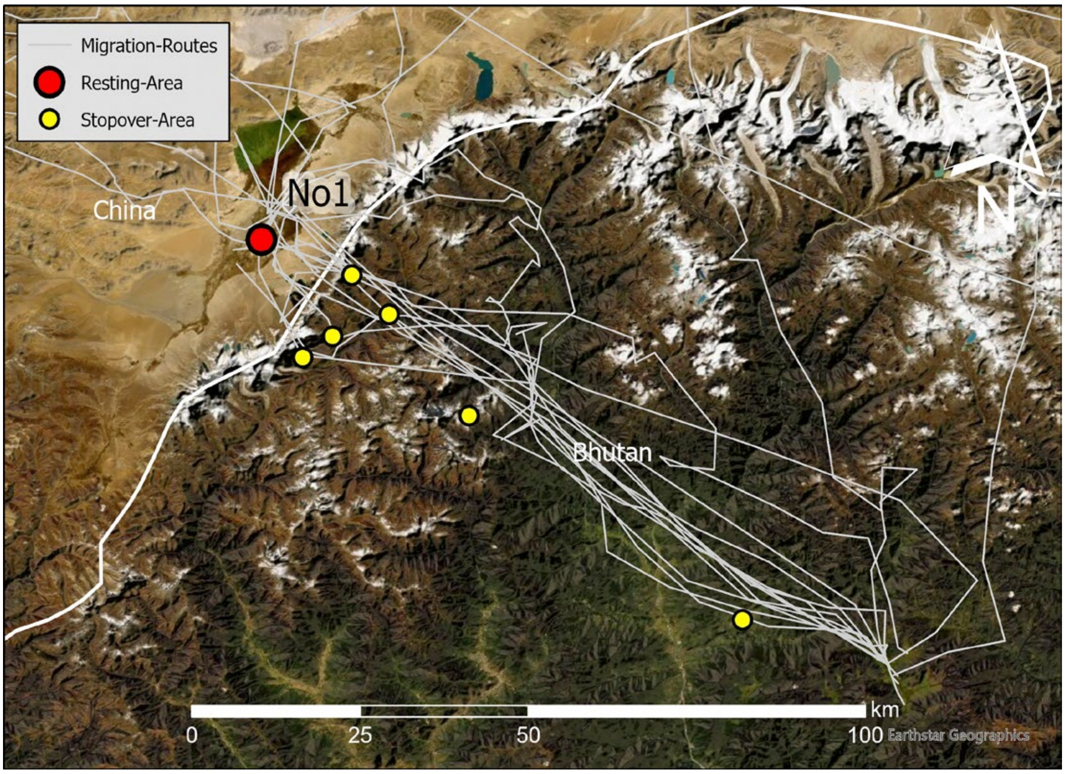


Figure 18: *Stopover areas located in Bhutan as well as the first resting area for spring migration from Phobjikha. Map: Earthstar Geographics*

The ratio of resting to stopover areas is 2 to 8 for the southern flyway, and therewith lower than the ratio of resting- to stopover areas (16 to 18) for the northern flyway, i.e. the flyway with from or towards Bumdeling. In other words, to reach one suitable resting site cranes of Phobjikha need in average four stopovers, whereas Bumdeling cranes need just about one stopover. This difference is possibly caused by different terrains that cranes have to overfly. Both, migrating cranes from Phobjikha and Bumdeling need to cross the Greater Himalayan mountains. For this they need suitable weather conditions, which makes stops necessary. The Greater Himalayan mountains are a larger part on the total migration flyway of Phobjikha cranes, but just a small part for the cranes from Bumdeling. That explains the large proportion of stopovers on the southern flyway.

On the southern flyway, all cranes either rested at the resting area No. 1 located at Douqing Lake in the Tibet Autonomous Region of China (Figure 18 and Figure 19) or even stayed there during the summer, because of the sparsely occurring resting opportunities in the nearby area and because of the relatively large size of Douqing Lake and the adjacent wetlands. If necessary, a quick stopover was made, if this resting area could not be reached within the first flight of spring migration.

On the northern flyway the cranes migrate more or less along the Yarlung Tsangpo (Brahmaputra) river. Here the occurrence of wetland areas suitable for resting is much higher, which is another reason for the high ratio of resting to stopover sites compared to the southern flyway.

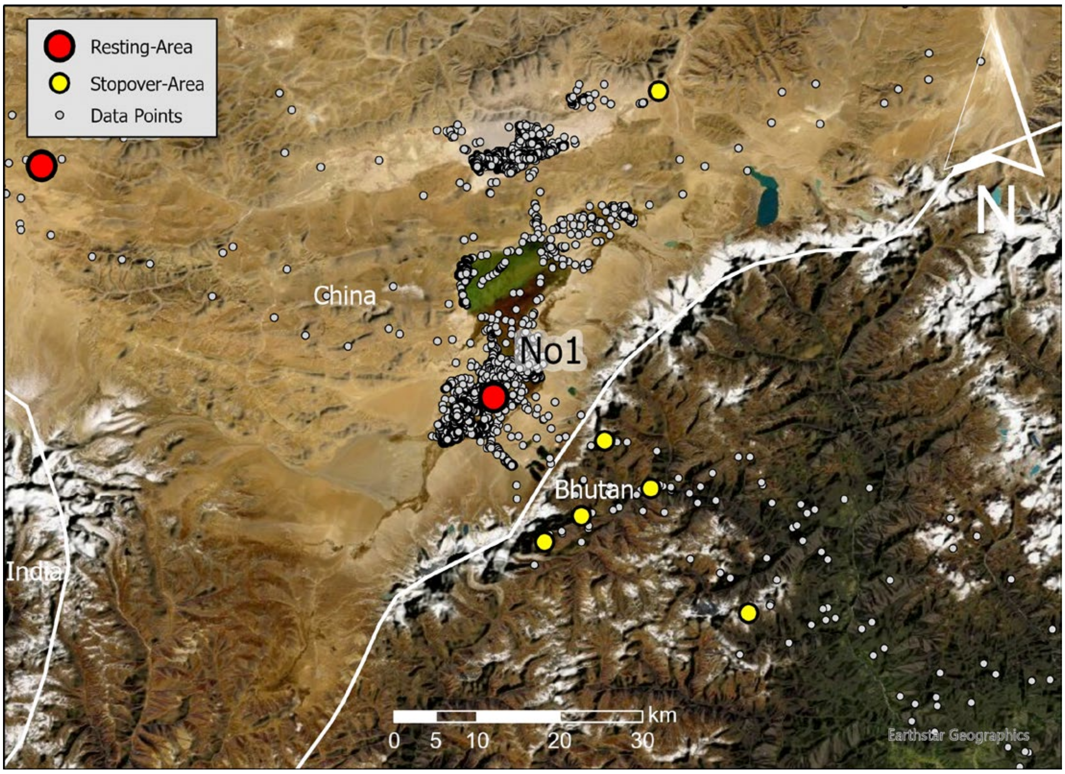


Figure 19:
Resting Area No. 1 and the data points of the cranes migrating on the southern flyway.
Map: Earthstar Geographics

Resting site No. 1 on the southern flyway (Figure 18 and Figure 19) and resting site No. 4 (Figure 20) on the northern flyway were used by more than one crane.

All six cranes on the southern flyway rested at area No. 1. Additionally, three of them even used this area as their regular summering ground. Therefore, this area is essential for the cranes migrating on the southern flyway, i.e. for the cranes wintering in Phobjikha valley. Because nowadays about 90 % of the cranes wintering in Bhutan stay in Phobjikha valley (see Figure 3), the preservation of resting area No. 1 is vital for the cranes wintering in Bhutan. Therefore, further analysis on roost-sites, foraging areas and home-range, using the data of this study is highly recommended for an effective in situ protection of BNC.

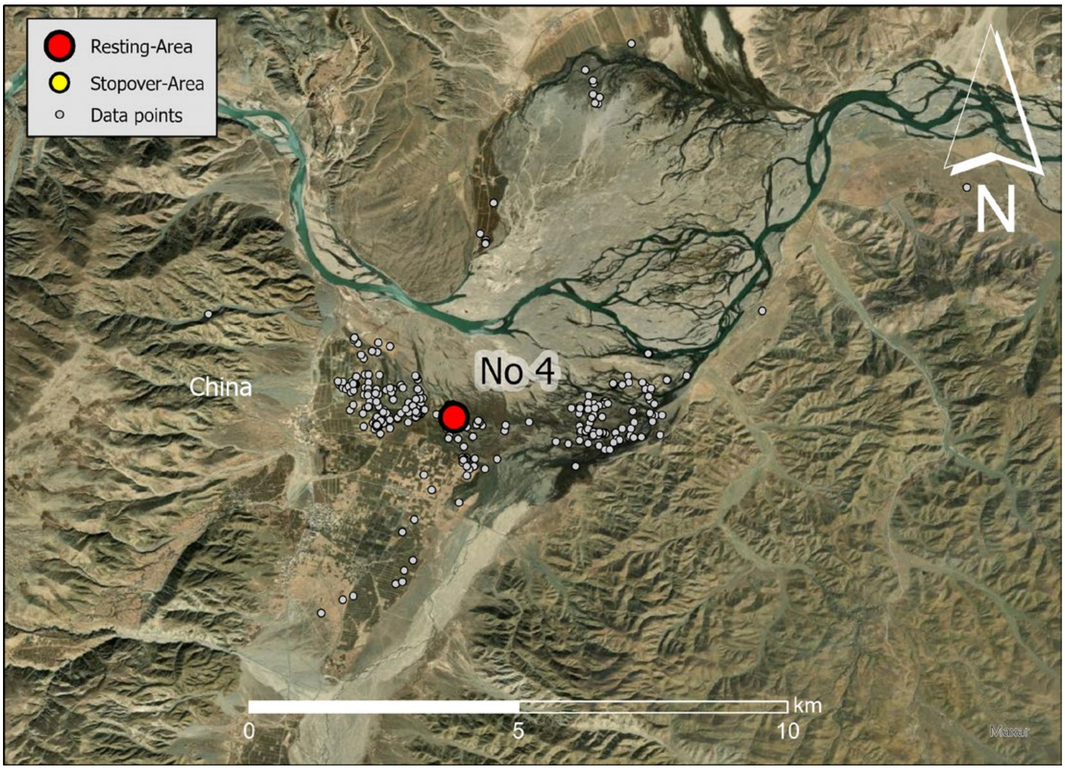


Figure 20: *Resting Area No. 4 and the data points of the cranes migrating on the northern flyway. Map: Maxar*

On the northern flyway, two of three cranes ("Dorji" and "Karma") rested at site No. 4 during in total three migrations. As sample size of cranes wintering in Bumdeling is small, it indicates that this resting site might be a very important one on the northern flyway. It is located in the delta, where the river Bo Reboduo flows into the Yarlung Tsangpo (Brahmaputra). As Figure 20 demonstrates the resting cranes roost in the riverbed of Yarlung Tsangpo and feed on the agricultural fields of the small adjacent villages like Maqiong.

3. Behavior and habitat use of the wintering sites in Bhutan

a) Wintering period

The six cranes tagged in Phobjikha ("Anneaguntera", "Wangchen", "Sonamw", "Kinley", "Tsheyphell" and "Nameless") arrived in Bhutan between 21st of November and 21st of December, but most arrivals (11 out of 12) were in the last third of November. They left Phobjikha between 5th and 24th of March, but the majority left between 5th and 12th of March (12 out of 13) as shown in Table 7.

Cranes wintering in Bumdeling ("Karma", "Samten" and "Dorji") arrived between 12th of October and 2nd December (n = 4), they left the valley between 28th of February and 14th of April (n = 6). The reason for the large variation in arrival and departure times by the cranes wintering in Bumdeling might be caused by the migration route, which is longer and contains more elevation differences. However, a larger sample size is needed to verify this assumption.

Tag Id	Crane name	Departure 2019	Departure 2020	Departure 2021	Arrival 2019	Arrival 2020	Arrival 2021
6602	Annea guentera	12.03.	10.03.	09.03.	29.11.	23.11.	20.11.
6603	WangC	08.03.	12.03.	10.03.	26.11.	22.11.	28.11.
6604	Sonamw	24.03.	–	–	–	–	–
7118	Kinley	–	08.03.	05.03.	–	21.11.	26.11.
7117	Tsheyphell	–	08.03.	09.03.	–	21.12.	11.12.
7116	Nameless	–	10.03.	07.03.	–	22.11.	26.11.
6606	Karma	21.02.	–	–	–	–	–
6607	Samten	12.02.	28.02.	12.03.	02.12.	22.11.	18.11.
6608	Dorji	01.03.	14.04.	–	12.10.	–	–

Table 7: *Dates of arrival and departures of tagged BNC within the investigation period*

Considering all cranes wintering in Bhutan together, the mean arrival time is the 329th day of the year, which was 25th of November in 2022. The mean departure day was the 68th day of the year, which was the 9th of March in 2022. On average the cranes stayed 104 days in Bhutan.

b) Home-Range

Home-Range is defined as the area used by a crane within a specific time (here: wintering period). Therefore, all data points between arrival and departure of a crane within its wintering area (e.g. Phobjikha valley) are included, if the points were located on the ground. Table 7 lists the data included in the home-range analysis. The data quantity varied between the individuals from crane "Nameless" with the largest number of GPS-fixes during winter time (n = 10.096) to "Wangchen" with a low data quantity (n = 174). Due to some transmitter failures, in which no GPS-data was fixed, the sample size was reduced from 9 to 7 cranes and from 15 to 9 seasons.

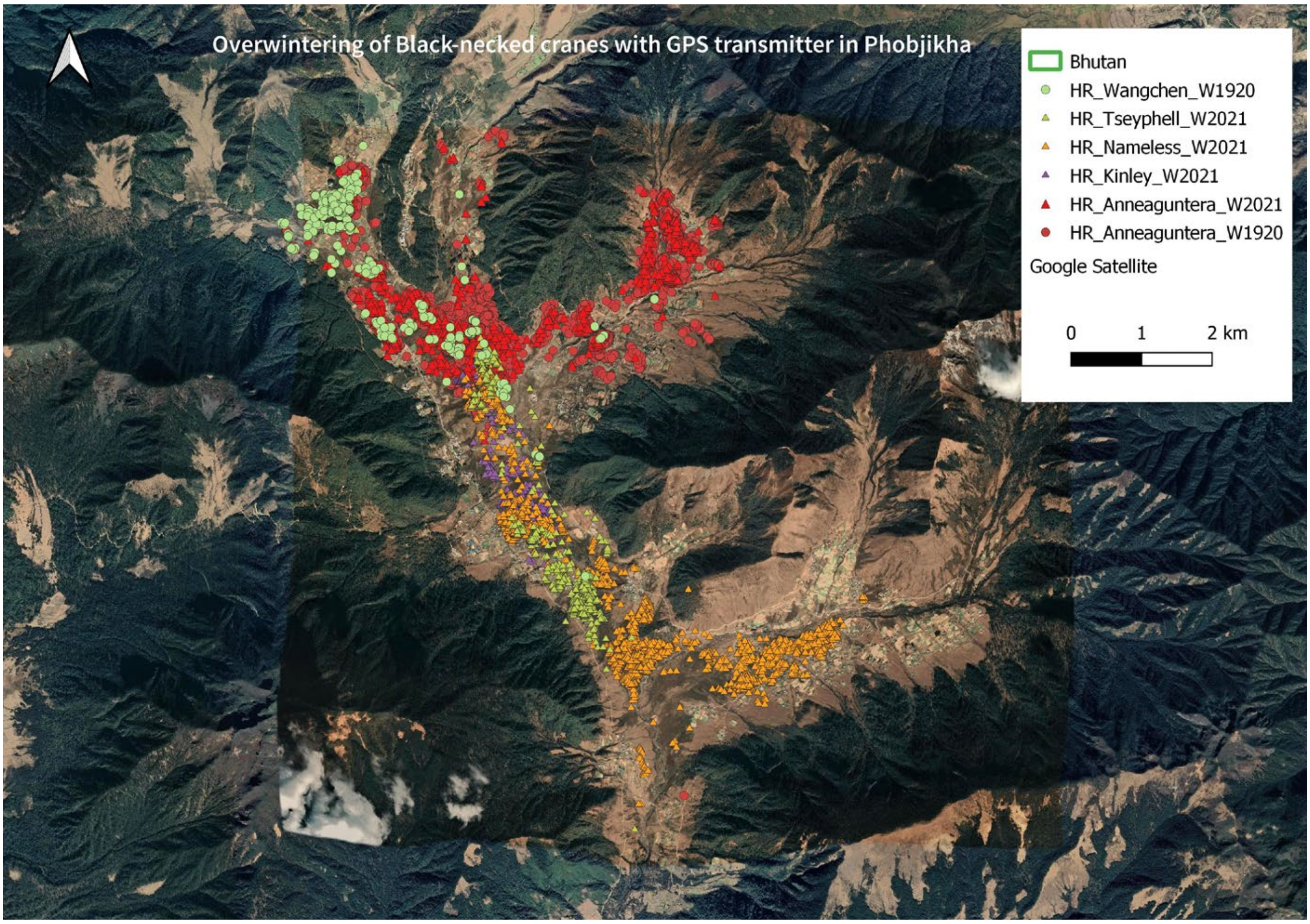


Figure 21: *Map of Phobjikha valley with all data points of the tagged cranes included in the Home-Range analysis*

There are two common methods in analysing the home-range in biology: minimum convex polygon (MCP) and kernel density estimation (KDE). The MCP basically draws a polygon around the data points and afterwards calculates the area within the polygon. To exclude outliers researcher often do not use 100 %, but 95 % of all data points. In this study the home-range is calculated with 100 % and 95 % of all data points, although the 100 % home-range is obviously overestimating the territory of the wintering cranes as shown by crane "Anneaguntera" in winter 2019/20 and winter 2020/21 (Figure 22) as an example.

Here the home-range of both winter seasons includes forest areas on the mountain slopes, which are not suitable for foraging, resting or any other crane activity. In winter 2020-21 one short trip of the crane led to almost doubling the home-range. The home-range by MCP 100 % is clearly overestimating the area used by wintering cranes, especially in a hilly landscape in which Black-necked Cranes occur.

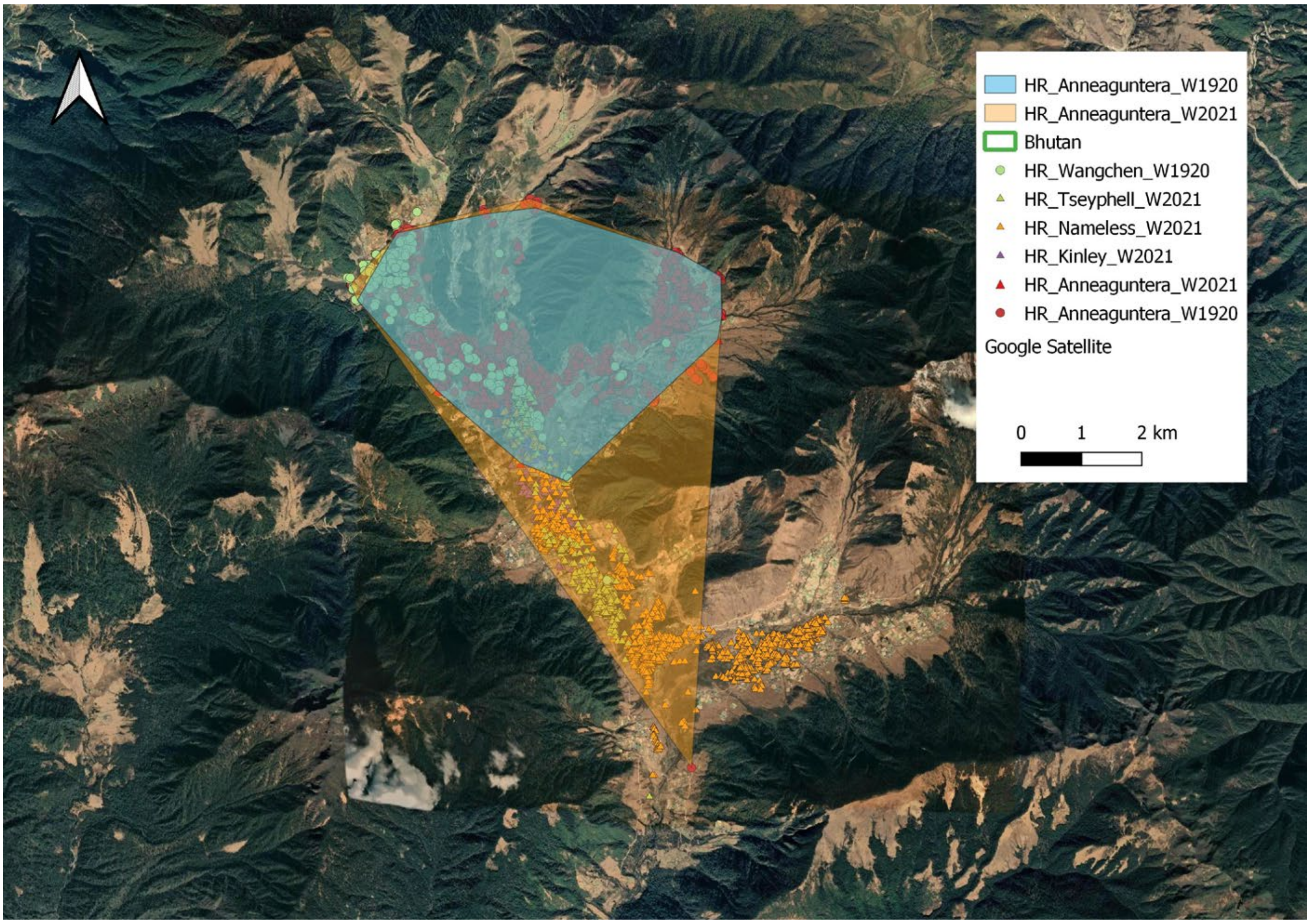


Figure 22:
Home-range of "Anneaguntera" in two winter periods is overestimated by using MCP including all (100 %) of the data points

The KDE uses the density of points to calculate the probability of potential points. The area with a probability of 95 % was calculated as shown in Figure 23. The figure shows that not all GPS-fixes are included, which leads to a slight underestimation of the areas a crane has used. However, the area patches are more precise and no patch without crane occurrence is included as happened by MCP home-range calculation (Figure 22).

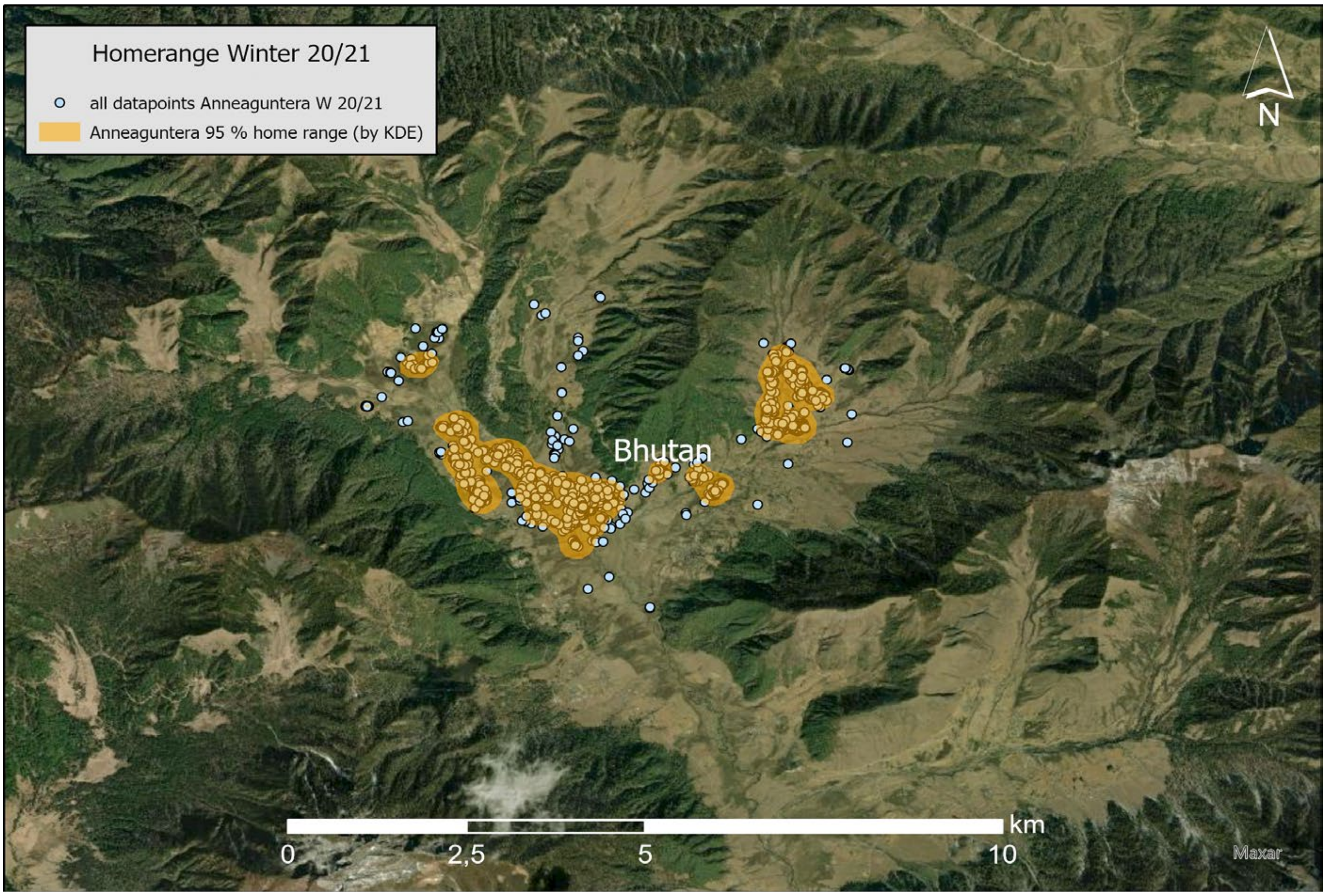


Figure 23: Home-range of "Anneaguntera" in winter 2020/21 calculated by KDE 95 %. Map: Maxar

Therewith, the KDE method is found to be the most suitable one for this analysis. The KDE home-range covers between 7–30 % of the MCP 100 area and 12–63 % of the MCP 95 area, depending on crane and season. This comparison is demonstrating the large difference in the results between these three methods. Nevertheless, all values are listed in the following table to be able to compare the results with other studies.

Crane, season (valley)	95 % KDE (km^2)	95 % MCP (km^2)	100 % MCP (km^2)
Anneaguntera, winter 19-20 (Phobjikha)	2.22	18.4	30.52
Dorji, winter 19-20 (Bumdeling)	4.23	16.84	46.93
Samten, winter 19-20 (Bumdeling)	3.96	6.3	12.8
Wangchen, winter 19-20 (Phobjikha)	1.63	6.06	15.01
Anneaguntera, winter 20-21 (Phobjikha)	3.62	15.04	17.33
Kinley, winter 20-21 (Phobjikha)	0.8	2.34	2.66
Nameless, winter 20-21 (Phobjikha)	3.22	14.41	16.74
Samten, winter 20-21 (Bumdeling)	1.25	6.3	6.91
Tsheyphell, winter 20-21 (Phobjikha)	1.00	4.13	8.65
Ø	**2.44**	**9.98**	**17.51**

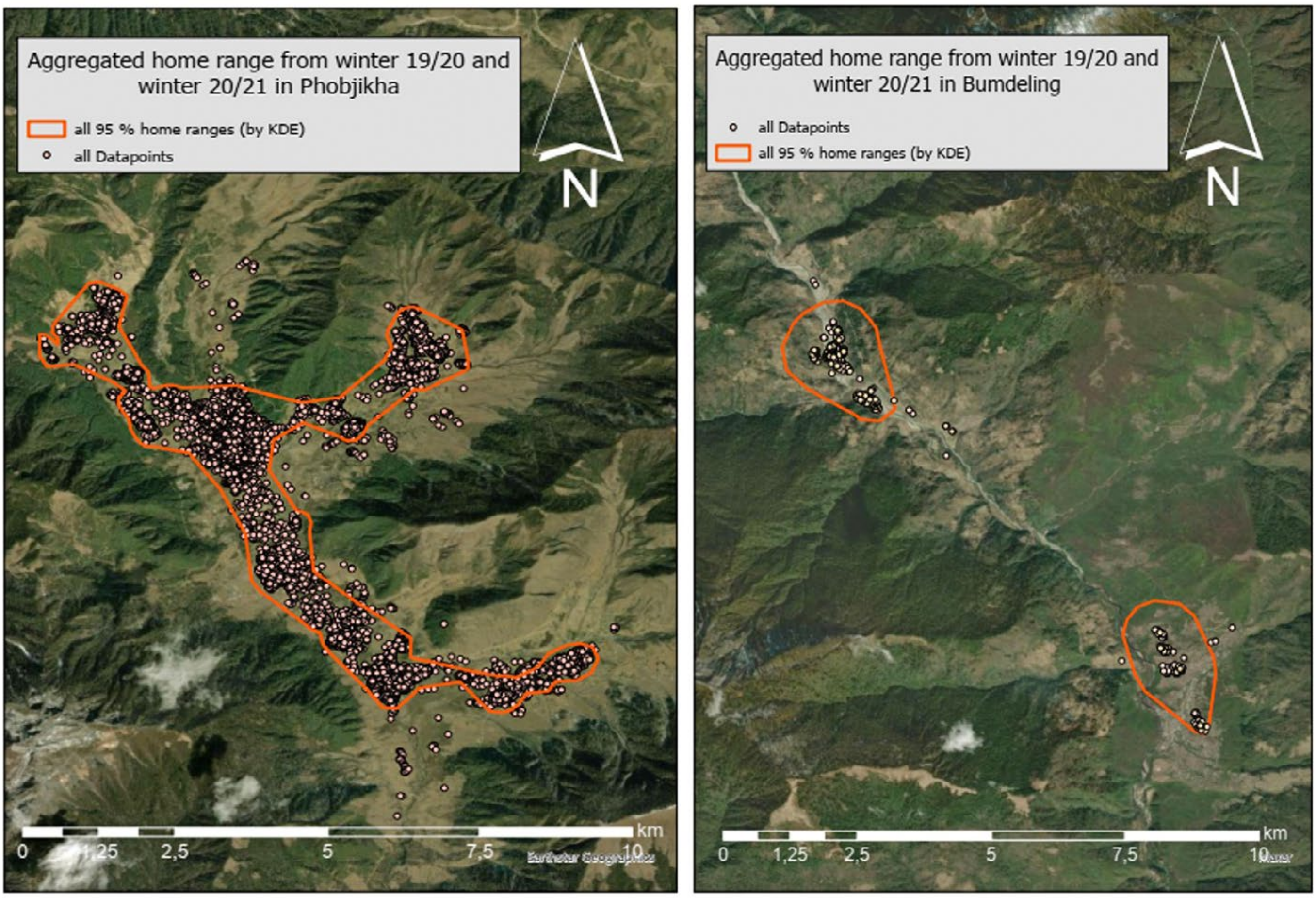
Table 8: Results of the home-range calculation of all seven cranes with three different methods.

Crane "Dorji" was found to have the largest home-range. After tagging in Bumdeling, it did not return to Bhutan the next winter, but stayed in Tibet, China. Its large home-range indicates a bad food availability. However, the analysis was concentrated to Bhutanese wintering grounds and thus this crane was not included in further analysis of aggregated home-range or roost-sites.

For conservation purposes the territory of a single individual is not relevant, but the territory of all individuals depending on that area. Therefore, the aggregated home-range is calculated for all cranes and seasons in Phobjikha as well as in Bumdeling valley. The KDE 95 % method was used and single patches were connected with an Arc GIS tool, if they were close together. As the result, wintering cranes in Phobjikha valley need at least an area of 12.56 km^2 and of 5.29 km^2 in Bumdeling valley. The large difference in size between the areas is amongst others caused by the sample size (Phobjikha: 5 cranes, Bumdeling: 1 crane). Thus, the area needed for Bumdeling cranes is likely to be underestimated.

These two aggregated areas can be seen as essential areas for cranes and are highly recommended to protect. They are demonstrated in Figure 24.

__Figure 24:__
Essential areas for BNC in the most important wintering sites of Bhutan: Phobjikha valley (left site) and Bumdeling valley (right site).
Map: Earthstar Geographics (left site), Maxar (right site)



In addition to the size, the calculation of home-range shows some other interesting insights. First, individuals seem to have a similar home-range over time. In other words, the same crane has almost the same home-range in two different winter periods. This is true for both cranes that were analysed for more than one season ("Anneaguntera" in winter 2019/20 and 2020/21 as well as "Wangchen" 2019/20 and 2020/21). The cranes are therewith site-loyal as shown in Figure 25.

Second, the home-range differs with the individual, which means the choice of the area used within the wintering site depends on the individual crane. Because of individual differences in the location of their home-range, cranes are differently affected by (positive or negative) changes in the area. Figure 25 clearly shows the different location of the home-ranges of the five individuals wintering in Phobjikha valley. The home-ranges overlap in the middle, where the most important roost sites are located. Whereas cranes occasionally meet for roosting in the night, they forage on different areas to presumably, prevent intraspecific competition.

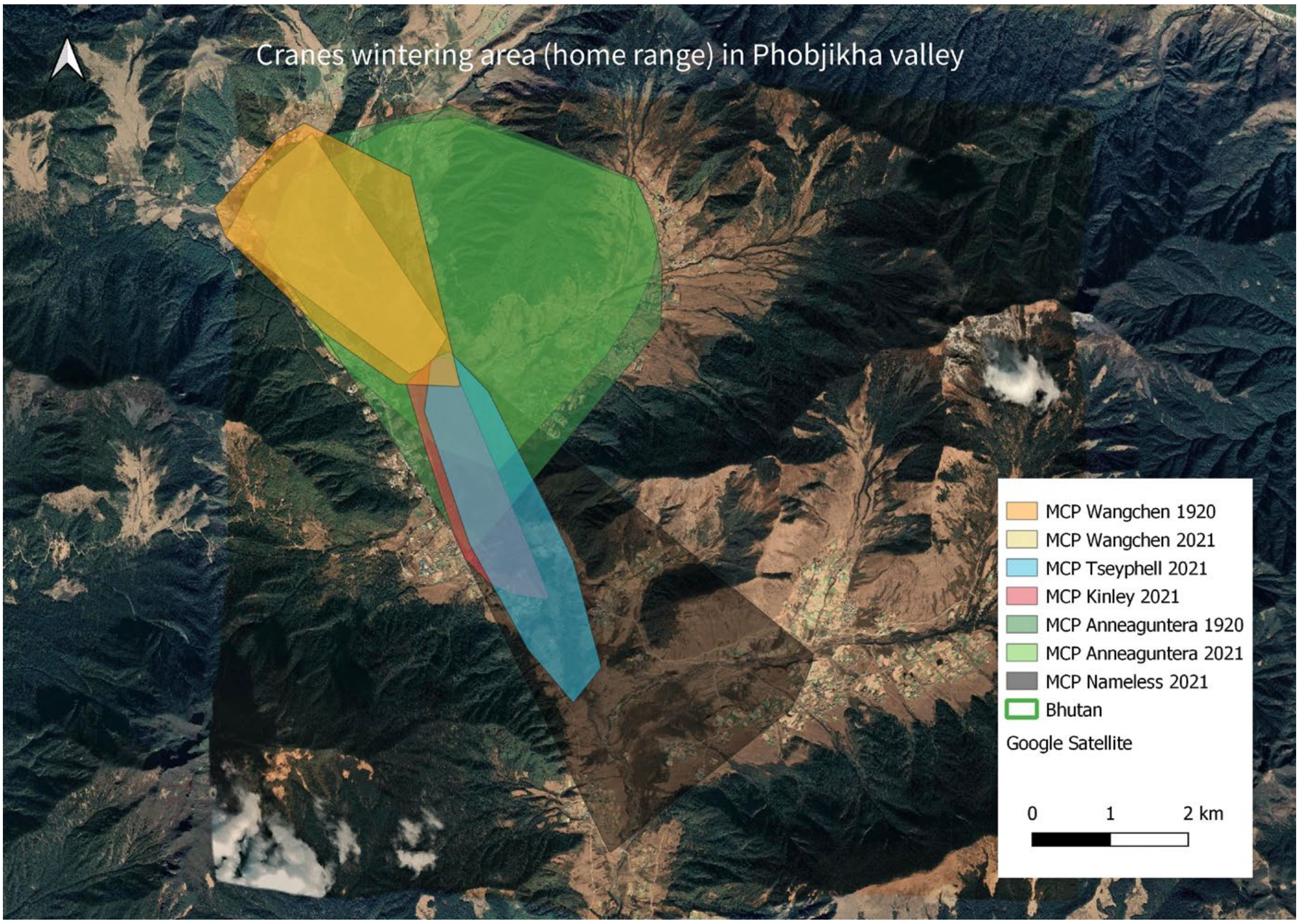


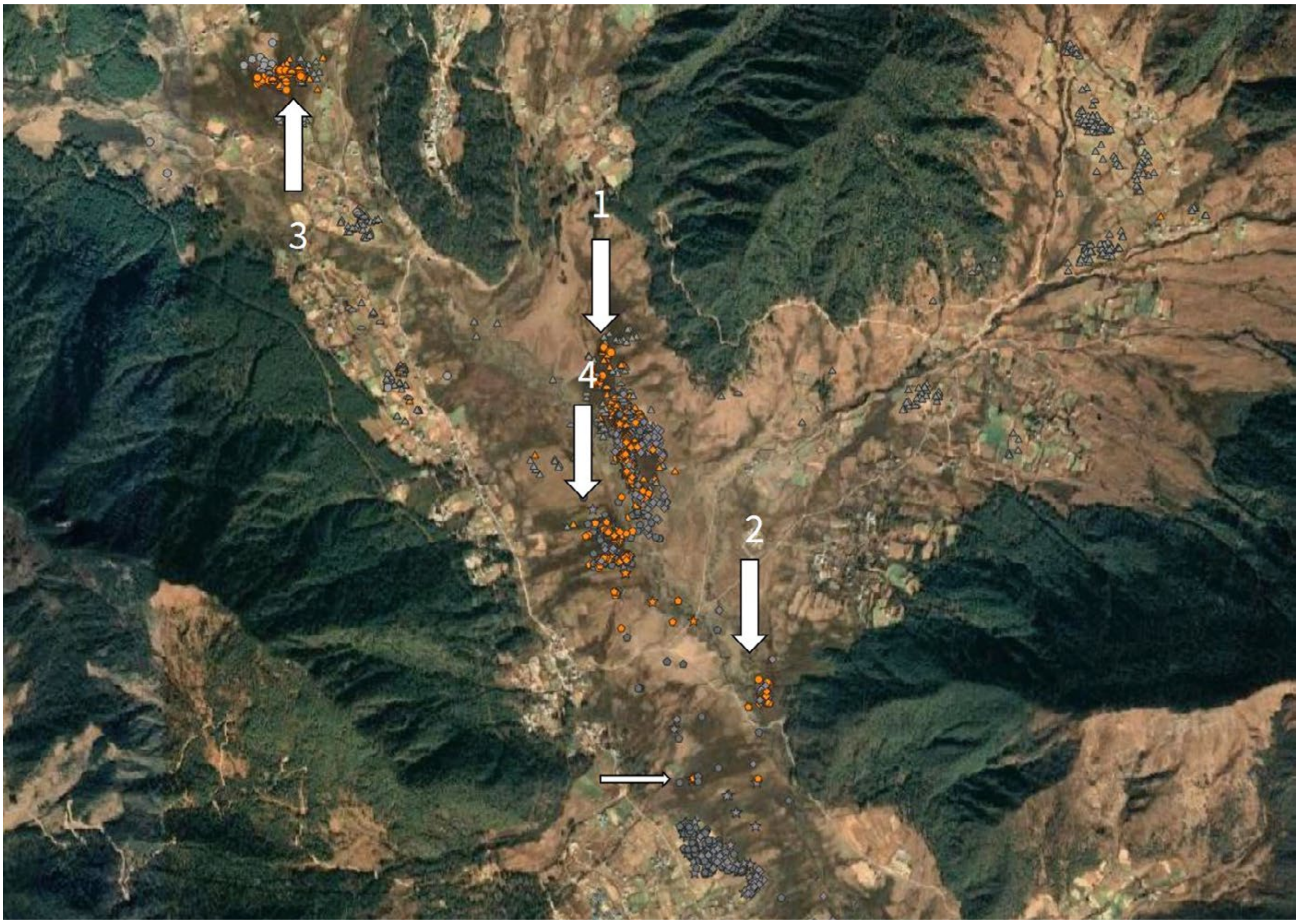
Figure 25: *Size and location of home-ranges (95 % MCP) of five individual cranes and seven winter periods. Map: Google Satellite*

The individuality of home-ranges is probably rooting in the fact that cranes where caught at two different roost sites in the valley. Cranes ("Wangchen", "Sonamw", "Anneaguntera"), which were caught at roost 3 (see Figure 26), prefer to stay in the northern part of the valley, whereas cranes ("Kinley", "Tseyphell", "Nameless"), which were caught at roost 2 (see Figure 26), prefer to be in the southern part. However, there is no correlation between the orientation of the home-range (north or south of the valley) and the migration routes or the location of the breeding sites. Thus, there is no occurrence of sub-populations amongst cranes wintering in Phobjikha valley.

c) Roost-sites

Figure 26 shows four major roosts for BNCs in Phobjikha valley. To derive the relevance of the roost sites, the proportion of nights per crane spent at different roost sites in Phobjikha was calculated. In total GPS data of 493 nights from five individuals and seven seasons was used. However, the data quantity ranges from 133 nights (crane "Nameless" in winter 20-21) to 19 nights (crane "Wangchen" in winter 20-21), because some tags were low on energy due to their generation of energy via solar cells.

The GPS-cranes spend 60.0 % of all nights at roost 1, 21.9 % at roost 4, 12.4 % at roost 3, 3.7 % at roost 2 and 2.0 % outside of the known roosts. Roost 1 and 4 are therewith the most important ones. Both are located along the riverbed of Phobjikha valley.



▲
Figure 26:
Location of the four most important roost sites in Phobjikha valley. The map shows night data (orange) and transition data (grey) of all GPS-cranes in Phobjikha. GPS fixes during the day are excluded.
Map: Google Satellite

In Bumdeling valley two roost sites within a distance of about 350 m were identified (see Figure 27). Both are located in the river bed and are in total 2.1 ha in size (measured by the nightly GPS-fixes). Unfortunately, the data base of this analysis is much smaller (one crane, two seasons) than in Phobjikha, because two of the tags did not work during the nights. Crane "Samten" spent most nights at roost 5 (77.3 % of all nights in winter 2019-20, 81.8 % of all nights in winter 2020-21), showing that this is the most important roost for this crane. However, as roost preference depends on the individual. So, that is not necessarily the most suitable roost for cranes in Bumdeling. The large distance of about 9.5 km between roosting site and foraging grounds of "Samten" indicates that there is no suitable roost in the south-east part of the valley, where the foraging grounds are located (see Figure 24).

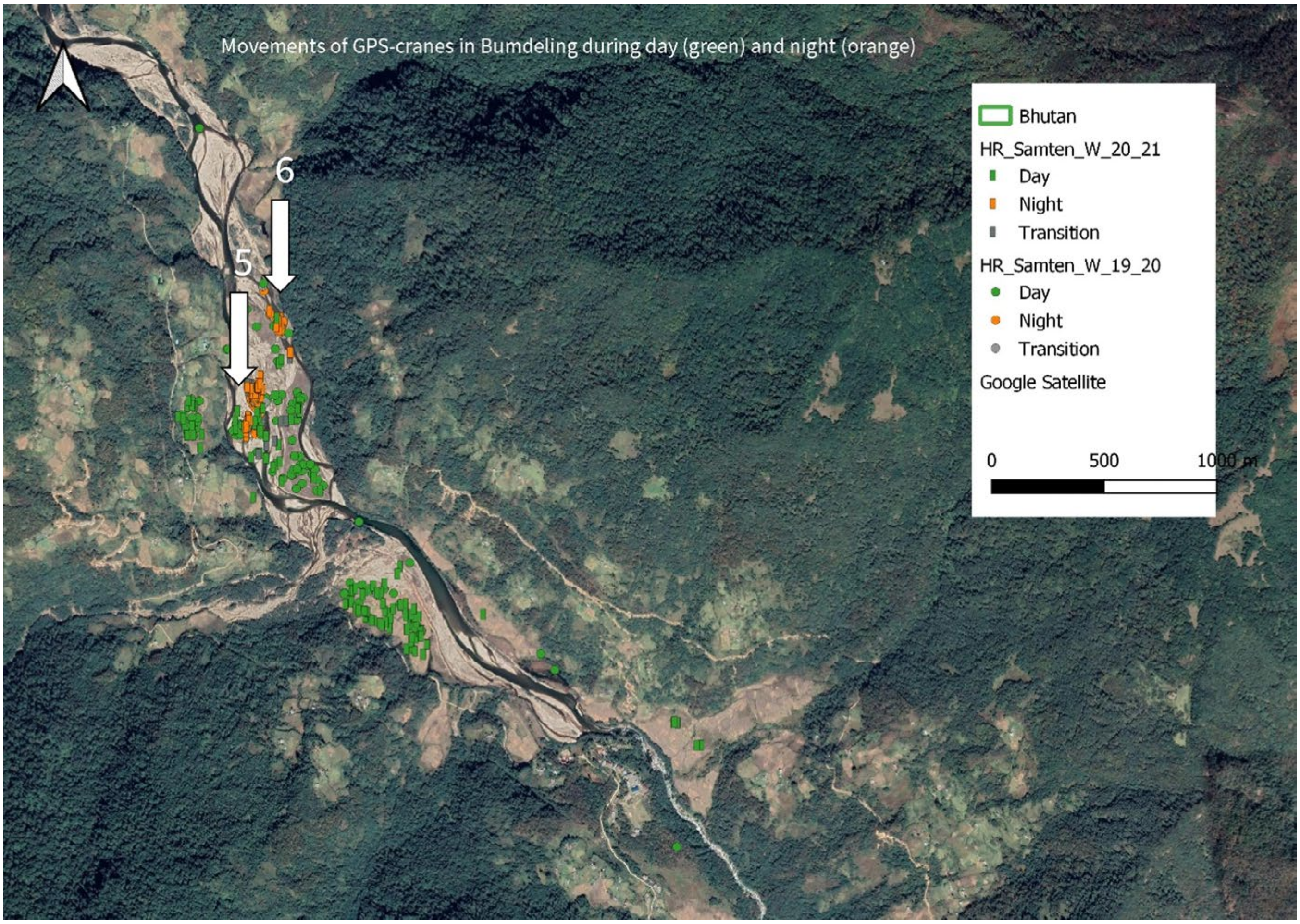


Figure 27: *Location of two roost sites in Bumdeling valley. The map shows night data (orange), transition data (grey) and day data (green) of the GPS-crane "Samten" during two winter. Map: Google Satellitee*

In addition to the relevance of the roost sites, the susceptibility is analysed. It is found that all cranes spend the nights at more than just one site. All seem to have "avoiding roost sites" as shown in the following figure for cranes in Phobjikha valley.

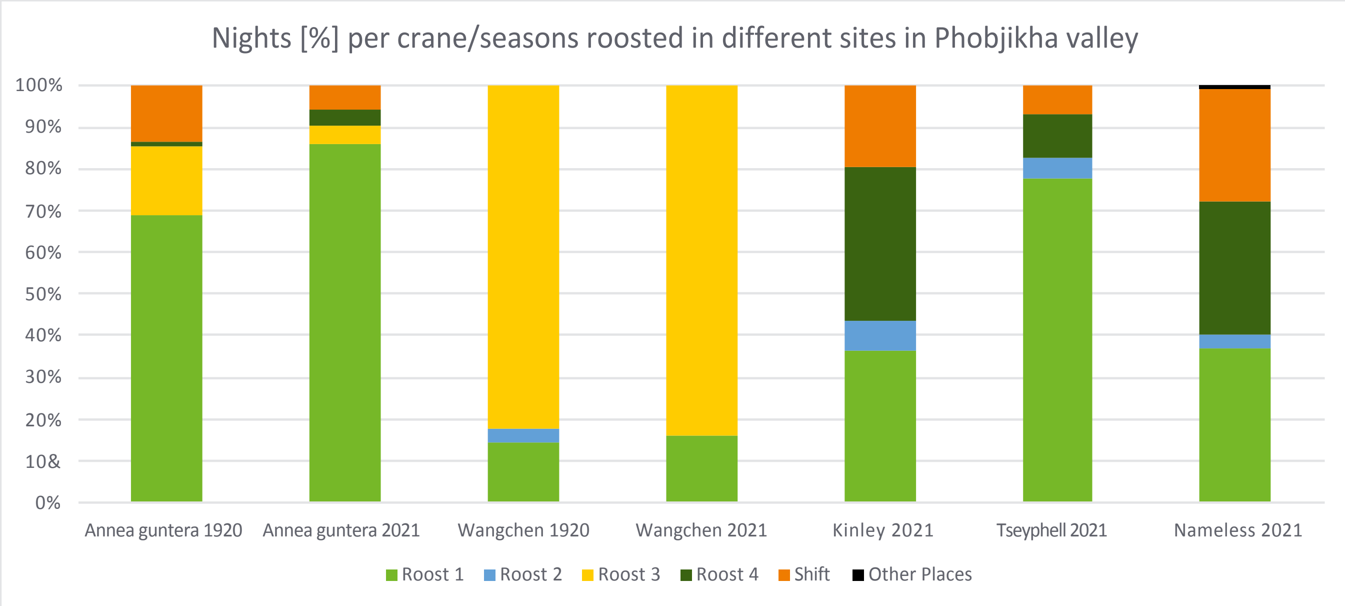


Figure 28:
Proportion of nights spend at different roost sites for all cranes in Phobjikha valley

The cranes "Anneaguntera" and "Tseyphell" prefer to roost at site 1, whereas "Wangchen" prefers to spend the nights at roost 3. The cranes "Kinley" and "Nameless" have two preferred sites: roost 1 and 4. Therewith, roost preference depends on the individual.

Moreover, cranes are site-loyal not just to their foraging grounds (see Figure 25), but also to the roost site as Figure 28 shows. Both cranes that were analysed for two seasons ("Anneaguntera" and "Wangchen") have the same roost preference in their first and second winter.

The necessity of „avoiding sites" for roosting can be explained when looking at nightly shifts of the GPS-cranes in Phobjikha valley. In 14.2 % of all nights (70 out of 493) cranes changed the roost site during the night, which indicates nightly disturbances. In 20.0 % of all nights with recorded crane movement (14 out of 70) cranes changed the roost more than one time during that night.

The following diagrams shows the ratio of nights without and nights with roost shifts. Therewith, it indicates the susceptibility of a roost.

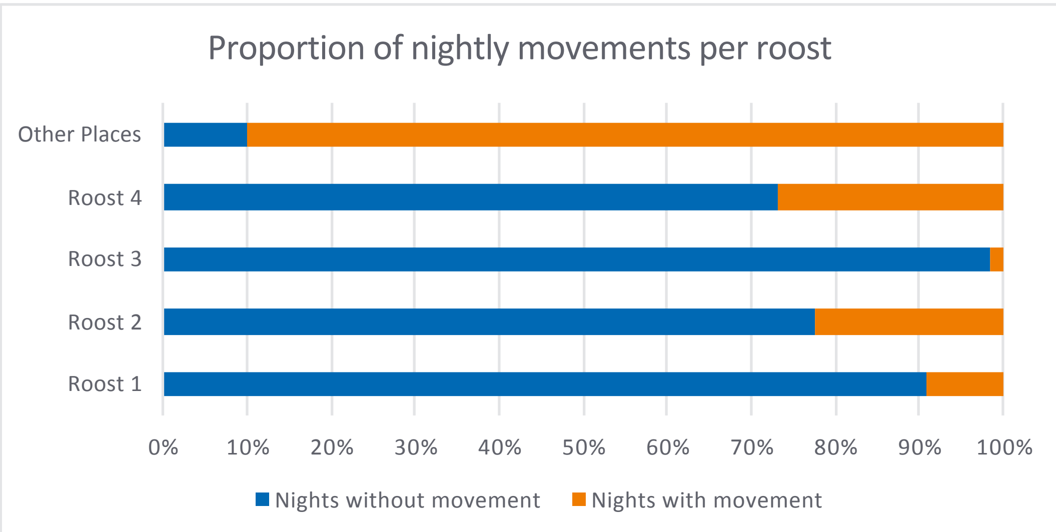


Figure 29:
Proportion of nightly movement at different roosts in Phobjikha valley

Roost 1 is the most important roost regarding the amount of overnight stays (60 %). In total cranes spent here 269 nights without shifts and 27 nights with shifts. Therewith, in just 9.1 % of all nights, cranes have left the roost. In roost 2 cranes completed 14 nights, but left the place in four other nights, the proportion therewith is 22.2 %. The least susceptible site is roost 3 with 60 completed nights and just 1 roost shift (1.6 % of all nights), whereas roost 4 is most susceptible with 79 completed and 29 uncompleted nights, which results in 26.9 % roost shifts of all nights.

Roost 4 is located very close to human settlements in the valley. It is likely that straying dogs, which can be found everywhere in the valley, sometimes disturb the cranes during the night. The high susceptibility of roost 2 can be also explained by its location and its size (Figure 30). The water body of this small wetlands often freezes during the night. At the same time the wetland is located very close to the forest, in which predators such as leopards occur (Choki et al. 2011). The places with relatively few nightly movements (roost 1 and 3) vary in size, but appear to be relatively far away of settlements and forests (see Figure 26).

Figure 30: ▸ *Water of the small sized roost No. 2 has frozen during the night, which makes cranes more vulnerable to predators. Photo: Anne Kettner*

The category “other places” was chosen, if a crane has not been located in one of the known roosts at sunset. In nine of all counted ten cases the associated crane had moved to one of the four known roosts during the night. Probably, in these nine nights the respective cranes just returned late from their foraging grounds. Only one night was completely spent outside a known roost. This place (90,1813600°E 27,4524465°N) was visited in November 2022 and was found to be a small wetland, temporarily used by few cranes, if conditions were well (Figure 31).

◀ *Figure 31:*
Temporary (almost dry) roost in Phobjikha valley in November 2022.
Photo: Anne Kettner

d) Habitat use

To obtain results about the daily habitat use during wintering, eight seasons from six different individuals were analysed, because crane ("Dorji") was excluded due to his spent wintering season in Tibet, for which no land cover data for further analysis was available. For illustration purposes, the land cover of Phobjikha valley and the data points of crane "Anneaguntera" in winter 2020-21 are shown in the next figure.

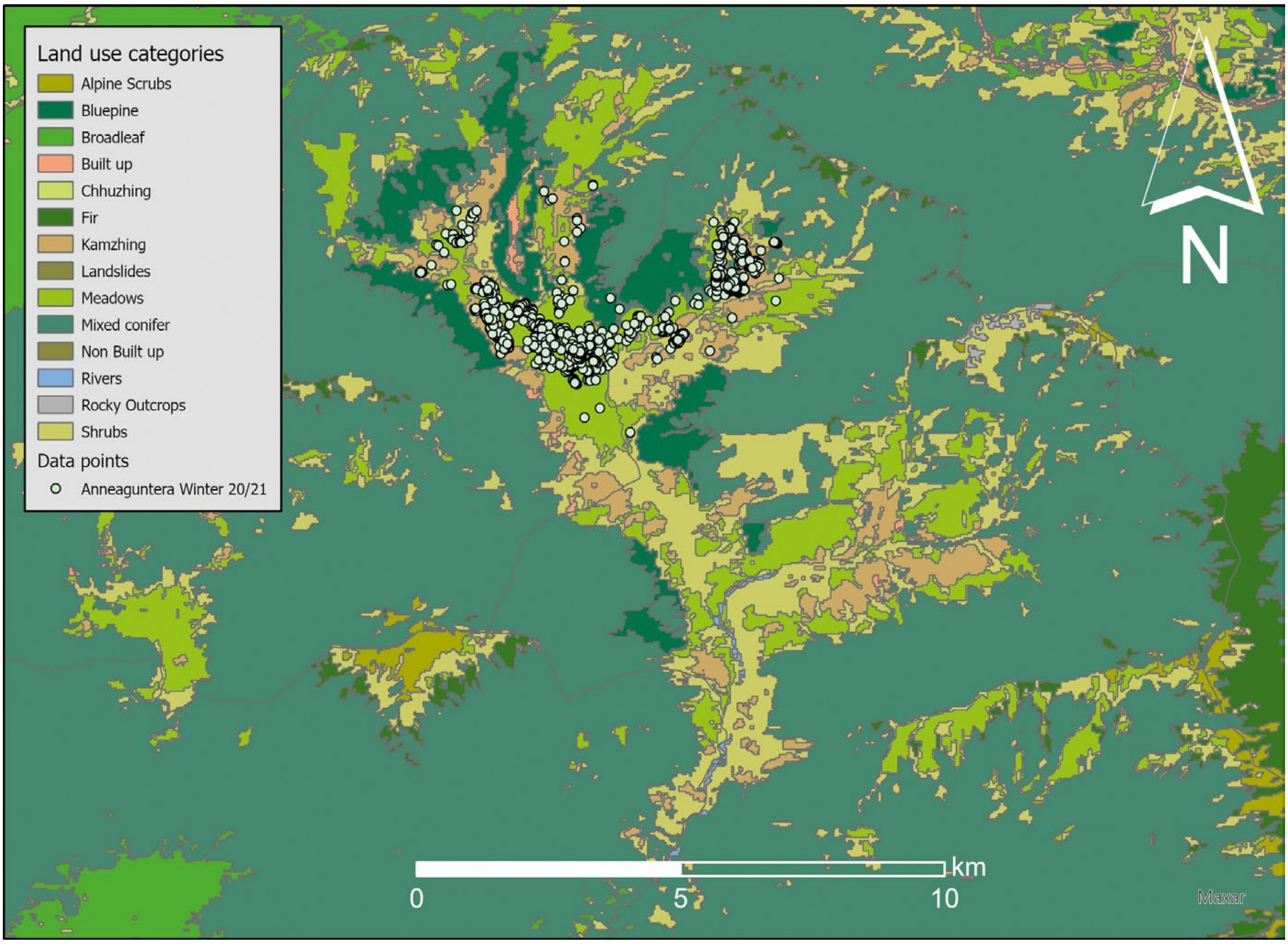


Figure 32: *The land cover categories of Phobjikha valley according to FRMD 2017 and GPS-fixes (light green) of one crane during one winter*

Cranes in Phobjikha valley are mostly on agricultural land during the day as shown in Figure 33. They stay mainly on fields (kamzhing: cultivated rain-fed areas [dry land]) (38 %) and meadows (37 %). However, habitat use changes during the day. In the morning cranes mostly stay on meadows (34 %), during midday on shrub land (19 %) and during afternoon on fields (34 %). Rarely, they are on other habitats such as river, mixed conifers, chhuzhing (irrigated and or bench terraced agricultural land for paddy based cropping systems) or bluepine.

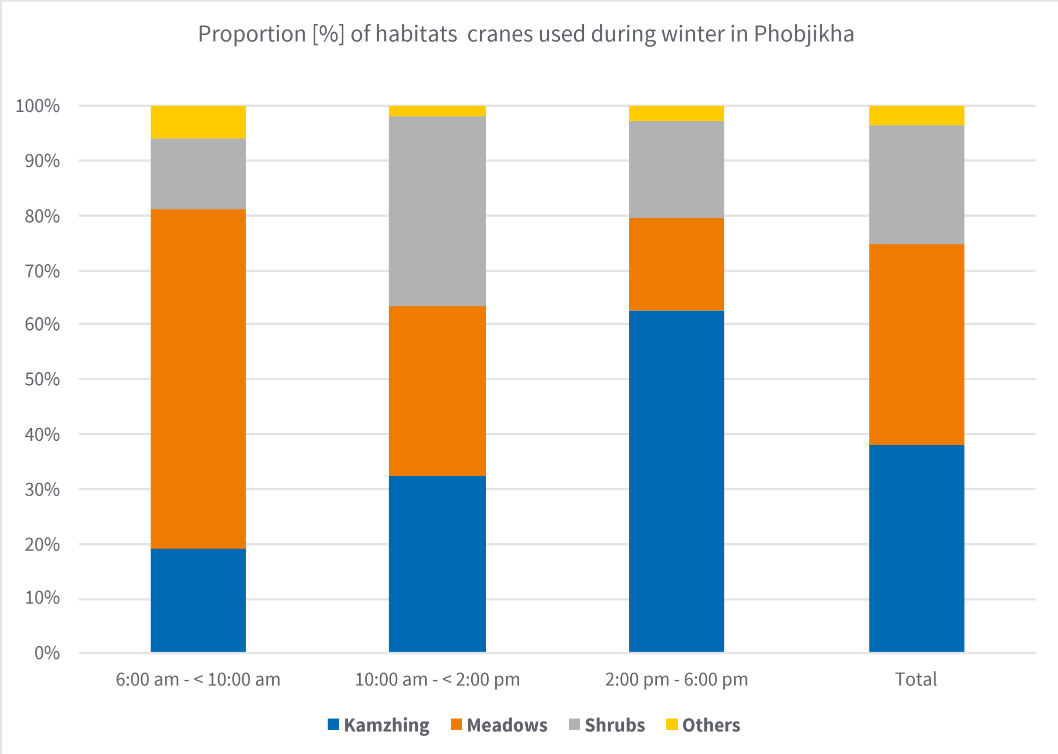


Figure 33:
Proportion of habitats used by cranes in Phobjikha sorted by day category

In Bumdeling cranes most often stay on chhuzhing (63 %). Throughout the entire day this is by far the preferred habitat (morning: 70 %, midday: 84 %, afternoon: 44 %). The second mostly used habitat by cranes in Bumdeling is river (20 %), followed by fields (kamzhing) (10 %) and shrubs (7 %).

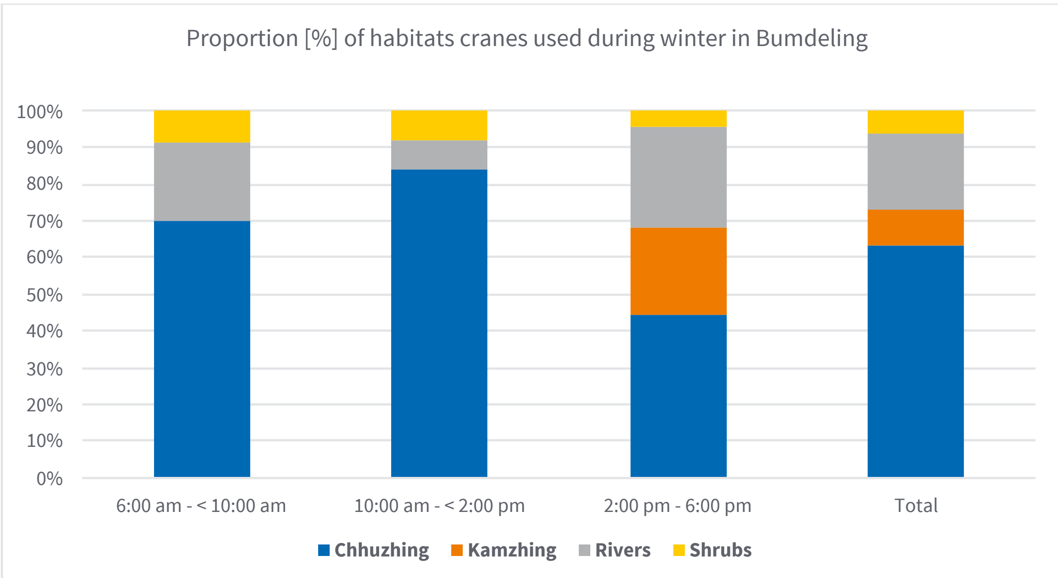


Figure 34:
Proportion of habitat used by crane in Bumdeling per day category

As landscapes of Bumdeling (Figure 35) and Phobjikha (Figure 36) differ, the results cannot be compared with each other. Nevertheless, some common features are noticeable. In both areas the mainly used habitats are those linked to human utilization, whether because it is currently cultivated (chhuzhing, kamzhing) or may have been previously cultivated (shrubs), or because it potentially originates from grazing (meadows). It is also noticeable that cranes do not or rarely occur on habitat with high vegetation, especially trees. The proportion of cultivated (fields / kamzhing), but not irrigated or terraced agricultural land, increases for both areas in the course of the day.

Figure 35: *Landscape of Bumdeling valley. Photo: Sherub Sherub*

Figure 36: *Landscape of Phobjikha valley. Photo: Anne Kettner*

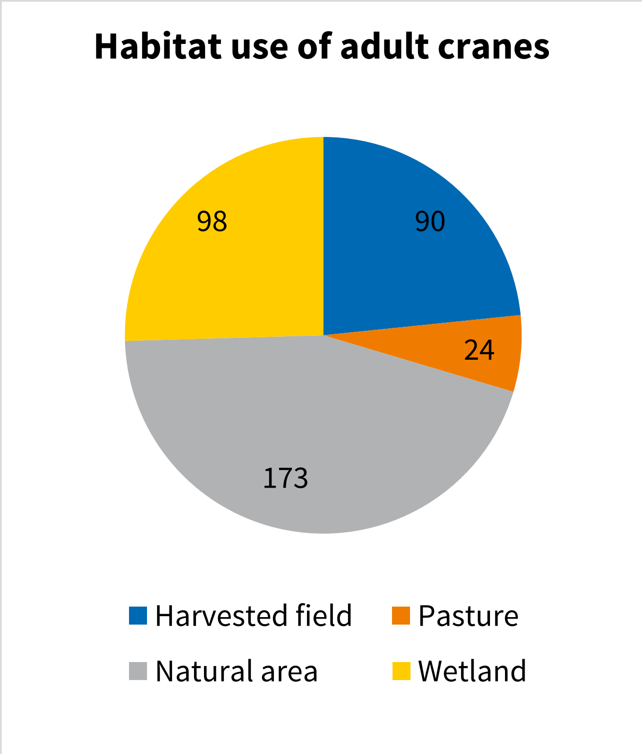
In addition to the habitat analysis by using GPS data, cranes on different habitats were mapped in January 2019, January 2020 and November 2022 in Phobjikha valley. Here, a larger sample size (compared to the GPS-analysis) was observed and the age (immature or adult) was noted (Figure 37). The disadvantage of this method is, that the cranes were just mapped at one time a day and not throughout the entire day or even one season, like it is possible with GPS-analysis. The most interesting new finding by this method was that habitat use of immature and adult cranes differs.

Figure 37:
Family with one offspring in Phobjikha valley in November 2022. Immature birds are still easily to distinguish from adult ones. Photo: Anne Kettner

Out of 620 mapped cranes in January 2019 the age of 427 individuals could be identified (Kettner et al. 2019). 43 cranes of those were immature ones. In January 2020 out of 1.283 recorded cranes 145 were immature birds (Nowald et al. 2020). Therewith, the proportion of immature cranes was 9.93 % in winter 2018-19 and 8.85 % in winter 2019-20.

Figure 38 exemplarily shows the habitat use of adult and immature cranes in Phobjikha valley in January 2019. Although different habitat categories were used during mapping compared to the GPS-analysis, it is obvious that fields, meadows/pasture and shrubs/natural area are the main habitats of cranes.

More interestingly, immature birds are less often recorded on (harvested) fields than adult birds. Just 9.5 % immature cranes were documented on fields, but 23.4 % adult ones. Therefore, immature cranes were more often recorded on all other habitat types than adult cranes: 47.6 % on natural area (adult: 44,9 %), 33.3 % on wetlands (adult: 25.5 %) and 9.5 % on pastures (adult: 6.2 %).



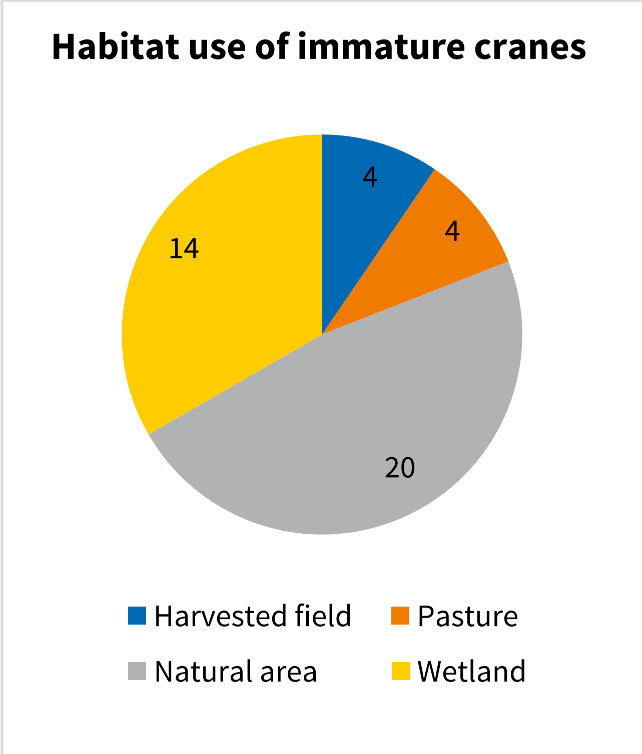


Figure 38: *Habitat use of mapped cranes (left: adult, n=385; right: immature, n=42) in January 2019 in Phobjikha*

The reason for this difference might be caused by attributes of the fields in Phobjikha valley. They are often very small in size, located next to the houses of the farmers, which often have cattle and dogs around, and are fenced, e.g. with stone walls, which reduces the visibility for cranes as shown by Figure 39. From a crane perspective these fields are a valuable source of food, but dangerous at the same time. Presumably, immature birds (and their family) prefer to stay on safer habitats, although food availability might be lower.

Figure 39: *Alert flock of adult cranes feeding on a typical harvested field next to a Bhutanese house in January 2019. Photo: Anne Kettner*

Conclusions and conservation for Black-necked Cranes

1. Summary of the project and its outcomes

The project "Research and Conservation of Black-necked Cranes in Bhutan" 2019-2023 was funded by the BMUV and implemented by RSPN, CCG and NABU. On the one hand, it aimed to gain new insights about migration and wintering patterns of cranes wintering in Bhutan by using GPS-data and thereby gather valuable information for the conservation of BNC in Bhutan as well as during migration, on the other hand it aimed to start a co-operational conservation process by conducting an international meeting including all surrounding countries at the end of the project.

The "International Black-necked Crane Conservation Network Meeting" took place from 8th – 9th November 2022 in Thimphu, Bhutan (RSPN, 2023a). Crane conservationists from Bhutan, China and India as well as from North America, Australia, Germany and other countries joined the conference to discuss the protection of Black-necked Cranes. There, first important steps in the international conservation of BNCs, in particular a "Black-necked Crane Conservation Strategy and Action Plan" for the coming 10 years, were taken.

The GPS-data showed that BNCs migrate on two totally different flyways from Bhutan to their breeding and summering areas on the Qinghai-Tibetan Plateau in western China. The migration flyway depends on the wintering area. Cranes wintering in Phobjikha valley, the major wintering site of Bhutan with about 90 % of the total crane population wintering in Bhutan, have to fly a significant shorter vertical and horizontal distance than cranes wintering in Bumdeling valley. Therewith, the migrations from Phobjikha is significantly less energy consumptive than the migration from Bumdeling. Nevertheless, all cranes have to cross the Greater Himalayan mountains reaching impressive altitudes of up to 7.441 m. Important resting sites along the migration routes and interesting extraordinary routes by single individuals are described in this report.

Furthermore, the analysis of the wintering behavior brought new insights about BNCs. For instance, the choice of foraging and roosting site differs between the individuals. The individuals keep their preference towards foraging and roosting sites from one winter to the other. All cranes stay in more than just one roost throughout the winter seasons. They seem to have "avoiding" roost sites, probably depending on water-level and disturbances in the valley. In about 14 % of all nights, cranes have left the original roost site and moved to another roost, indicating nightly disturbances in the respective wetland. The relevance and susceptibility of all roosts in Phobjikha and Bumdeling valley are describes in this report. As wetlands are small and nightly temperature low, some roosts are found to be insecure for cranes. Moreover, an essential area for BNCs in both valleys is identified by aggregated home-range analysis. This minimum area,needed to be conserved for cranes to continue wintering, contains 12.56 km^2 in Phobjikha valley and 5.29 km^2 in Bumdeling valley.

A habitat analysis has proven that cranes totally depend on agriculture. About three quarter of their daily time cranes are found on traditionally managed (dry) fields as well as pastural land in Phobjikha valley and on dry (kamzhing) as well as wet (chhuzhing) fields in Bumdeling valley. The habitat use differs between adult and immature birds and additionally, changes throughout the day.

2. Recommendations for conservation and further investigation

The following recommendations for the conservation of Black-necked Cranes and further investigations result from this study.

Protect roosts in Phobjikha alley:

- Reduce anthropogenic disturbances during the night, e.g. limit the access for straying dogs
- Enlarge small roosts in size and depth to enhance nightly security against predators
- Reduce anthropogenic disturbances during the day, e.g. touristic walking, because cranes use the roost for feeding and resting during the day, especially on windy days

Foraging grounds in Phobjikha valley:

- Maintain the traditional way of farming to ensure sufficient food availability in the harvested fields
- Maintain the traditional way of grazing, because pastural land contains food (e.g. insects on the left-overs of the cattle) and prevents the growth of large vegetation
- Reduce disturbance on the fields, especially by straying dogs, and improve visibility for cranes in the fields

Prioritizing crane conservation in Phobjikha valley:

- Conservation of cranes need to be a focus in Phobjikha valley, because it nowadays contains about 90 % of Bhutan's wintering population. The protection of this migratory bird is of international importance, but also valuable for ecology, culture and economic of Bhutan.
- Because of the high relevance of resting area No. 1 at Douqing Lake in Tibet for the entire BNC population wintering in Phobjikha, additional protection efforts in this area would be highly effective and therefore of high interest for Bhutan. This provides good opportunities for cooperative cross-border protection efforts of both countries.

Appreciate Black-necked Cranes:

- The results of our investigation showed that this crane species overflies the highest mountains on our planet, reaching altitudes of up to 7.441 m over mean sea level and breeding in areas of about 4.500 m. Realize their performance and try to respect these wonderful crane species!

Further investigation:

- As most GPS-transmitters are still working, the amount of information of the individuals increases day by day. It is highly recommended to repeat the analysis done in this study (migration and wintering pattern) in some years to have a larger sample size in terms of seasons and find out potential changes throughout the life of these cranes.
- A more detailed analysis of resting sites as well as summering/breeding areas (for instance by using home-range calculation) to gain interesting information for in-situ conservation is recommended, because such analysis was beyond the scope of our study, but could easily be done using the data of this project.
- An analysis of the acceleration data, which is constantly collected by the tags (in addition to the GPS position), would give further details into the activities of the respective individuals. Again, this analysis was beyond the scope of this study.
- Additional tagged individuals are needed to enlarge the sample size, statistically verify the results of this study and/or find additional information, such as flyways or resting sites. More individuals from Phobjikha, but also from all the other wintering sites in Bhutan, are helpful to identify important areas and behavior pattern for effective conservations. Catching and tagging cranes at the breeding sites might be an alternative to catching in the wintering sites.
- The impact of climate changes on BNC must be a focus of future investigations, because it is likely to cause dramatical behavioral changes especially for alpine animal species. The shift of BNCs within Bhutan could be a first evidence for this change. Eurasian cranes for instance are found to strongly change their migration flyways, including resting and wintering sites, over the last two decades possibly as a result of climate change (Nowald et al., 2022).
- Explore the breeding and resting sites, identified in this study to find out about conservation needs along the entire distribution of cranes wintering in Bhutan.
- Share data with adjacent countries to close knowledge gaps and find conservation partners.

3. Final project workshop

RSPN organized the "International Black-necked Crane Conservation Network Meeting" with the financial support of BMUV, ICF and NABU International. 13 international and 35 national participants from 15 different organizations joined the conference from 8th – 9th November 2022 in Thimphu, Bhutan (Figure 40). The network meeting aimed to bring together regional and international researchers, conservationists and related partner institutions engaged in the study and management of Black-necked Cranes and their habitat to share information about the species and to plan collaborative actions (RSPN, 2023a).

Figure 40: *Participants of the International Black-necked Crane Conservation Network Meeting 8th – 9th November 2022 in Thimphu. Photo: RSPN*

One the first day the participants were welcomed by Dr. Kinley Tenzin, the Executive Director of the RSPN, Mr. Lyonpo Yeshey Penjor, the Minister of Agriculture and Forests, as well as by Mr. Dasho Paljor J Dorji, a special advisor of the National Environment Commission of the Royal Government of Bhutan. Afterwards keynote addresses were delivered by Dr. George Archibald (ICF), Dr. Suresh Kumar (Wildlife Institute of India) and Mr. Nils Schmelzer (NABU International). The first day was the knowledge sharing session of the Network Meeting. Interesting insights into biology and conservation of BNCs were presented, including presentations about the national conservation efforts of India, China and Bhutan as well as about the BNC network in China and the Central Asian Flyway Initiative. An overview of all presentation is given by Table 9.

Topic of presentation	Presenter	Organization (country)
BNC conservation and plans in India	Dr. Pankaj Chandan	National Development Foundation (India)
BNC conservation and plans in China	Prof. Heqi Wu	Kunming Institution of Zoology (China)
BNC conservation and plans in Bhutan	Mr. Jigme Tshering	RSPN (Bhutan)
Research and conservation of BNC in Bhutan – migration	Dr. Günter Nowald	CCG (Germany)
Research and conservation of BNC in Bhutan – wintering behaviour	Ms. Anne Kettner	CCG (Germany)
Cranes and agriculture	Prof. Stephen Garnett	Charles Darwin University (Australia)
Stressors and ecosystem dynamics for managing BNC habitat in Phobjikha, Bhutan	Mr. Om Katel	College of Natural Resources, Royal University of Bhutan (Bhutan)
BNC dietary composition in Bhutan	Dr. Sherub	UWICER (Bhutan)
BNC network in China	Prof. Yang Xiaojun	Kunming Institution of Zoology (China)
Central Asian Flyway Initiative	Ms. Neha Sinha, Dr. Hum Gurung	Bombay Natural History Society, Birdlife Asia (India)

Table 9:
Presentation during the on 8th Nov. 2022 of the Network Meeting. Source: RSPN (2023a)

One the second day the international group worked on a framework for cooperative conservation on BNCs. Spike Millington (ICF) introduced the idea of a BNC conservation cooperation framework to the participants and moderated the workshop. In this session, the three participating countries gathered information about breeding and wintering sites, the number of cranes and threats on these sites as well as about present and future conservation measurements needed for Black-necked Cranes. After this international group work, they shared the information and discussed more possibilities for information sharing instruments as well as political and financial instruments needed for international conservation efforts.

At the end of this day a draft of a ten year “Black-necked Crane Conservation Strategy and Action Plan” was developed (ICF, 2023) and a way to finalize the framework planned. It will be published within this year and is intended to be an instrument for future conservation activities regarding the BNC. At the end of this day, Dr. George Archibald (ICF) shared his vision for the BNC conservation in the region with the participants and therewith inspired the international group to continue their cooperative conservation activities.

The majority of the international participants joined a field trip after the Network Meeting in Thimphu to visit Phobjikha valley and the Black-necked Cranes festival as well as the White-bellied heron centre and other destinations.

4. Cross-border cooperation and vision

Beyond the scientific focus of the project, it was a goal to address international cooperation at the civil society and state level, and to provide positive impulses for the intensification of international collaboration in BNC conservation. Overall, there haven't been many collaborative international conservation programs. However, the Chinese based Black-necked Crane Network has been an important pillar for exchanges between BNC researchers and conservationists. In 2012, this network was established by the International Crane Foundation, the National Bird Banding Centre of China, and the Kunming Institute of Zoology of the Chinese Academy of Sciences. Over the years, a total of 7 network meetings have been conducted. These meetings have served as a valuable platform for assessing the overall situation of cranes and occasionally, scientists from India and Bhutan participated in these meetings (CMS 2020).

In the frame of this project, we reached out to engaged civil society organizations and were able to contribute to existing efforts. In a first step we joined forces to facilitate a side event during the Convention on Migratory Species COP13 in India. Together with the ICF and WWF India, the authoring organizations exchanged on current conservation efforts and discussed key priority actions for Black-necked Cranes. The exchange between NGOs and government representatives was continued during the first International Black-necked Crane Conservation Network Meeting in Bhutan (see previous chapter).

The conference spotlighted conservation activities in Bhutan and strengthened the network among range state actors. The participating organizations proposed the Black-necked Crane as a flagship species for cooperation in the frame of the Central Asian Flyway within CMS. Furthermore, it was decided to develop a renewed Global BNC Conservation Strategy Action Plan. On Bhutanese side, these joint efforts received immense governmental support by the Ministry of Agriculture and Forests as well as the Nature Conservation Division under the Department of Forest and Park Services. His Excellency Lyonpo Yeshey Penjor, Minister of Agriculture and Forests, addressed the importance for crane conservation in his keynote speech during the International Black-necked Crane Conservation Network Meeting. Support was also given by Dr. R. Suresh Kumar from the Department of Endangered Species Management within the Wildlife Institute of India. In conclusion, it is the common vision of BNC conservationists and researchers to enhance cross-country collaboration on all levels. Within the framework of international conventions there is a great chance of pushing this development.

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List of abbreviations

AM: Autumn migration

BMUV: Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection of Germany.

BNC: Black-necked Crane

BNHS: Bombay Natural History Society

CCG: Crane Conservation Germany

DD: Decimal degrees

e.g.: Latin “exempli gratia” = for example

EGM: Earth Gravitational Model

GPS: Global Positioning System

GIS: Geographic Information System

KDE: Kernel Density Estimation

MCP: Minimum Convex Polygon

MSL: Mean Sea Level

NABU: Nature and Biodiversity Conservation Union

ICF: International Crane Foundation

i.e.: Latin “id est” = that is

RSPN: Royal Society for Protection of Nature

SM: Spring migration

UMTS: Universal Mobile Telecommunications System

WGS: World Geodetic System

WWF: World Wide Fund For Nature

Appendix

Resting areas (labelled) and stopover areas of all recorded 17 migrations; (S): summering area for the respective crane, SM: spring migration, AM: autumn migration, DD: decimal degrees.

ID	Label	Cranes	Seasons (2019-21)	Type of area	Longitude (DD)	Latitude (DD)
A1	No 1	Anneaguntera, Chimi (S), Wangchen (S), Nameless, Tsheyphell, Kinley (S)	SM19, AM19, SM20, AM20, SM21	Resting	89,342515	28,018325
A2		Dorji	SM19	Stopover	89,54187	29,354462
A3	No 2	Dorji	SM19	Resting	89,094795	29,180814
A4		Dorji	SM19	Stopover	88,845591	29,18181
A5	No 3	Dorji	SM19	Resting	88,367836	29,230353
A6	No 4	Dorji, Karma	SM19, AM20, SM21	Resting	88,156192	29,315263
A7		Dorji	SM19	Stopover	87,106874	30,918998
A8	No 5	Dorji	SM19, SM20	Resting	87,229785	31,355208
A9	No 6	Dorji	SM19	Resting	87,585014	31,099529
A10		Dorji	SM19	Stopover	88,017758	30,777893
A11		Dorji	SM19	Stopover	88,260703	31,158976
A12		Dorji	SM19	Stopover	87,362614	31,627039
A13		Samten	SM19	Stopover	89,872617	29,41622
A14	No 7	Samten	SM19, AM19, SM20, AM20, SM21	Resting	88,77063	28,889746
A15		Samten	SM19	Stopover	86,670495	29,457709
A16	No 8	Samten	SM19, SM21	Resting	84,476223	29,364929
A17		Wangchen	SM19	Stopover	89,397473	27,865051
A18	No 9	Karma	SM19	Resting	90,426228	28,985818
A19	No 10	Karma	SM19	Resting	89,431752	29,05916
A20		Karma	SM19	Stopover	89,630435	28,869334

ID	Label	Cranes	Seasons (2019-21)	Type of area	Longitude (DD)	Latitude (DD)
A21		Karma	SM19	Stopover	87,758753	29,077246
A22	No 11	Karma	SM19	Resting	86,577068	28,598703
A23	No 12	Karma	SM19, SM21	Resting	86,434175	28,675814
A24		Karma	SM19	Stopover	84,078464	29,69696
A25		Karma	SM19	Stopover	81,5107208	30,7955504
A26		Samten	AM19	Stopover	87,1897754	29,3890587
A27	No 13	Samten	AM19, AM20	Resting	87,5546566	29,3790057
A28	No 14	Samten	AM19, AM20	Resting	87,7958613	29,3256125
A29	No 15	Samten	AM19	Resting	89,400261	29,3397234
A30		Samten	AM19	Stopover	91,24288	28,0888385
A31		Karma	AM19	Stopover	87,2163689	29,2446192
A32	No 16	Karma	AM19, AM20	Resting	87,7046147	29,2271355
A34		Dorji	SM20	Stopover	87,6777061	30,6572046
A45		Samten	SM20	Stopover	88,4758085	29,0495818
A46		Samten	SM20	Stopover	87,1556088	29,3255099
A47	No 17	Samten	SM20, SM21	Resting	85,3039395	29,3109359
A48		Wangchen, Anneaguntera	SM20	Stopover	89,5129935	27,921561
A49		Kinley	SM20	Stopover	89,4375786	27,8925882
A53		Nameless	AM20	Stopover	89,5216946	28,3424765
A54		Anneaguntera	SM21	Stopover	89,619331	27,7897234
A55		Kinley	SM21	Stopover	89,9845523	27,5239052
A56		Nameless	SM21	Stopover	89,4630295	27,9723513
A57	No 18	Nameless	SM21	Resting	88,8516633	28,2631202
A58		Nameless	SM21	Stopover	88,541038	28,399301

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