Argos 衛星追跡システムを用いたチベットアンテロープ（***Pantholops hodgsonii***）の季節移動のパターンと生息地利用に関する研究

マナエワ・カリーナ

2014 年度

博士論文

Argos 衛星追跡システムを用いたチベットアンテロープ（*Pantholops hodgsonii*）の季節移動のパターンと生息地利用に関する研究

（Migration Patterns and Habitat Use of the Tibetan Antelope (*Pantholops Hodgsonii*) Based on Argos Tracking in Qinghai-Tibetan Plateau, China）

学籍番号91481003　　マナエワ・カリーナ

指導教員　食生産利用科学専攻　教授　星野仏方

酪農学園大学大学院酪農学研究科

Migration Patterns and Habitat Use of the Tibetan Antelope (*Pantholops Hodgsonii*) Based on Argos Tracking in Qinghai-Tibetan Plateau, China

（Argos 衛星追跡システムを用いたチベットアンテロープ（*Pantholops hodgsonii*）の季節移動のパターンと生息地利用に関する研究）

Graduate School of Dairy Science,

Rakuno Gakuen University

MANAYEVA, Karina

The Dissertation Committee Chair

Laboratory of Environmental Remote Sensing

Hoshino Buho

September, 2014

Abstract

The Tibetan antelope (*Pantholops hodgsonii*), an endemic species of the Tibetan Plateau, listed as an endangered in IUCN, migrates over the long distances in order to give birth and only females do seasonal migration, which is the unique feature of this species. To identify the ecological drivers of the Tibetan antelope migration in terms of geographical characteristics, topographical variables of their ranges and the factors affecting the habitat selection within the seasons, the Argos transmitter satellite monitoring of the Tibetan antelope have been performed. The analysis included the LoCoH Hull method for the home range estimation and the Maximum Entropy analysis for the habitat selection modelling, made for the first time for this species. From August 2007 the location data provided the detailed spatial and temporal information. The analysis of the Argos system accuracy in given conditions revealed the less accurate and rarer signals during the winter season. Location errors were concentrated in the latitudinal direction, 67.52% of locations were accurate. The main pastures of the studied females were divided on three groups by their locations. The calving ground continued to be stable while wintering places changed easily. The necessity of the accession to the mutual migration route, as well as the similar timing of migration was shown. The Tibetan antelope used to start the migration in the middle of May and came back in the middle of August, however, due to the large amount of population delayed their migration next to the artificial barriers, the migration dates has shifted. The detailed route of females migration was not clear before this first time ever Argos monitoring. The annual habitation area varied from 2024 to 2908 km^2, and the wintering place located in a valley with the average home range of 441 km^2. The home ranges located near the artificial barriers (railway and a highway) had the shape, dependent on the linear construction and the migration corridor was wider in that area. The Maximum Entropy analysis showed the area, estimated as suitable for habitation, however, almost half of the most suitable area was out of the identified home ranges. The results suggest reducing the anthropogenic influence on the migration of Tibetan antelopes.

Table of Contents

List of Tables

List of Figures

Acknowledgements

This study was supported by Grant-in-Aid for Scientific Research (A) (No. 19255005, Project leader is: Prof. Buho Hoshino) by the Japan Society for the Promotion of Science (JSPS).

I offer my gratitude to the supervisor Dr. Buho Hoshino for continuous support during the whole period of research. I owe particular thanks to Dr. S. Ganzorig, whose suggestions and advises leaded my study. I thank all the team of this research project for their work and useful advises, particularly Nakazawa, T., Igota, H., Jiang, Z., Liu, C., Yoshida, T., Kaneko, M., Motokawa, M., Kaji, K., Wu, X., Ohtaishi, N., Mahmut, H., Masuda, R., Minari, Y., Ikaria, K., Nurtazin, S. T. I would like to thank the State Forestry Administration of China (Beijing) for providing with the permission to perform a field work. I thank Dr. C. Liu, Mr. Bian Kun, Mr. H. Zhang, Mr. T. Feng and all research colleagues who helped during the field survey on behalf of Shaanxi Institute of Zoology (Northwest Institute of Endangered Zoological Species), Xi-An, China.

The PhD research was supported by The Rakuno Ikueikai Foundation (April 2011 – September 2011), The Heiwa Nakajima Foundation (April 2012 – March 2013) and The Rotary Yoneyama Foundation (Ebetsu Rotary Club) (Apr. 2013-March 2014).

Chapter 1 Introduction

The combination of ecological-niche based models with Geographical Information Systems (GIS) has prompted conservation biology studies with more robust analytical methods (Guisan and Zimmermann, 2000). GIS are useful tools to analyze geographic-related processes for conservation planning, such as the identification of suitable habitat areas for rare species (Gaubert et al., 2006) or over large and remote study areas (Travaini et al., 2007), the assessment of conservation status of poorly known species (Papes and Gaubert, 2007), and the design of reserves (Brito et al., 1999).

This study uses GIS and remote sensing tools on endemic Tibetan antelope (*Pantholops hodgsonii* or Chiru), performing the first attempt of such survey on that species. This species inhabits at the high-elevation alpine and desert steppe with flat to rolling terrain in the Tibetan Plateau and only recently has been studied in any detail. Due to its highly valued wool the antelopes were heavily hunted in Tibet and the population once had sharply declined to nearly extinct in the past several decades (Schaller, 1998; Leslie and Schaller, 2008). Since early 1990's hunting on Tibetan antelopes has been prohibited and several reserves to protect their habitats were established in China. Although the population of Tibetan antelopes now is one of the best-protected wildlife in China, the antelope is listed as endangered species because of exploitation and competition with domestic livestock of pastoralists (Ruan et al., 2005). The current populations probably might be around 100,000 animals. Long-distance seasonal migrations of large herds of ungulates, driven by needs, such as food, water, avoiding predation and harsh climatic conditions, are widely known (Singh et al., 2010; Ito et al., 2013). At least 5 populations of the Tibetan antelope are migratory, some moving up to 300–400 km; others are non-migratory (Schaller, 1998). The Qinghai-Tibet railway, which opened in July 2006, cut across the range of the Tibetan antelope population and may disturb the migration of the population. It was found that the infrastructure development including railway construction in the Tibetan Plateau might be the main factor that threatens this species now and in the future (Xia et al., 2007). Because of its distribution in highly elevated and harsh environment of the Tibetan Plateau the biology and ecology of this unique species remain poorly understood. Despite the fact that seasonal migration of the Tibetan antelope and some of the calving places (Huiten Lake) were known as early as from 19th century (Przhevalsky, 1879), many details of such behavior are still unknown. Recent studies in China revealed the presence of several calving places (Schaller and Junrang, 1988; Schaller, 1998; Schaller et al., 2006; Bleisch et al., 2009; Hoshino et al., 2011, Kaji et al., 1989).

The aims of this study are to clarify the seasonal migration patterns and home ranges of the Tibetan antelope using the satellite tracking data derived from Argos transmitter collars and to identify: (1) biogeographic patterns in species range; (2) environmental factors related to species occurrence; (3) probable areas for species occurrence. High resolution presence data collected from transmitters and in a training area were combined with environmental factors to derive the models of species occurrence, which will be extrapolated to a projection area. Results of this study are intended to decrease the current lack of knowledge about distribution and occupied habitats by Tibetan antelope. It is expected to use methods for the quantification of area of occupancy for highly endangered mammals in one of the most remote and barely studied regions of the World. The Argos position information frequently provides of correct data of animal locations in a space and time during the years of remote survey. So far, Argos PTT monitoring provides data which are used to understand the species behavior and also helps to create the proper conservation management.

1.1 Object of study

The Tibetan antelope, commonly called the chiru (*Pantholops hodgsonii*) is a large mammal of Bovidae, Artiodactyla spieces, endemic of the Tibetan plateau (**Appendix A**). The Tibetan antelope is monotypic. At least 5 populations of *P. hodgsonii* are migratory, some moving up to 300–400 km; others are non-migratory.

This species is endangered because of exploitation and competition with domestic livestock of pastoralists; extant populations count is probably about 100,000. It is virtually unknown in zoos, but young have been born and orphans have been reared successfully in a 200-ha fenced enclosure in native habitat. The species has undergone a severe decline in the past several decades (Schaller, 1998; Ruan et al., 2005). Due to its highly valued wool the antelopes were heavily hunted in Tibet and the population number is sharply declined. Since early 90s hunting on Tibetan antelopes has been prohibited and several reserves to protect its habitats were established in China (Shaller, 1998; Leslie and Schaller, 2008). The species had been included to the CITES list of endangered animals of China, it is under the strong protection, the population status – declining. This species inhabits high-elevation alpine and desert steppe with flat to rolling terrain in the Tibetan Plateau, in highly elevated and harsh environment and only recently has been studied in any detail so the biology and ecology of this unique species remain poorly understood. The population of Tibetan antelope now is one of the best protected wildlife in the area. However, the newly built Qinghai-Tibet railway cut across the population of the Tibetan antelope, and may disturb the migratory of population. It was found that the infrastructure development including railway construction in the Tibetan plateau might be the main factors that threaten this species now and in the future (Xia et al., 2007).

The Tibetan antelope has height in shoulders 80-85 cm (male) and 70-75 cm (female), weighs 35-40 kg (male), 24-28 kg (female), hair color: from brown to gray, the abdomen is white, with eye-catching spots, female is yellowish brown, diameter of fiber is generally between 10-12 microns, the smallest 6 micron. Body length: 50-60 cm for adult male. Life period: not more than 8 years, habitat: integration ranges from a dozen to thousands inside the population, living at an altitude of 4300 m to 5100 m (minimum 3250 m, maximum 5500 m) at alpine grasslands, meadows and alpine desert. Quantity: less than 75,000 (1998 estimation, according to Schaller). The main diet includes *Gramineae*, *Cyperaceae* and *Artemisia* (*Meconopsis*) plants.

Antelope adapted to low oxygen environment (so far, it has not kept to a zoo or other similar place). Antelope grazes mainly in the morning and evening. However, food conditions are poor at winter and spring, it forages extended time, so that animals can often be seen moving around during the day; however, if in summer and autumn pasture became abundant, animals have rest at noon in the lake, river or lower cavity. Tibetan antelope's primary instinct is to run against an enemy, because of strong well-proportioned limbs, good running antelope has a special advantage, running up to 70 km per hour, even a pregnant female can run quite quickly. In summer, the migration period, the Tibetan antelope females required more energy and physical force to give birth to a lamb. The female Tibetan antelopes spent most of their time foraging despite of reproductive status, which could be explained by the food competition associated with the combination of low biomass, short growing season and presence of competing herbivore species (Lian et al., 2007). The Tibetan antelope is an herbivorous ruminant, a mixed feeder (Cao et al., 2008), seasonally eating grasses, sedges, forbs, and select parts of dwarf woody vegetation. Annual percent use of various plants is graminoids: *Stipa*, 3.7–47.3%, *Kobresia*, 1.1–33.1%, *Carex moorcroftii*, 0.5–22.8% herbaceous plants: *Potentilla bifurca*, 0.3–31.1%, *Leontopodium*, 0.2–11.9%, dwarf shrubs: *Ceratoides compacta*, 0.2–63.5% , *Ajania fruiticolosa*, 21.2% (Schaller, 1998). Seasonally the sedge *Kobresia* is eaten most often in summer. Summer diets of spatially segregated male and female were somewhat disparate; males selected *Kobresia* and forbs, and females selected forbs, notably *Potentilla*, and avoided grasses and sedges (Harris and Miller, 1995). On calving grounds, ruminal contents of adult females had 57% *C. compacta* and 43% grasses and sedges, principally *C. moorcroftii* (Schaller et al., 2006).

The migration and breeding of antelope directly related to habitation area, the vast majority of long-distance migration has conducted to calving, and then antelopes move back to the original habitat. Previous observations also showed that 3 year-old sexually mature female antelope, delivers 1 calf per year. Each year, from mid-November to mid-December is the mating period, calving comes to mid-June to early July, gestation lasts 200 days. In the mating season, males compete intensively and after, the victorious males organize small groups, female and male ratio ranging from 1:1 to 1:26. One month before calving, females began migration to the lake Huiten Nur by fixed routes. Widespread distributed antelopes collect to groups to reach the calving ground, the maximum number of group is up to 3000, when the calving begins, wolves, vultures and other predators are also more concentrated in surroundings, cruising and hovering near the birth place. Newborn antelope weights between 1.84 - 3.2 kg the average value is 2.78 kg, newborn began to suck within half an hour after standing up, in an hour can begin to follow a female. After about a month of physical recovery, a small antelope with a female began to return to the habitat. In a case of the harsh life in the plateau, half or more newborn calf could die less than in two months after birth. After calving period, females with newborn, adult males and fawns, spreads by small groups until next mating time. The total distribution in Qinghai-Tibet Plateau is on about 600.000 km^2. Some populations are settled, while others, the largest, migrate. Four such populations are distinguished in

Qiangtang region (Schaller, 1998). Tibetan antelope's population density: Qinghai Yushu region - 1.58 / km, Tuotuohe - 1.47 / km (Schaller and Junrang, 1988), at the Hoh Xil region 2.08 / km (Feng, 1993); at Kunlun Mountains in Xinjiang region, were 0.6 head, 1.50 and 1.38 / km); in northern Tibet is 2.09 / km (Feng, 1993).

Despite the fact that seasonal migration of Tibetan antelope and some of its calving places (Huiten or Zhuonai Lake) were known as early as from 19th century (Przhevalsky, 1879); many details of such behavior are remains understood. Determining population size at calving grounds is difficult (Schaller et al., 2006). Frequent movement of animals can cause large daily variation in density estimations, inclement weather often hinders visibility, and many areas are hard to access. The data, however, indicate that c. 4,000 female Tibetan antelope used the area in 2001 even after poaching had occurred. These calving grounds are therefore comparable to the calving grounds in western Xinjiang described by Schaller et al. (2006; see also Ridgeway, 2003), which were estimated to support 4,000–5,000 females and are considered to be one of the most important in the species' range. Based on the number of animals that we observed and reports from other regions (Schaller et al., 2007), the Arjinshan calving grounds is an important site and requires active monitoring and effective protection. (Bleisch et. al., 2009)

Due to its highly valued wool the antelopes were heavily hunted in Tibet and the population number sharply declined. Since early 90s hunting on Tibetan antelopes has been prohibited and several reserves to protect its habitats were established in China (Shaller, 1998; Leslie and Schaller, 2008). The species has undergone a severe decline in the past several decades (Schaller, 1998; Ruan et al., 2005). The population of Tibetan antelope was formerly subjected to poaching but is now one of the best protected wildlife in the area. However, the newly built Qinghai-Tibet railway cut across the population, and may disturb the migratory of population. Recent studies in China revealed presence of several calving places and indicated that female antelopes may travel up to 250 km from winter pastures to a summer calving sites (Schaller and Junrang, 1988; Schaller, 1998; Schaller et al., 2006; Bleisch et al., 2009; Hoshino et al., 2011).

Our research conducted on adult, 2-3 years old females, representatives of Hoh Xil Nature Reserve population, captured during the period of highway and railway crossings in order to come back from the calving ground to the main pastures, along with the new born calves. The antelopes were captured near the Wu-Bei underpass (N35° 15'; E93° 09') of Qinghai-Tibet railway using nets, provided by common morphometric measurements, and collared with satellite-based Argos platform transmitter terminals (PTT) in August 2007 (2 females), August 2009 (2 females) and August 2010 (5 females) (**Table 1.1).**

Table 1.1. Morphometric parameters of captured and monitored Tibetan antelopes.

Date	Age	Lactating	Weight, kg	Height, cm	Body length, cm	ID number
10/08/2009		Yes	31.8			75835
10/08/2009		Yes	22.8			75836
10/08/2009		Yes	22.2			75838
08/08/2010	2	Yes	27.1	80	65	75844
05/08/2010	3+	No	23.1	85	65	75839
06/08/2010	3+	Yes	35.2	95	71	75837
07/08/2010	3+	Yes	29.9	88	70	75841
08/08/2010	4-5	Yes	26.0	80	75	75843
08/08/2010	2	No	21.6	83	54	75840

Fig. 1.1. The distribution of the study object, according to IUCN (International Union for Conservation of Nature)

1.2 Area of study

The Hoh Xil Nature Reserve area is an isolated region in the northwestern part of the Tibetan plateau in China. It is China's least and the world's third-least populated area. The region covers 83 000 km² at an average elevation of 4 800 m, between the Tanggula and Kunlun mountain chains in the border areas of Southwest China's Tibet Autonomous Region, Northwest China's Qinghai Province and the Xinjiang Uyghur Autonomous Region. It is one of the major headwater sources of the Yangtze River and Yellow River. 45 000 km², at an average elevation of 4 600 m, were made into a Hoh Xil national nature reserve in 1995. The Qinghai-Tibet railway runs along the eastern boundary of the reserve.

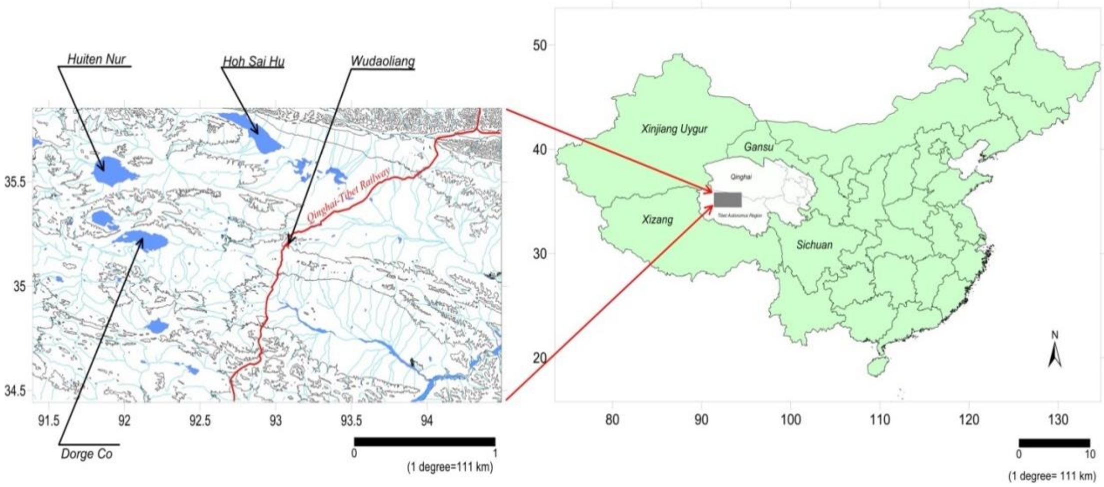


Fig. 1.2. The study area. Hoh Xil Nature Reserve, Tibetan Plateau, China.

The climate of the area characterizes by severe conditions. The average annual temperature from southeast to northwest gradually reduces, the warmest area is -4.1℃, the coldest -10℃ (estimated value), minimal temperature is -46.4℃, the average precipitation trend is decreasing from southeast to northwest, between 173 ~ 495 mm. Precipitation is mainly concentrated in summer, with clear rainy and dry seasons. Within the distribution of annual precipitation the most concentration is from May to September, can account for more than 90% of annual precipitation, including the warm season (June to August) can account approximately 70% of the total precipitation (Wu and Zhang, 1998). There is the high value of wind speed, the distribution of annual average wind speed increases from east to west. The air in Tibet is much thinner, with oxygen partial pressure being 35% to 40% below that at sea level. The soil types: mostly alpine meadow soil, alpine steppe soil and alpine cold desert soil, followed by swamp land, scattered in a swamp soil, cracked soil, saline, alkaline earth and sand. Region ranges due to geographic location, terrain height, terrain slope and surface position and other hydrothermal differentiation factors, the natural landscape represents by alpine meadow - steppe replacements to alpine desert with a small amount of the grassland distribution. Alpine periglacial vegetation had a greater area of distribution. Alpine meadow, alpine swamp distributed only in very few areas.

In the study area, the vegetation is primarily alpine grassland and alpine meadow dominated by *Stipa purpurea*, *Carex moorcroftii*, *Oxytropis densa*, *Oxytropis falcata*, *Astragalus densifolrus*, *Astragalus confertum* and *Pleurospermum hedinii* (Yang et al., 2006). The biomass of graminoids, sedges and forbs were 6.07±1.39 g, 13.87±5.39 g and 30.23±6.90 g, respectively (Lian et al., 2007) **(Table 1.2, Fig. 1.3).**

Despite the harsh climate, Hoh Xil is home to more than 230 species of wild animals, 20 of which are under state protection, including the wild yak (*Poephagus grunniens),* kiang (*Equus Kiang*), white-lip deer, brown bear (*Ursus arctos*), and the endangered Tibetan antelope (Feng et al., 2008, Schaller, 1998). Biota in this area is poor, but consists of a large proportion of endemics.

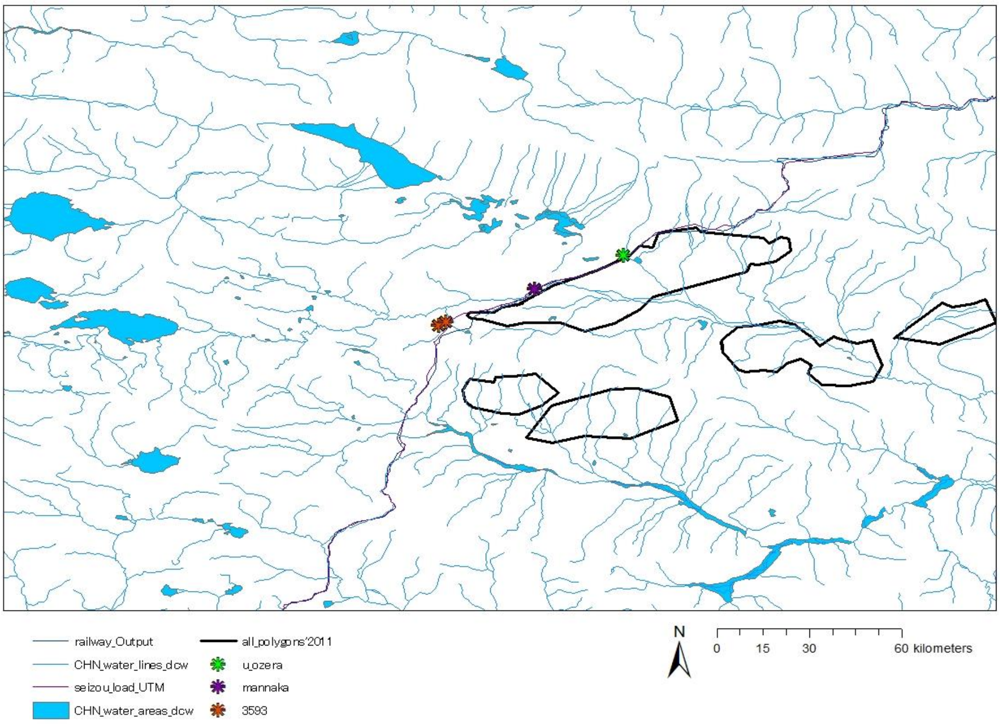


Fig.1.3. Locations of the plant species diversity survey at the study area. The black line polygons represents the studied Tibetan antelopes main pastures.

Table 1.2. Species list of vegetation located in study area.

	Species name		
	Plot ❋	Plot ❋	Plot ❋
1	*Kobresia pygmaea*	*Ephedra monosperma*	*Kobresia robusta*
2	*Kobresia pusilla Ivanova*	*Leontopodium pusillum*	*Carex digyne*
3	*Kobresia schoenoides*	*Delphinium candelabrum*	*Carex moorcroftii*
4	*Carex ivanovae*	*Callianthemum pimpinelloides*	*Neotorularia humilis*
5	*Carex sagaensis*	*Phyllolobium heydei*	*Ajania khartensis*
6	*Allium carolinianum*	*Astragalus confertus*	*Pleurospermum hedinii*
7	*Bistorta vivipara*	*Oxytropis chiliophylla*	*Poa indattenuata*
8	*Sibbaldianthe adpressa*	*Oxytropis stracheyana*	*Littledalea tibetica*
9	*Erysimum funiculosum*	*Corydalis mucronifera*	*Stipa purpurea*
10	*Dontostemon glandulosus*	*Corydalis qinghaiensis*	*Stipa purpurea*
11	*Cremanthodium ellisii*	*Semenovia millefolia*	*Deyeuxia tibetica*
12	*Pedicularis oederi*	*Lagotis brachystachya*	*Kengyilia thoroldiana*
13	*Callianthemum pimpinelloides*		*Astragalus mahoschanicus*
14	*Knorringia pamirica*		*Astragalus polycladus*
15	*Littledalea tibetica Hemsl.*		*Oxytropis stracheyana*
16	*Stipa purpurea*		*Dilophia salsa*
17	*Rhodiola tibetica*		*Saussurea subulata*
18	*Astragalus strictus*		*Saussurea arenaria*
19	*Astragalus tulinovii*		*Glaux maritima*
20	*Oxytropis pauciflora*		*Heracleum millefolium*
21	*Dilophia salsa*		*Pedicularis cheilanthifolia var. isochila*
22	*Aster asteroides*		
23	*Corydalis mucronifera*		
24	*Triglochin maritimum*		
25	*Delphinium tangkulaense*		
26	*Androsace robusta*		
27	*Meconopsis horridula*		

Chapter 2 General methods

2.1 Animal capturing and the transmitter installation

The female Tibetan antelopes were captured near the Wu-Bei underpass (altitude 4597 m) of Qinghai-Tibet railway (representatives of the North-Western population); using nets, and collared with satellite-based Argos platform transmitter terminals (PTT) (model ST-20 A-3210, Telonics Inc., USA) in August 2007 (2 females: ID 75835 and ID 75836), August 2009 (2 females: ID 75838 and ID 75842) and in August 2010 (5 females: ID 75837, ID 75839, ID75840, ID 75841 and ID 75844). The duty cycles of the collars were settled on: 4h on/92h off and 6h on/90h off (**Table 2.1**).

Table 2.1 Technical parameters for Argos PTT collars

Series	Duty cycle	Transmission time GMT	Unit Watt	Neck size Cm	Cast and belt color	Argos antenna	VHF frequency (MHz)	VHF time schedule GMT
St-20	4h on/92h off	7:00-11:00	0.5	45-55	Brown	External remote antenna	145.1-145.5	3:00-9:00
Note	4 hours per 96 hours							
St-20	6h on/90h off	6:00-12:00	0.5	50-60	Brown	External remote antenna	146.6-145.95	3:00-9:00
Note	6 hours per 96 hours							

Those collars provided of the positional information (Latitude, Longitude and Elevation), the dates and time of transmission.

2.2 Argos system accuracy in conditions of Tibetan Plateau

Only relatively accurate locations were used for analysis and those data that fit into known migration corridor (Xia et al., 2007, Hoshino et al., 2011) and were correspondent to the maximum ground travel limits of the animals were included. Erroneous locations that necessitated an unrealistically high speed of travel were removed (after Hays et al., 2001).

The location data were received through e-mail from the Argos Company and processed by the software, created in Remote Sensing Laboratory of the Rakuno Gakuen University, to remove noise and error text and to suit for the further analysis. The accuracy of the position information was classified as LC (Location Class). Argos User's manual state that the estimated accuracy in latitude and longitude is <100m for LC G, <250 m for LC 3, between 250 and 500 m for LC 2, between 500 and 1500 m for LC 1 and >1500 m for LC 0. The LC Z was removed as an error due to its insufficient accuracy. Antelopes ID75837, ID75842 (ID37 and ID42) were not involved to the seasonal migration, therefore all the location information from its collars received from the wintering grounds. The locations statistics was calculated using the standard formulas in Excel, the elevation and location accuracies were compared with the Aster GDEM (Global Digital Elevation Model) imagery data.

2.3 Environmental characteristics of habitat

Received positional and temporal information was compared with the climatic (temperature, snow cover, etc.), geographical (landscape) data, vegetation and water resources conditions in different places and time, occurrence of the natural and anthropogenic limitations, derived from the satellite imagery and databases.

2.3.1 Topography

Analysis of distances, durations and other specifics of migration as well as the main habitation area of 9 Tibetan antelopes was made on the base of satellite information in according to physical parameters of the animals and habitat. To utilize Argos PTT tracking data, the Global Digital Elevation Model (GDEM, a product of METI and NASA), global three-dimensional terrain, acquired by the satellite on-board Earth observation optical sensor ASTER and the water resources parameters were used. The topographical information of the water bodies, its characteristics, roads and railways were used from the China Geographical Database, available online. Data were processed at the ArcGIS10.1, ENVI 5.0, and Surfer 11 software. The tilt angle (Slope), shadow (Shaded Relief) and slope orientation (Aspect) were calculated by the satellite imagery analysis software ENVI 5.0, the Topographic Modeling (© Exelis Visual Information Solutions (VIS) ITT Corporation).

2.3.2 Vegetation Index

The product of SPOT Vegetation for NDVI (Normalized Difference Vegetation Index) was used to calculate the NDVI of locations and surrounding area. NDVI is an index, usually used to represent the activity of the vegetation and the vegetation amount, the value ranges from -1 to +1.

$$NDVI = (NIR-RED) / (NIR + RED)$$

RED is the red band of visible light reflectance (electromagnetic waves of 700-1100 nm), NIR is the near-infrared region of the infrared light (waves of 620-750 nm).

SPOT Vegetation is an Earth observation sensor on board; the SPOT-5 resolution has become a 1km. The processed data of SPOT Vegetation was stored as the digital number from 0 to 255, to calculate the NDVI the following equation used:

$$NDVI = (DN * 0.004) -0.1$$

2.3.3 Snow Index

An ON /OFF database of the snow cover from the product of MODIS Snow Cover was created. The MODIS Earth observation system uses the visible and infrared waves range sensor, which is established on the Terra / Aqua satellite (Earth Observing System EOS), the resolution is 500m. The MODIS Snow Cover data was classified into 11 classes, and should be reclassified into two classes to estimate the presence of snow in the present study.

2.3.4 Distances from the rivers and lakes

From the vector data of the rivers and lakes, which were processed at the DIVA-GIS software, the raster data of the distance from the rivers and lakes was created and the Euclidean distance was calculated, using the Spatial Analyst tool of ArcGIS 10.1 (© ESRI Inc.).

2.4 Field work

In 2011 and 2012 summers, the field survey had been made to monitor the Tibetan antelopes on the time they cross the highway and railway on their route to the calving ground (2011) and from it, back to the wintering pastures (2012). In order to observe the herds of Tibetan antelope females, returning from the breeding ground to the wintering places, 11 days of survey had been made from July 27 to August 6, 2012. At that period of time, females concentrated next to the highway, mainly in front of Wu-Bei underpass in order to cross the highway and then railway and finally return from the long summer migration.

The field census included the animal observation, vegetation survey, estimation of highway and railway traffic load and the local population interviews.

2.4.1 Wildlife census

Included: observation, counting; line transect census; estimation of the antelope herd structure, visible behavioral issues. In the section between Wudaoliang settlement and the Chumaer Bridge, the wildlife on the both sides of the highway was observed, attention paid especially on Tibetan antelopes. The distance from the highway, direction, number of animals, sex, time of the noticing, GPS coordinates of the location, were written into the census list. The herds of the Tibetan antelopes, appeared nearby were counted of number, distinguishing males, females and offspring, directions of the herds movement; and also the observation time and GPS coordinates were recorded.

2.4.2 Camera-trap

The camera-trap (Garden watch cam, © Brinno Co., Ltd.) was established at the Wu-Bei underpass on the several positions, during the period of August 2nd to August 6th. The camera was set to do shooting automatically each 20 seconds interval.

Appendix D (camera-trap pictures)

2.4.3 Vegetation survey

The vegetation survey included: soil moisture, plant height, coverage, spectral reflectance, plant diversity and volume etc. It was made in the random 1m × 1m square plots, made in surrounding areas of the census (Wu-Bei underpass, Chumaer Bridge, area beyond the linear barriers, area between the railway and the highway).

2.4.4 Estimation of highway and railway traffic load

The traffic load was counted in the section between Wudaoliang settlement and the Chumaer Bridge, recording the time period of each census (e.g. morning from 7 a.m. till noon, afternoon from 2 p.m. till 5 p.m.).

2.5 Features of migration, influence of the linear barriers

To estimate the features of the migration and the influence of the linear barriers (highway and railway), the Argos location spatial and temporal data were analyzed. Distances, directions and dates of migrations were taken into attention.

2.6 Home ranges based on nonparametric kernel method

A Local Convex Hull (LoCoH) nonparametric kernel method was applied to construct the animal HR models. This method generalizes the minimum convex polygon (MCP) method, and was shown to be more appropriate than parametric kernel methods for constructing HRs and utilization distributions (UDs), because of its ability to identify hard boundaries (e.g., rivers, cliff edges) and convergence to the true distribution as sample size increases (Getz et al., 2007). The software for all three methods of Local Convex Hull home range estimation (k-, r- and a-LoCoH) is available at http://locoh.cnr.berkeley.edu. The k-LoCoH home range with isopleth's values (number of nearest neighbors) 10-15-20-25 was calculated for each individual, separating migration from wintering area.

2.7 Estimation of the habitat selection (Maximum Entropy)

The Maximum Entropy (MaxEnt) model was used in order to clarify the potential distribution and habitat selection of the Tibetan antelope. The model was created by using the information of the current distribution and the parameters of the environment in the habitat of the species (Phillips et. al., 2004).

For the MaxEnt modelling analysis, the software based on the maximum-entropy approach for species habitat modeling was used.

The software is available at http://www.cs.princeton.edu/~schapire/maxent/ . This software takes as input a set of layers or environmental variables (such as elevation, precipitation, etc.), as well as a set of geo-referenced occurrence locations, and produces a model of the range of the given species.

2.7.1 Creating a standardized distribution database

The Tibetan antelope location data obtained from the Argos PTT arranged into the tables, for each individual, containing the latitude and longitude information. It required to transfer data into a CSV format, using ArcGIS 10.1 (© ESRI).

2.7.2 Creating an environmental database

The environmental data: distances, digital elevation data (DEM), surface angles (Slope), shadows (Shaded Relief), slope directions (Aspect), distances from river, distances from lake, regular vegetation index (NDVI), snow cover, were formatted into one standard, suitable for the MaxEnt software.

Chapter 3 Argos system accuracy in conditions of Tibetan Plateau

3.1 Introduction

Jessica S. Bolis (2013) described the history of telemetry from radio-telemetry, until new generations of satellite telemetry technology and the advances and advantages of Argos system on wildlife long term remote monitoring. Many wildlife studies rely on the researcher's ability to relocate captured study animals. Studies of home range, habitat use, foraging behavior, activity patterns, dispersal and migration depend on such relocation data. Prior to the development of tracking systems, relocation data were often impossible to collect in large enough quantities to answer many research questions for free-ranging wildlife (Le Munyan et al., 1959, Ellis and Lewis, 1967). The current Argos manual describes the system as "a global satellite-based location and data collection system dedicated to studying and protecting our planet's environment (CLS-America 2011)". Transmitters that make use of the Argos system to relay data are called platform terminal transmitters (PTTs) and are designed and produced by various companies. The first Argos-compatible PTTs were placed at stations on land and floating ice as well as onboard ocean buoys. These PTTs delivered a variety of meteorological, hydrologic, and oceanographic data. Fancy et al. (1988) provide an extensive list of early deployments on animals in the 1980's, including the first deployment on a humpback whale (*Megaptera novaeangliae*) in 1983. Other species on the list include wide ranging terrestrial species, such as caribou (*Rangifer tarandus*) in Alaska and the Arctic, muskox

(*Ovibos moschatus*) in Alaska, grizzly bears (*Ursus arctos*) and polar bears; marine mammals such as sperm whales (*Physeter macrocephalus*), West Indian manatees (*Trichechus manatus*), gray seals (*Halichoerus grypus*), and crabeater seals (*Lobodon carcinophagus*); and birds such as bald eagles (*Haliaeetus leucocephalus*) and Antarctic giant-petrels (*Macronectes giganteus*). Some of these first PTTs were experimental units that provided no or very few locations before failing. Subsequent applications of Argos technology were often focused on recording long range movements of marine species, including an examination of foraging strategies of wandering albatrosses (*Diomedea exulans*) in the Indian Ocean (Weimerskirch et al. 1993), migration routes of Adelie penguins (*Pygoscelis adeliae*) in the Ross Sea off Antarctica (Davis et al., 2001), and tracking a subset of species in the Tagging of Pacific Pelagics (TOPP) program to study pelagic habitat use throughout the Pacific ocean, including salmon sharks (*Lamna ditropis*) and leatherback turtles (*Dermochelys coriacea*; Block et al., 2002). The Argos system has undergone several upgrades since its inception. In 1983 there were only 2 earth-orbiting satellites carrying Argos instrumentation; today there are 6 (CLS-America 2011). Argos has upgraded the algorithm they use to calculate locations several times, with the most recent upgrade in 2011 when they transitioned from the least squares to the Kalman filtering algorithm. The least-squares algorithm used information from only 1 satellite pass to calculate a location, whereas the new Kalman filtering algorithm uses a random walk model to predict the next location based on information from the previous one. Testing by Argos indicates that use of the new algorithm will increase the overall number of locations, as well as the quantity of high-quality (low-error) locations (Bernard and Belbeoch, n.d., Lopez and Malard, 2011). The location classes are designated as LC G, 3, 2, 1, 0, A or B, and the LC 3, 2, 1 and 0 are provided only when at least four uplinks are received on an overpass; LC A occurs when a location is determined from three uplinks; and LC B when a location is determined from one or two uplinks. From 2011 several improvements of LC designation updated due to the different algorithms used. Programmable duty cycles allow researchers to tailor data collection to the objectives of their study. While PTTs continue to be used to provide location data, they increasingly include additional sensors to collect data about an animal's physiological state or local environmental conditions, which are then transmitted via the PTT. Improvements to telemetry systems includes: decreased weight, longer battery life, incorporation of solar panels for avian applications, conjunction with GPS. Some recent applications of GPS telemetry systems include defining patterns of habitat use and selection by female grizzly bears in northern British Columbia (Milakovic et al., 2012), locating cougar (*Puma concolor*) predation events to study kill rates and prey composition in Alberta, Canada (Knopff et al., 2010), and monitoring spatial use by feral swine (*Sus scrofa*) in Texas in response to aerial gunning as a population control method (Campbell et al., 2010). Nowadays, over 3000 animals are tracked via Argos. These include mammals, marine animals and birds all over the world. Once this information collected and studied, conclusions can be drawn about migratory pathways, animal's resting, breeding and wintering grounds, the way the young become independent, they bring the authorities the information needed to set up protection programs. Decisions can be taken more on the basis of fact than guesswork.

3.2 Frequency of receiving the locations

An average frequency of received signals appeared to be 2.18, and 1.8 for the accurate locations **(Table 3.1)**. The longest usage of Argos transmitter in given settings was 1809 days, or 5 years. However, this length appeared from the collar, transmitted less frequently **(Fig. 3.2.)**, the shortest period of usage was 688 days, with an average of 1106.8 days of usage. Within that period, the average number of locations received from one collar was about 458 accurate and 555 raw. No signal received from 5 of 9 transmitters nowadays.

The Frequency may depend on the weather conditions (wind, precipitation) and the time of the received locations in according to the Tibetan antelopes` different activity during the daytime. The number of locations received differs according to the season, less locations received in winter and spring. More locations received in September and the fewer amounts received in December and March. **(Fig. 3.1).**

Table 3.1. Monitoring periods and amount of locations for collared individuals

Monitored individual	Period	Number of days	Number of locations		Number of days with signals	Estimated number of signals per day	
			Raw	Accurate		Raw	Accurate
ID35	28.08.2007 - 01.08.2011	1312	373	350	328	1,14	1,07
ID36	20.08. 2007 - 02.08.2012	1809	199	140	452	0,44	0,31
ID37	12.08.2010 - 03.03.2012	688	169	123	172	0,98	0,72
ID38	17.08.2009 - 16.04.2013	1338	480	373	334	1,43	1,12
ID39	05.08.2010 - 14.04.2013	983	664	547	246	2,70	2,23
ID40	08.08.2010 - 17.03.2013	928	467	356	232	2,01	1,53
ID41	05.08.2010 – 14.04.2013	983	825	699	246	3,36	2,84
ID42	17.08.2009 – 14.03.2012	940	967	769	235	4,15	3,28
ID44	08.08.2010 - 14.04.2013	980	852	761	245	3,48	3,11
Average		1107	555	458	276	2,18	1,80

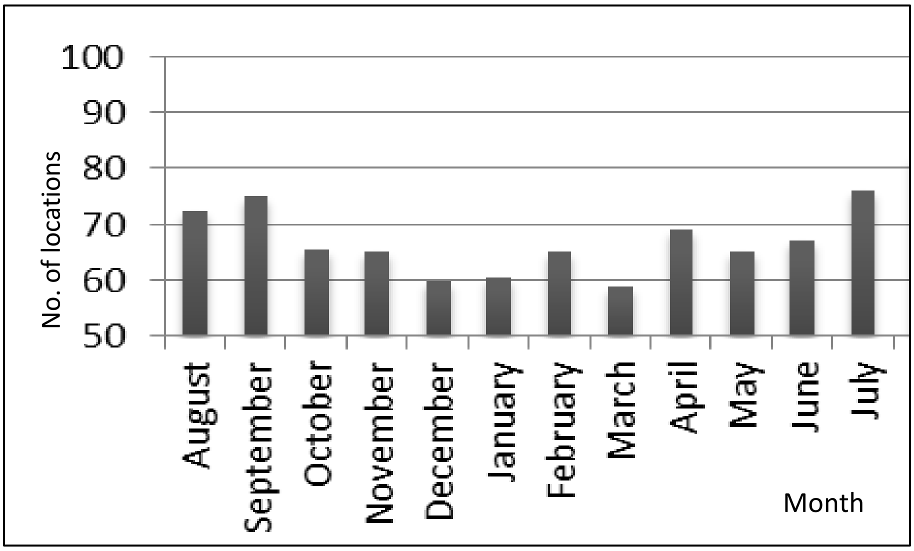


Fig. 3.1. The average number of locations received, divided by months

More locations received from the later transmitters, from Tibetan antelopes ID 41, ID 42, ID 44, the transmitters, established in 2007 sent fewer amounts of locations. **(Fig. 3.2.)**

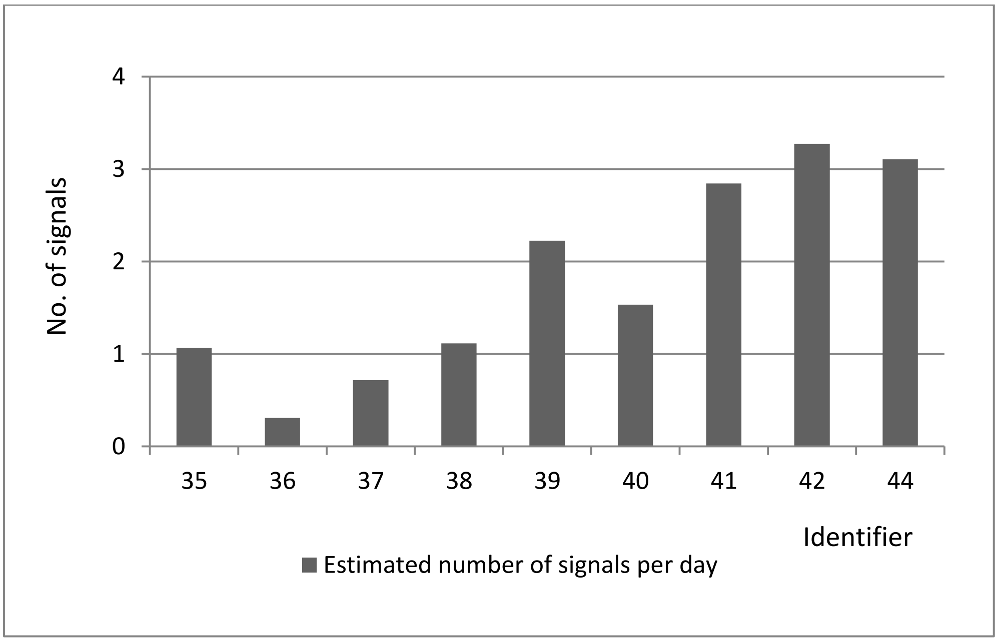


Fig. 3.2. Average number of location points received per day

According to the settings and expected warranty, the percentage of successful work of the collars was 68.14%. Collar ID36 could transmit the signals for 1809 days, 118% of the expected usage, however, the frequency of transmitting the signals was low **(Table 3.2)**.

Table 3.2. Operational life

Identifier	Start date	End date	Days of usage	Expected working days (warranty)	Success %	Mean annual points (success)	Mean annual points (raw)
ID35	28-Aug-08	1-Apr-11	1312	1095	61.83	350	373
ID36	20-Aug-07	2-Aug-12	1809	1095	118.17	140	199
ID37	12-Aug-10	3-Mar-12	688	1095	37.17	123	169
ID40	8-Aug-10	17-Mar-13	928	1095	62.10	356	467
ID42	17-Aug-09	14-Mar-12	940	1095	61.46	769	967
				min	37.17	123	169
				max	118.17	769	991
				aver	68.14	348	435
				SD	29.93	260	322

The maximum average number of locations received in September, the minimum average number of locations received in May (**Appendix B (the number of locations received, divided by months)**).

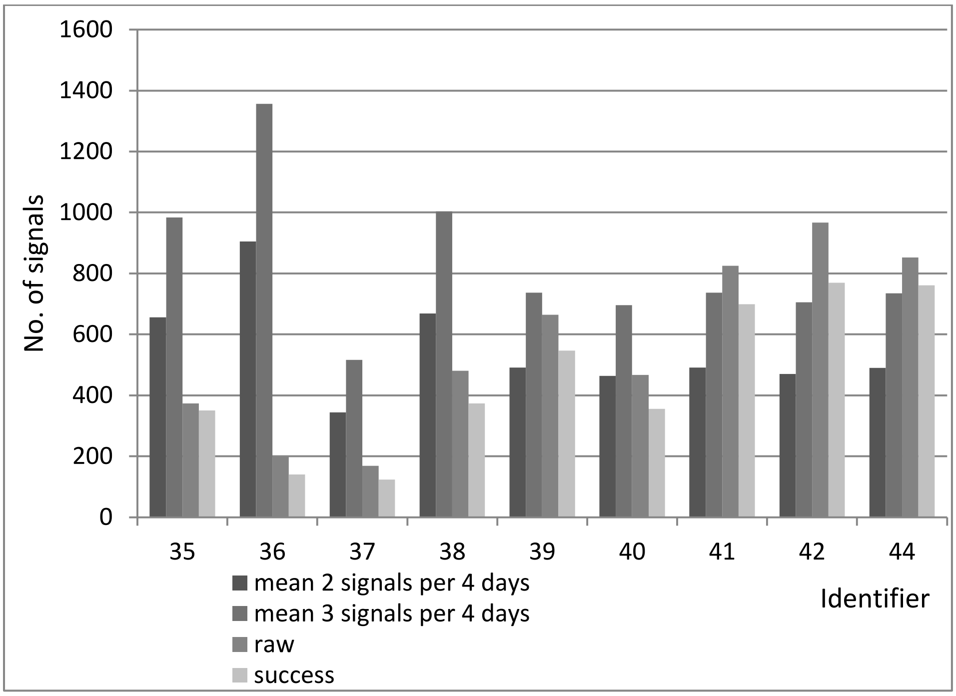


Fig. 3.3. Average amount of signals received per each transmitting session.

Average amount of signals received per each transmitting session (Fig. 3.3) shows that the mean number of signals from the collars ID37 and ID36 were less than 1, from the collars ID35 and ID38 were about 1- 1.5 signals, from the collars ID40 it was 2 signals, from the collars ID39, ID41, ID42, ID 44 were 2.8 -3.3 for raw and 2.4-2.8 for accurate locations **(Fig. 3.3).**

3.3 Argos accuracy

The percentage of succeeded locations was 67.52 in average. The collar ID35 transmitted 93.6% of relatively accurate locations; the less accurate was the collar on the antelope ID37 – 46.1%. The collars ID36 and ID37 performed the less frequent and less accurate data **(Table 3.3).**

The average altitude difference between Argos positional data and DEM satellite image data is 58.626 m, no significant difference between seasons revealed. Argos data shows lower value of altitude **(Table 3.4)**

Table 3.3 Percentage of accurate data.

Identifier	Dates of usage	Number of locations	%
ID35	28/08/2007-1/04/2011	349	93.57
ID36	20/08/2007-02/08-2012	117	58.79
ID37	12/8/2010-3/03/2012	78	46.15
ID38	17/08/2009-17/06/2013	312	62.03
ID39	5/08/2010-17/06/2013	441	60.83
ID40	8/08/2010-17/03/2013	325	69.59
ID41	5/08/2010-17/06/2013	602	68.41
ID42	17/08/2009-14/03.2012	627	64.84
ID44	8/8/2010-17/06/2013	661	72.00
min		169	46.15
max		991	93.57
aver		390	67.52
SD		212	69.35

Table 3.4. Average altitude difference between Argos positional data and DEM satellite image data.

	ID35	ID36	ID37	ID38	ID39	ID40	ID41	ID42	ID44
July-Aug 2012	9.00	61.09	58.24	66.47	56.96	58.02	59.32	59.32	52.48
Average annual	64.75	70.33	70.04	72.16	60.57	57.08	65.17	73.60	52.42

Less accurate and rarer signals were received during the winter and spring seasons **(Fig.3.4).** Location errors were concentrated in the latitudinal direction. Analyzing the number of accurate locations received, divided by the habitation area, the relatively high amount of locations received during the short migration period. The maximum locations from the calving ground were 80, from the collar of ID42 **(Table. 3.5).**

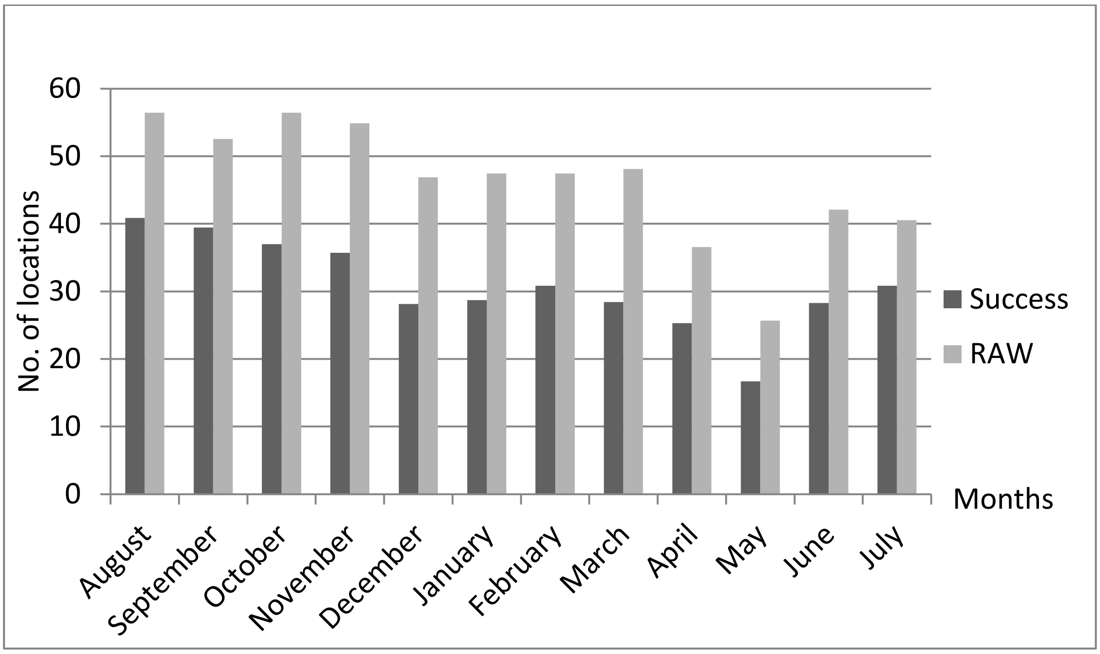


Fig. 3.4. Amount of locations received, divided by months. “Success” columns show the accurate locations.

Table 3.5. Number of accurate locations received per month, divided by the habitation area

Identifier	Dates	Min	Max	Aver	SD	Average			
						annual	wintering	migration	calving
ID35	28/08/2008 -1/04/2011	15	47	29.2	9.3	350	27.6	37.5	27
ID36	20/08/2007 -02/08-2012	7	20	12.1	4.0	140	12.7	7.5	16
ID37	12/8/2010-3/03/2012	1	22	10.2	6.9	123	12.6	1.5	6
ID40	8/08/2010-17/03/2013	17	52	29.7	12.1	356	30.0	27.5	31
ID42	17/08/2009 - 14/03.2012	45	80	64.1	10.1	769	67.6	49.0	63
min				8.4	4.4	123			
max				68.1	10.3	769			
aver						348			
SD						260			

3.4 Influence to animal behavior (socialization, reproduction)

In August 4th 2012 the Tibetan antelope with Argos collar had been noticed during the highway crossing along with the herd, followed by the calves. Therefore, the collars do not alter the normal behavior, reproduction success or a status in herd of the studied females. Through the locations information, it was found through the Argos locations data that it was the antelope ID44 **(Fig.3.5).**

Tibetan antelope ID44 finished its migration on 8th of August in 2010, in 2011 the dates of migration were as follows: from 12th of June till 3rd-7th of August (58 days). In summer 2012 the migration started earlier and lasted 70 days, from 25th-29th of May till 1st-5th of August.

Fig. 3.5. Tibetan highway, near the Wu-Bei underpass. 04/08/2012

3.5 Conclusions

Estimating the Argos system accuracy in high-mountain area revealed the less accurate and rarer signals during the winter season. Location errors were concentrated in the latitudinal direction, 67.52% of locations were succeed. Average altitude difference between Argos positional data and DEM satellite image data is

58.7 m, no significant difference between seasons revealed. Argos data shows lower value of altitude. The maximum length of usage was 1809 days. Mean 3 signals per each session were receiver from later established collars, after 2010, when Argos revised their settings. So far, the Argos PTT system succeeded in usage at the given conditions on the Tibetan antelope females, transmits frequent location signals with high amount of accurate data, could be successfully used for monitoring of the Tibetan antelope, do not alter the normal behavior of the species.

Chapter 4 Environmental characteristics of habitat

This chapter contains the characteristics of the environment such as the altitude, slope, NDVI, calving ground features and the field census materials. The habitat of the Tibetan antelope characterizes of high elevation and therefore the rather harsh conditions. According to the locations received, the wintering areas locate in a valley between 4390 - 4531 m above the sea level. The topography map **(Fig. 4.1)** shows the features of the habitation area of the studied Tibetan antelopes (elevation), the valley of wintering pastures, the migration route, and a position of calving ground.

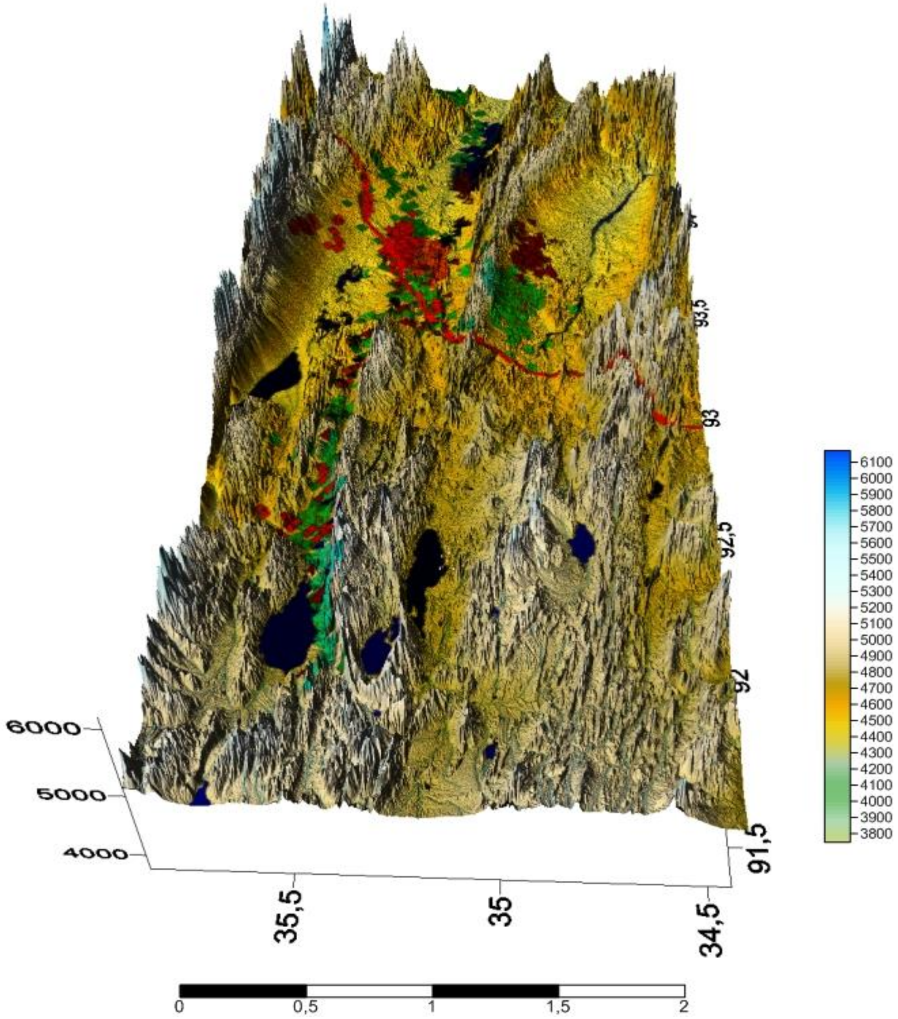


Fig. 4 .1. Topography map of the study area. Main pastures, migration route and the calving ground. Red line shows the highway and the railway (Surfer 11).

The average elevation of the calving ground is 4719 m above the sea level, it locates about 300 m higher than the main, wintering places, and most of the studied Tibetan antelopes preferred the lower elevated area at the autumn season **(Fig. 4.2).** The Tibetan antelope ID36 inhabits at the Southward area, beyond the hills, and had the altitude ranges of the main pastures for about 50m -100m **(Fig. 4.3).**

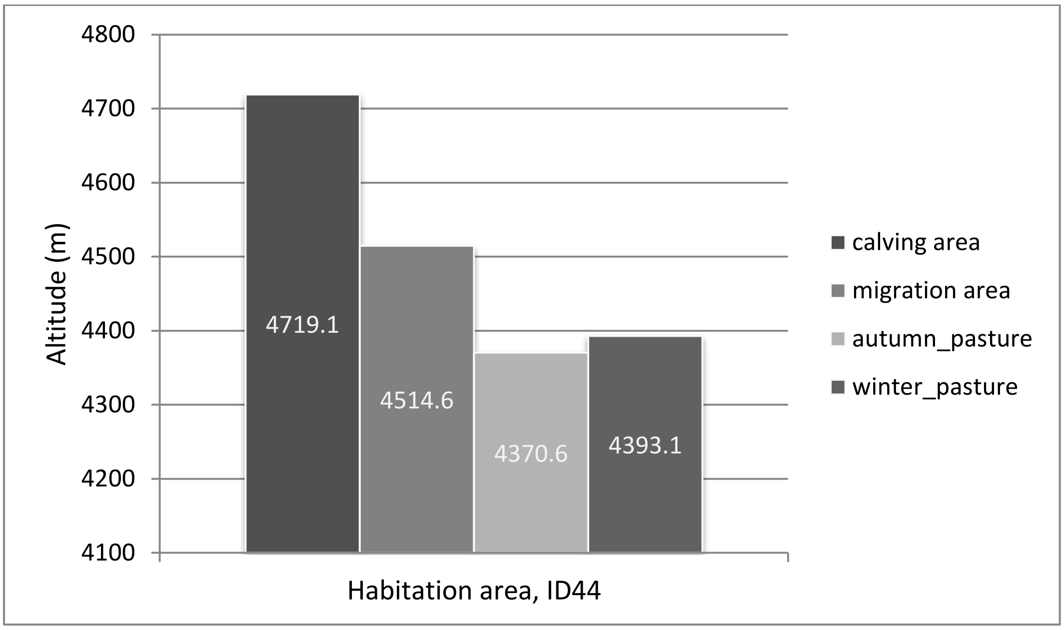


Fig. 4.2. Average elevation of the Tibetan antelopes` habitat.

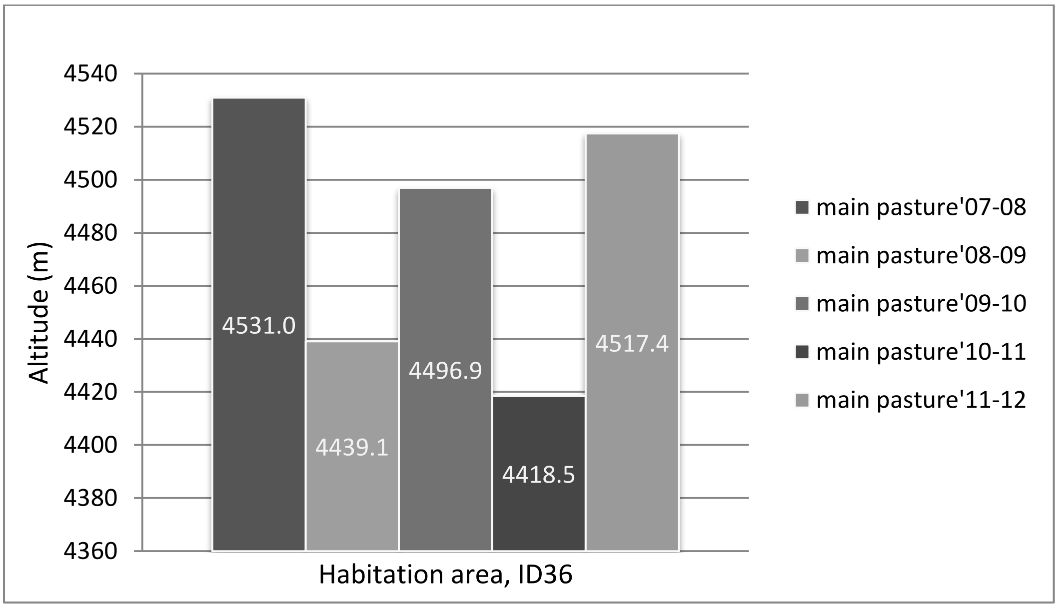


Fig.4.3. Altitude ranges of the Tibetan antelope ID 36 wintering pastures.

The average habitat slope is usually low, antelopes prefer the flat area, however it inhabits at the hillside and locations received from the high slope areas. During the migration period, the average slope was about 17 degrees, the slope at the main pastures and at the calving ground is similar – about 9 degrees **(Fig. 4.4, 4.5).**

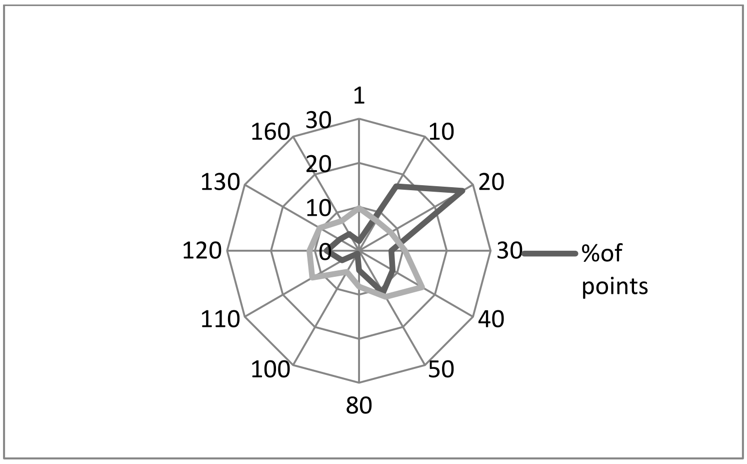


Fig. 4.4. Habitat slope (°).

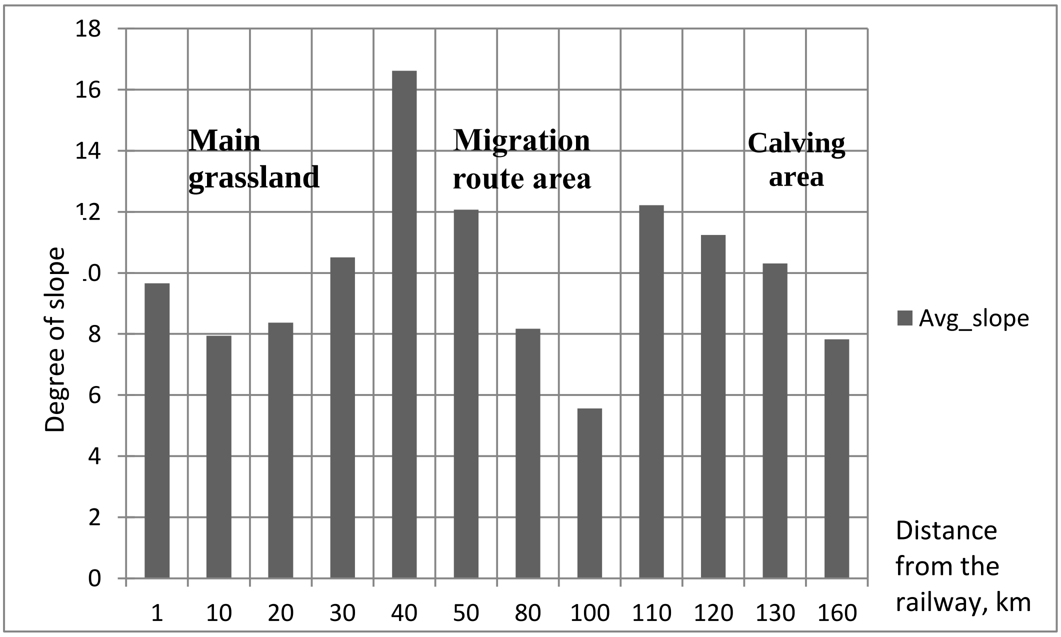


Fig. 4.5. Average slope, divided into 3 areas: calving, migration and the main pasture.

The Normal Difference Vegetation Index (NDVI) of the area showed the accordance between the migration dates (initiation and termination) and chosen route. At the **(Fig.4.6)** it is seen that the NDVI was high by the time the Tibetan antelopes started the migration, by the time females reached the calving ground, the NDVI was still high at the area of calving (higher elevation) but already went down at the main pastures area, and in August when the females return to their main habitat, the NDVI reamains still higher at the migration route.

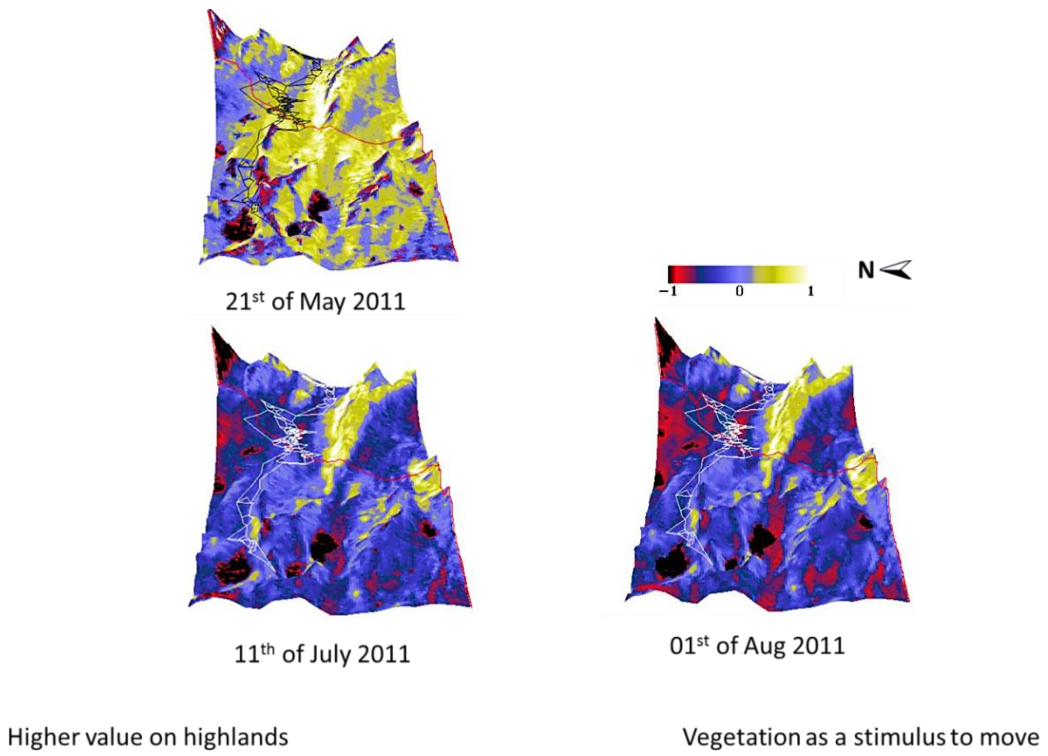


Fig. 4.6. NDVI value of study area during the summer migration. (The home range of the Tibetan antelope ID35).

The average NDVI value during the migration season is the highest; it is higher, compare to the calving season points, calculated at the calving place (**Fig.4.7).**

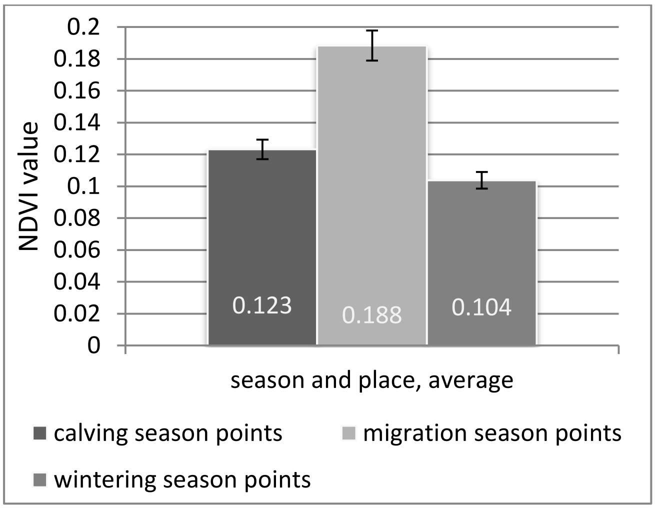


Fig.4.7. Average NDVI in different seasons, according to the locations.

The average annual NDVI at the calving area characterizes of the lower value, the highest annual average index found at the migration route, the value at the main pastures is higher than at the calving ground, which is important in autumn and spring, however, the Tibetan antelope females appear at the calving ground at the peak of its vegetation index. The vegetation index is not on its peak during the Tibetan antelope females migration at the migration route area, however it is relatively high, therefore the migration route pays the important role in Tibetan antelope females and offspring grazing **(Fig. 4.8).**

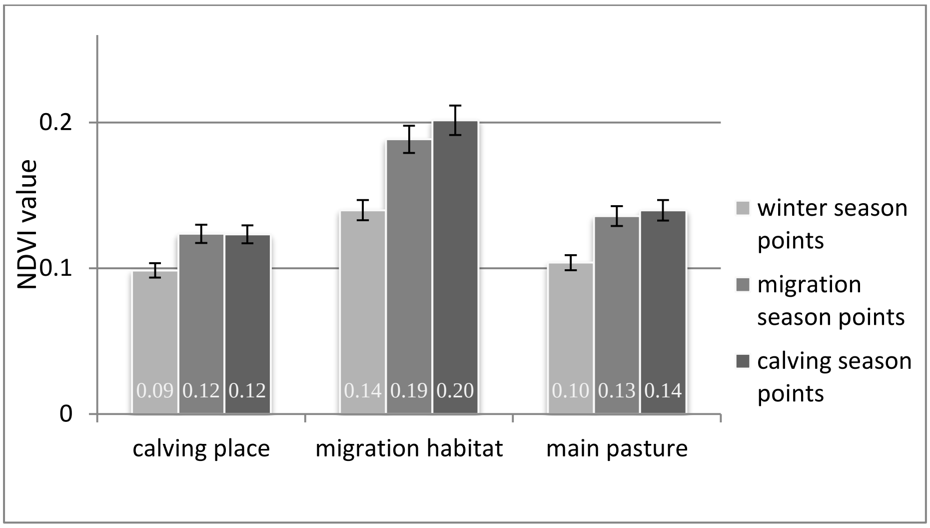


Fig.4.8. Average NDVI in different seasons and places, according to the locations.

4.1 Calving ground

Female Tibetan antelope, migrate seasonally, and follow the specific routes on the Qinghai- Tibet Plateau during the course of a migration. Female antelopes leave their winter ranges with plenty of food resource and travel to relatively barren breeding grounds, such as Huiten Nur Lake in Hoh Xil Nature Reserve and Muztag Feng in Arjin Shan Nature Reserve; and after breeding, they return to their winter ranges. It remains unclear why they migrate to the particular breeding grounds. Although a variety of explanations have been offered, most of them fail to give the sufficient illustration and proof. Here a hypothesis for their migration proposed, taking into consideration of both the snowfall cline and the geological vegetation evolution of its habitat, where snowfall makes the main type of precipitation owing to its high elevation and low temperature. In the hypothesis, the breeding grounds are possible the original habits of Tibetan antelope according to the geological vegetation evolution of Qinghai-Tibet plateau. Because snowfall decreases gradually from southeast to northwest within the Qinghai-Tibet plateau, it`s hypothesized that female Tibetan antelope migrate from winter ranges (in the southeast) to breeding grounds (in the northwest) to avoid relatively high snowfall. It is hypothesized that the climatic conditions in breeding grounds favor survival of newborns (Wu, 2007) **(Fig. 4.9)**.

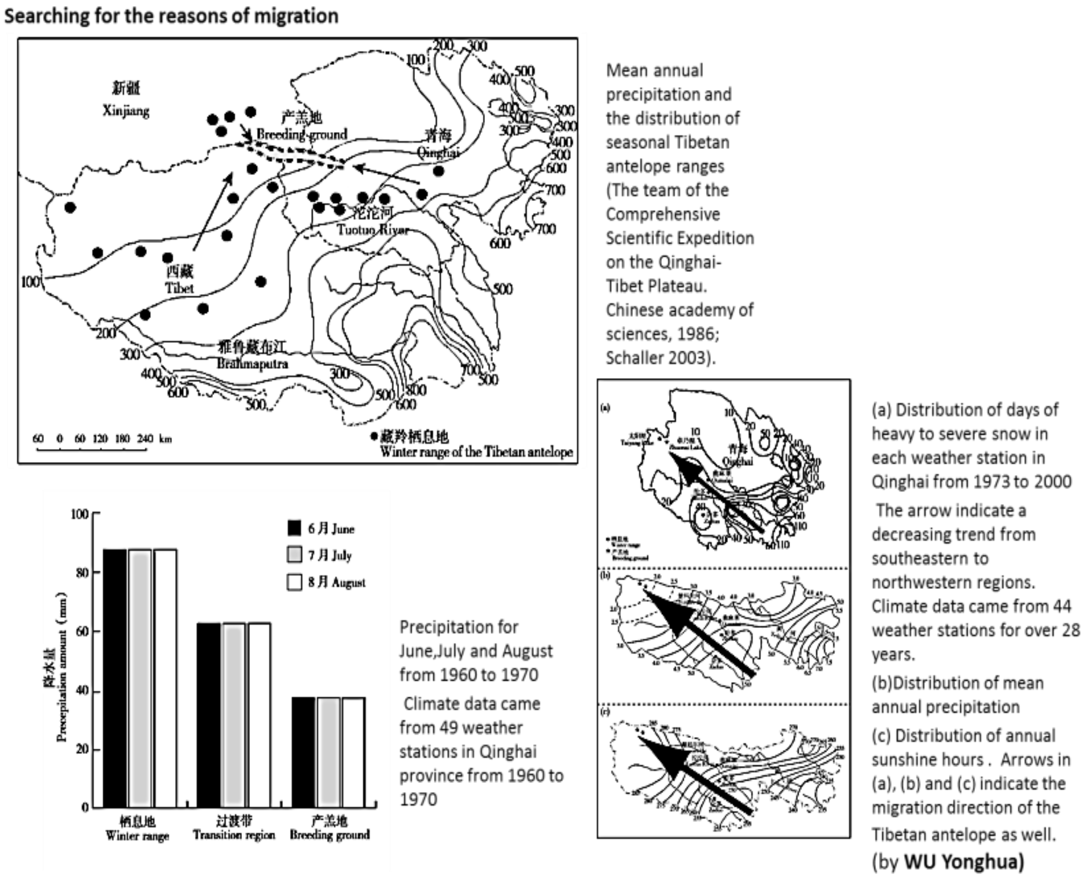


Fig. 4.9. Hypotheses of the Tibetan antelope’s reasons of migration onto particular calving ground (Wu Y.).

In the hypothesis, assumed here, the resources are limited in TP and it is very important to distribute the population evenly when population growth is too fast (newborn). To prevent the shortage of food in very important period of reproduction, males stay on main pastures while females migrate foraging during the way by a narrow migration corridor to the calving place, which is located near the Huiten Nur Lake, the historical calving ground of the Tibetan antelope. This calving migration might promote genetic exchanges between populations and maintain all populations as a metapopulation (Du et. al., 2010). In addition, in arid lands, especially in conditions of Tibetan plateau, water resources availability plays a vital role **(Fig. 4.12)**. During the summer time there are many rivers and stable fresh water resource on Huiten Nur Lake, in winter time the wildlife should find the springs or stay closer to rivers with unfrozen surface. According to the LST (Land Surface Temperature) information of wintering pastures, there is a trend of more locations appear on area with higher LST, which means lower snow depth and location of springs and rivers.

The profile view of the Huiten Nur Lake area and the migration corridor relief **(Fig.4.10, 4.11)** shows the flat area of the calving ground and the preferable route features, antelopes chose the area with lower slope; however the migration corridor is narrow. Several lakes exists at the area around the Tibetan antelope distribution, however several of it are saline **(Fig. 4.12)** and the Huiten Nur Lake is an important freshwater resource. The area has a vantage-ground for the calving, surrounded by hills, flat and wide, on a higher altitude (less precipitation, less severe conditions of the snowfall, more sunshine hours, and less insects) and secure position from the predators from the lakeside.

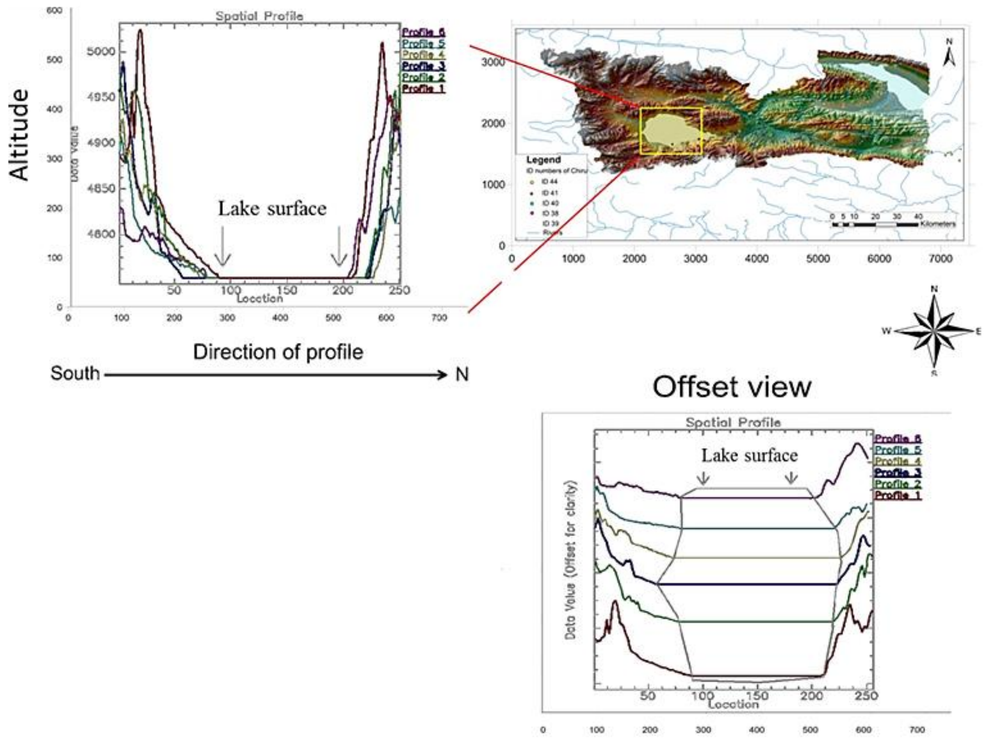


Fig. 4.10. Profile view of the Huiten Nur Lake area relief.

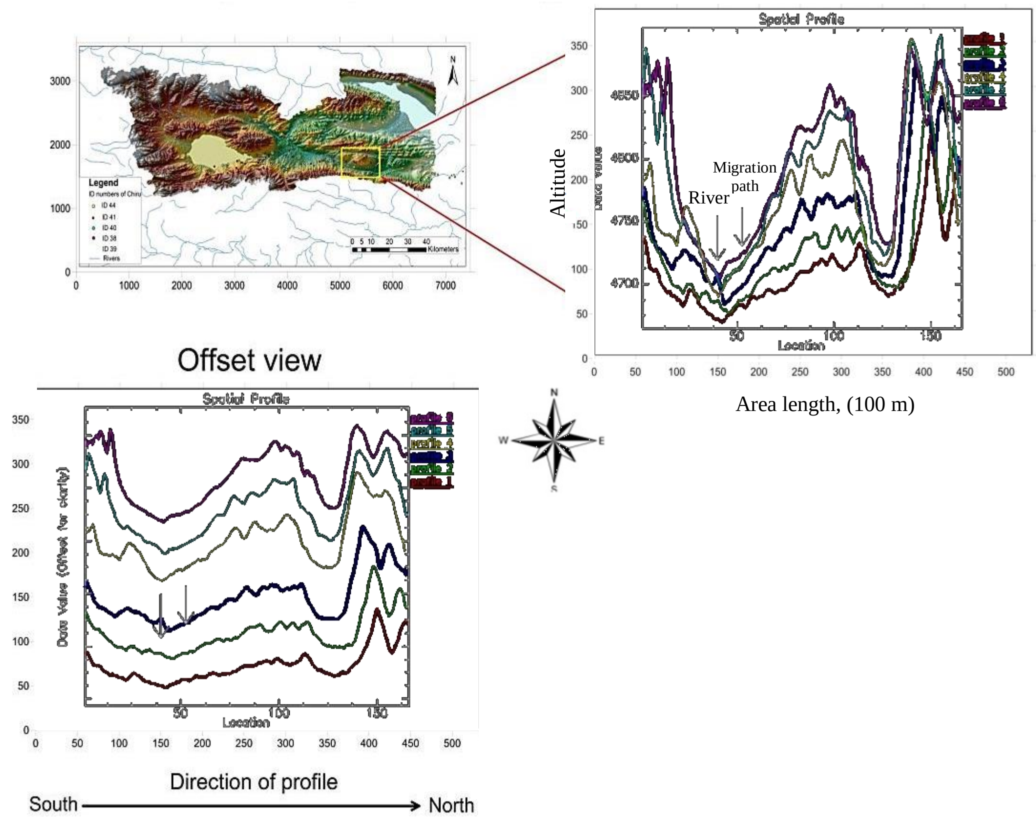


Fig. 4.11. The profile view of the relief of the Tibetan antelope migration corridor.

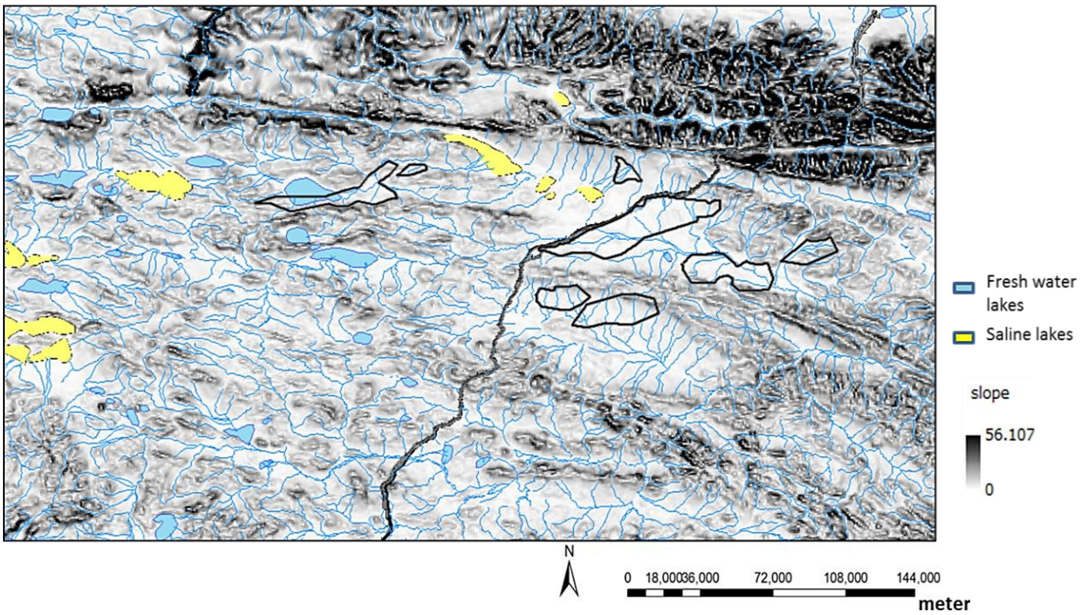


Fig. 4.12. Habitat of the Tibetan antelope. The polygons of the home ranges and the proximity of the freshwater lakes.

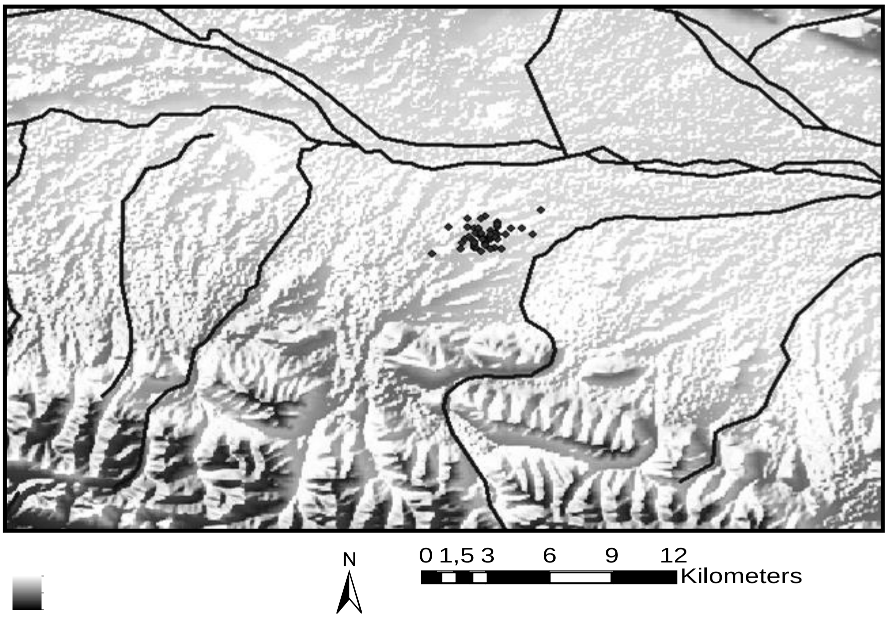


Fig. 4.13. Features of the non-migrating individual habitat, Tibetan antelope ID37.

The features of the non- migrating Tibetan antelopes (ID37 and ID 42) habitat are shown in the **(Fig. 4.13, 4.14).** The Tibetan antelope ID37 habitat located between two river banks, on a distance of 68 km from the railway, the mean NDVI value in that area is 0.22; the average altitude is 4379 m. The Tibetan antelope ID42 habitat also located between the river banks, on a distance of 16 km from the railway, the average NDVI value is 0.26; the average altitude is 4252 m. These positions also show the importance of the proximity of the freshwater bodies.

Table 4.1. Features of the non-migrating individuals' locations.

Identifier	Dates	Number of location points	Average number per month	Min locations received in	Max locations received in
ID37	12/8/2010-3/03/2012	123	10,166	July	October
ID42	17/08/2009-14/03.2012	769	64,083	July	November

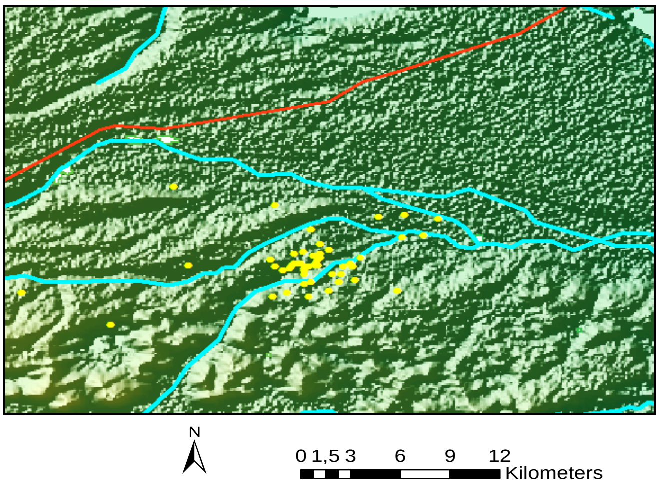


Fig. 4.14. Features of the non-migrating individual habitat, Tibetan antelope ID42.

4.2 Field work

The territory of the study area, is highly loaded by the industrial development, such as electric stations, mineral water plant, coal mining, weather-changing bullets, water reservoirs, military base camps; the trucks transports goods every day, the traffic between lhasa and Golmud is intensive, tourism develops and the tourists spots (temples, sightseeing platforms) being built to attract more people. At the field work in 2012 from 27^{th} of July till 6^{th} of August the rivers had a big flow due to the heavy rains, it influenced on the highway. We experienced traffic jams in that remote area.

In 2011 and 2012 summers, the field survey had been made to monitor the Tibetan antelopes on the time they cross the highway and railway on their route to the calving ground (2011) and from it, back to the wintering pastures (2012). In order to observe the herds of Tibetan antelope females, returning from the breeding ground to the wintering places, 11 days of survey had been made from July 27 to August 6, 2012. At that period of time, females concentrated next to the highway, mainly in front of Wu-Bei underpass in order to cross the highway and then railway and finally return from the long summer migration.

Wildlife census

Contains line transect census along with the herd observation and counting; estimation of the antelope herd structure, visible behavioral issues. During the survey in 2012 we observed a peak and counted the number of Tibetan antelope female herds' concentration, seen near the railway and highway. **(Table 4.2)**

The herds usually spend plenty of time in this section. After crossing the highway, antelopes concentrate again near the underpasses and ran fast through the shadow of the bridge; following the leading female, then continue to move without a rush towards their winter pastures. However, there are bigger underpasses, not so far from Wu-Bei, but Tibetan antelopes rarely use them during the crossing. Reason could be the inconvenience of that track before reaching the underpass, narrow space between the river and the highway in front of that underpass, to collect in a group, rest and graze.

The line census in surroundings of the Wudaoliang settlement showed the peak of the Tibetan antelope population. Tibetan antelope population in August 2nd, it has become 1499 heads; it is about 30% of the total number of Tibetan antelope which observed during the survey **(Table.4.2).**

Table. 4.2. Number of the Tibetan antelopes, observed near the railway from July 27^{th} to August 6^{th}, 2012

	27 Jul	28 Jul	29 Jul	1 Aug	2 Aug	3 Aug	4 Aug	5 Aug	6 Aug	Total period
Total	303	474	146	550	1499	1037	299	323	488	4919
Male	0	7	0	0	2	4	1	3	2	19
Female	276	411	136	49	1123	817	201	238	204	3855
Child	27	56	10	101	374	216	97	82	82	1045

The herds of the Tibetan antelopes, appeared nearby were counted, distinguishing males, females and offspring. The opportunity to observe the males was rather rare (1%), the female/offspring ratio was approximately 78/21%. Only 27% of adult females were with offspring. In addition, when the census was divided into Northern and Southern directions of the observation from the road, 82% of the total observed animals were to the North, the Southern part contained only 18%, there was a big concentration of the animals between the river and the highway, provoking to cause the overgrazing at that area and increase the chance of the female of losing the cub.

Camera-trap

The camera-trap (Garden watch cam, © Brinno Co., Ltd.) was established at the Wu-Bei underpass on the several positions, during the period of August 2^{nd} to August 6^{th} 2012. The camera was set to shoot automatically each 20 seconds interval. **(Appendix D camera trap shoots)**

The number of the picture shoots, its date and time was recorded by the camera trap **(Table.4.3).** In August 2^{nd}, many antelopes had been observed to the North from the highway, and on the next day in August 3rd, many Tibetan antelope pictures have been taken.

Table 4.3. The camera trap recordings from August 1st till 6th, 2012

Setting place	Setting period	Setting period (min)	Number of Chiru photoes	Photo-shooting frequency
Wu-Bei underpass	8/1 17:12-22:35	323	0	0
Wu-Bei underpass	8/2 7:18-22:35	917	28	0.03
Wu-Bei underpass	8/3 7:19-16:10	531	582	1.1
Wu-Bei underpass	8/4 12:19-22:11	592	31	0.05
Wu-Bei underpass	8/5 7:30-13:31	361	0	0
Wu-Bei underpass	8/6 7:31-22:07	876	98	0.11

Vegetation survey

The spectral reflectance of *Carex sagaensis* and *Carex moocroftii* has different characteristics. The Tibetan antelope females prefers *Carex moocroftii* in their diet **(Fig.4.15, 4.16)**

The attitude of soil moisture and plant height at the study plots (**Fig. 4.17)** shows the dependence of the plant height on the soil moisture.

The vegetation parameters of the study area, based on the random sample plots **(Table. 4.4)** are as follows: the average species richness was 5.75 (from 3 to 9 species estimated); the average dry weight of the samples from the 1m X 1m plots was 31.17 g; the average percentage of coverage was 49.75 with the plant height of 22.36 mm and the soil moisture of 13.48.

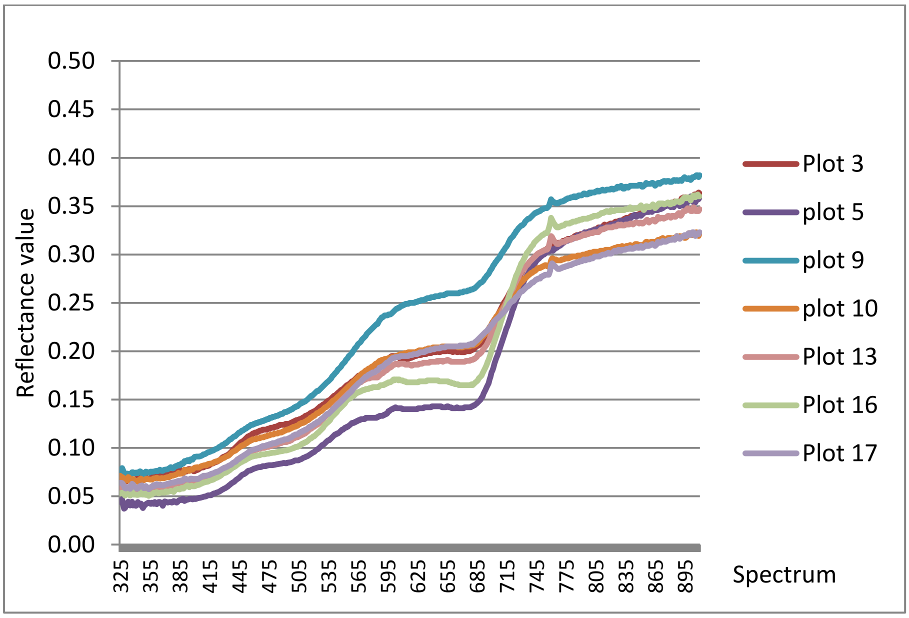
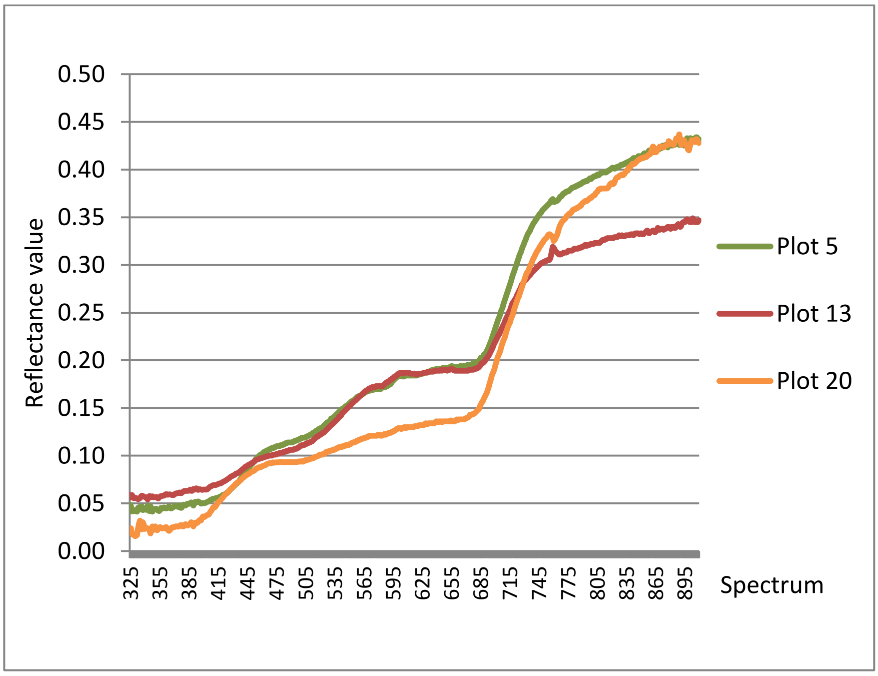


Fig. 4.15. Spectral reflectance of *Carex sagaensis* from different areas.



2

Fig. 4.16. Spectral reflectance of *Carex moocroftii*.

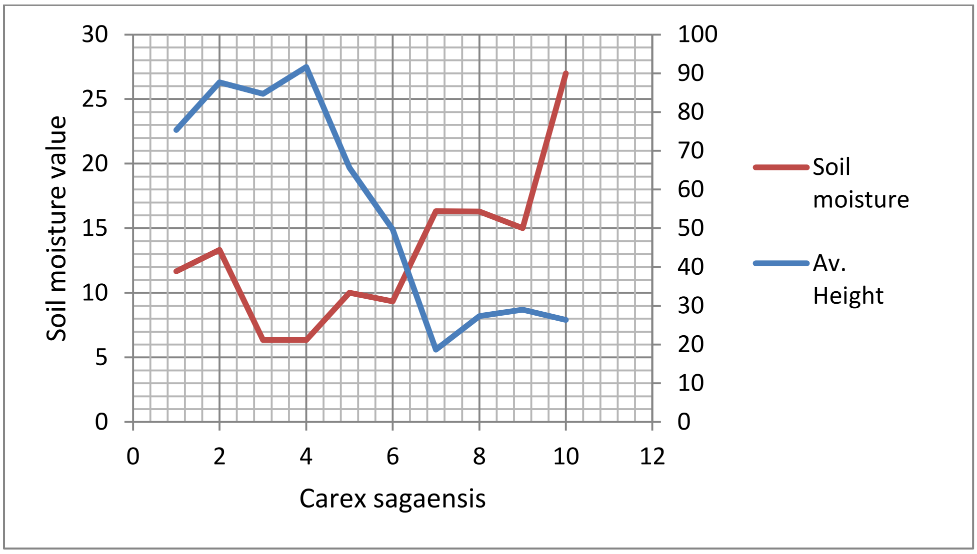


Fig. 4.17. The attitude of soil moisture and plant height at the study plots.

Table 4.4. The vegetation parameters of the study area, based on the random sample plots (June 2011).

Plots	species richness	dry weight, g	coverage %	height mm	soil moisture
1	4	19.68	28	26.1	14.7
2	5	32.80	77	20.1	12.0
3	5	27.16	47	30.0	6.7
4	4	8.07	21	26.7	16.3
5	6	12.48	20	15.9	9.3
6	7	15.27	40	32.0	11.3
7	6	61.10	67	17.2	14.7
8	3	27.66	74	26.5	33.4
9	9	69.29	47	26.7	6.7
10	8	29.20	27	21.3	7.7
11	5		84	11.0	17.7
12	7	40.22	65	14.9	11.3
Average	6	31.17	50	22.4	13.5

Estimation of highway and railway traffic load

The traffic load was counted in the section between Wudaoliang settlement and the Chumaer Bridge, recording the time period of each census (e.g. morning from 7 a.m. till noon, afternoon from 2 p.m. till 5 p.m.).

The traffic load at the area around the Wu-Bei underpass from 22nd till 29th of June 2011 was about 33.14 cars per 30 minutes from 9:30 till 18:00. Time to time many military trunks appeared at the days of the survey.

4.3 Conclusions

Environmental characteristics of habitat showed that the average slope of the migration is 17-22^{0}, with a big range from 3 to 37^{0}, NDVI value appears to be lower in a calving place; the highest value was on the migration route. Chapter 4.1 contains information about the calving ground topography and hypotheses about the reasons of migration to that particular area. The study enlightens the question of the reasons of migration. Since vegetation index is lower in calving place, but the peak of vegetation growth falls on the migration route it tells that grazing during the travel is important. To prevent the shortage of food in very important period of reproduction, males stay on main pastures while females migrate foraging during the way. Water recourses availability plays a vital role, during the summer time there are many rivers and stable fresh water on Huiten Nur Lake, the calving ground; in addition, this area is wide and flat giving an opportunity to observe more, being aware of predators. Chapter 4.2 contains the field work results. During the field survey in 2012 the female/offspring ratio was 78/21%. Only 27% of adult females were with offspring. The peak of the linear barriers crossing held on 2nd of August, when number of migrating animals was accounted for approximately 30% of the total population.

Chapter 5 Features of migration, influence of the linear barriers

5.1 Introduction

Earlier research results showed that the infrastructure construction, including the railway and the highway, probably was the main factors that threaten this species (Qiu and Feng, 2004, Xia et al., 2007). But if there were wildlife underpasses, the antelope soon adjusted their migration routes and crossed the road by using the underpasses (Yang and Xia, 2008).

China National Highway 109 connects Beijing with Lhasa. It runs westwards of Beijing via Datong, Yinchuan and Xining to Golmud before turning southwest to Lhasa. The total distance of the highway is 3 901 km. The section of the highway within western Qinghai and Tibet, from Golmud to Lhasa, is paralleled by the Qinghai-Tibet Railway. "Tasked with carrying upwards of 85 per cent of goods in and out of Tibet, the Qinghai-Tibet highway has been dubbed the "Lifeline of Tibet." Since it was opened to traffic in 1954, the central government has spent nearly 3 billion yuan (US$362 million) on three major overhauls. It was asphalted in 1985."(Gyaco, 2005).

Numerous observations and researches have confirmed the permafrost degradation along the Qinghai–Tibet Highway (Ma et. al., 2004). From 1970 to 1990, the mean annual ground temperature has raised around 0.3–0.5°C in the seasonally frozen ground area and patchy permafrost zone along the Qinghai–Tibet Highway, while in the continuous permafrost regions, the mean annual ground temperature (about at depth of 10–15 m) has risen to about 0.1–0.3 °C. The northern boundary of continuous permafrost migrated into southward for about 0.5–1.0 km and the south boundary into northward 1–2 km, respectively, under natural conditions. In contrast, under the engineering effects, the corresponding values were 5–8 and 9–12 km, respectively. The air temperature increase has a direct effect on the permafrost engineering environment, which will increase the intensity and quantity of frost destroy for the constructed structure. While for the constructing engineering, the unstable cold regions environment will increase the difficulty in selection of design principles and determination of the permafrost stability. The global surface air temperatures were projected to increase by 1.4 to 5.8 °C during 1990 to 2100 (IPCC) while the air temperatures in Qinghai–Tibet plateau would increase to about 2.2–2.6 °C after 50 years according to the reporter of The Environmental Evolvement and Evaluation of West China. The temperature increment in Qinghai–Tibet plateau is greater than that of the average global increment for the global temperature fluctuation. Therefore, to design the railway in the permafrost zone in Qinghai–Tibet plateau faced an austere challenge (Jin et al., 2000; Feng et al., 1998).

The Qinghai–Tibet railway, Qinghai–Xizang railway or Qingzang railway is a high-elevation railway that connects Xining, Qinghai Province, to Lhasa, Tibet Autonomous Region, in the People's Republic of China. The length of the railway is 1 956 km (1 215 mi). Construction of the 815 km (506 mi) section between Xining and Golmud was completed by 1984. The 1 142 km (710 mi) section between Golmud and Lhasa was inaugurated on July 1, 2006 by Chinese President Hu Jintao.

This railway is the first to connect the Tibet Autonomous Region to any other province, which, due to its elevation and terrain, is the last province-level entity in mainland China to have a railway. Testing of the line and equipment started on 1 May 2006**.** (Shanglin, 2006) Passenger trains run from Beijing, Chengdu, Chongqing, Guangzhou, Shanghai, Xining and Lanzhou**.** The line includes the Tanggula Pass, which, at 5 072 m (16 640 feet) above sea level, is the world's highest railway. Tanggula railway station at 5 068 m (16 627 feet) 33°00′18.50″N 91°38′57.70″E is the world's highest railway station. 1 338 m (4 390 feet) Fenghuoshan tunnel is the highest rail tunnel in the world at 4 905 m (16 093 feet) above sea level. The 4 010 m (13 160 feet) Guanjiao tunnel is the longest tunnel and culminating point (3 700 m) between Xining and Golmud and 3 345 m (10 974 feet) Yangbajing tunnel is the longest tunnel between Golmud and Lhasa. More than 960 km (600 mi), over 80% of the Golmud-Lhasa section, is at an elevation of more than 4 000 m (13 123 feet). There are 675 bridges, 159.88 km (99.34 mi) in total, and about 550 km (340 mi) is laid on permafrost. In the Golmud to Lhasa section 45 stations are open, 38 of which are unstaffed, monitored by the control center in Xining. The trains are specially built for high elevation environment. The operational speed is 120 km/h (75 mph), 100 km/h (62 mph) over sections laid on permafrost. The railway from Golmud to Lhasa was completed on October 12, 2005. It opened to regular trial service on July 1, 2006. Since October 2006, five pairs of passenger trains run between Golmud and Lhasa, and one more pair between Xining and Golmud. The line has a capacity of eight pairs of passenger trains. A projected railway to Tibet was included in proposal in

1917–1920 to build 100 000 km (60 000 miles) of track across the entire country**.** Since the formation of the Tibet Autonomous Region in early 1950s, the Chinese government pursued the aim of a railway to Tibet. Engineers were sent to investigate the possibility, but a lack of technology and a shortage of money prevented the project from starting. The 815 km section of the future Qingzang Railway from Xining to Golmud, Qinghai opened to traffic in 1984. But the remaining 1 142 km (710 mi) section from Golmud to Lhasa could not be constructed until technical difficulties of building railroad tracks on permafrost were solved. This section was formally started on 29 June 2001, finished on 12 October 2005, and signaling work and track testing took another eight months. It was completed in five years at a cost of $3.68 billion. The Qingzang Railway project involved more than 20 000 workers and over 6 000 pieces of industrial equipment, and is considered one of China's major accomplishments of the 21st century. The construction of the railway was part of the China Western Development strategy, an attempt to develop the western provinces of China, which are much less developed than eastern China. The railway will be extended to Zhangmu via Shigatse (日喀则) to the west, and Dali via Nyingchi (林芝) to the east. A further extension is planned to link Shigatse with Yadong near the China-India border**.** The railway is considered one of the greatest feats in modern Chinese history by the government, and as a result is often mentioned on regular TV programs. Three lines will originate from Golmud in Qinghai province and run to Chengdu in Sichuan province, Dunhuang in Gansu province, and Korla of the Xinjiang Uygur Autonomous Region. The sixth will link

Xining, capital of Qinghai, with Zhangye in Gansu. The six lines are expected to be in operation before 2020. Construction work of the Lhasa–Shigatse extension began on September 26, 2010. In October 2012, the beginning of the construction of a 506-km Golmud-Dunhuang railway line was announced. This single-track electrified rail line will run from Dunhuang (in Gansu Province) to the Yinmaxia station on the Qinghai–Tibet Railway north of Golmud. The project is expected to take 5 years. Since Dunhuang, located in the westernmost part of Gansu, is connected to the Lanxin Railway, the Golmud-Dunhuang link will allow a fairly direct connection between Tibet and Xinjiang. In a meeting between Chinese and Nepalese officials on 25 April 2008, the Chinese delegation announced the intention to extend the Qingzang railway to Zhangmu (Nepali: Khasa) on the Nepalese border. Nepal had requested that the railway be extended to enable trade and tourism between the two nations**.** Although the Chinese Ministry of Railways spokesman of the Qinghai–Tibet Railway has announced extending the railway southward to Shigatse, it has not confirmed a further extension to India, Bangladesh and other railway networks, but the land bridge concept from time to time rumors in various newspapers. The Qinghai–Tibet Railway will be connecting close to India. An official in charge of the Tibet Autonomous Region Development and Reform Commission had pointed out: "Tibet Railway is completed, with Lhasa as the basis, will be built east of Lhasa to Nyingchi line from Lhasa to Shigatse west building line of the south building of the Qinghai-Tibet Shigatse to East Asia and other three Railway Line. These extensions will be opened to traffic within a decade. Then, the three railway extension will form a large Y-shape, the length will be over two thousand kilometers". Although the Chinese government never planned an extension to India, many people have embarked on the possibility of this. Qinghai People's Congress, Vice Secretary General is one of them. In an interview, "21st Century Business Herald", he supported a motion to establish a connection between the Pacific and Indian railway bridge on land, possibly linking the east coast port city of Lianyungang, eastern China, Xi'an, Lanzhou, Xining, Lhasa, Shigatse, through Nepal, and finally arriving in Patna, India, New Delhi, Mumbai and Karachi (Pakistan), China and India and Pakistan to achieve rail transport. Liu Palit thinks has stated regarding the Qinghai-Tibet Plateau in South Asia continental bridge, "The past is not the Qinghai-Tibet Railway, which route is the only choice, now, starting from Tibet, a land bridge politically more meaningful". If the idea of the railway arrived in Nepal's plains region of Nepal, it is very easily connected with the Indian railway network. Experts said that "if the railway opened in Nepal, but also enable the railway system in India and Bangladesh, Nepal and China through connectivity, all countries will benefit**."** There are many technical difficulties for such a railway. About half of the second section was built on barely permanent permafrost. In the summer, the uppermost layer thaws, and the ground becomes muddy. The heat from the trains passing above is able to melt the permafrost even with a small change in temperature. The main engineering challenge, aside from oxygen shortages, is the weakness of the permafrost. Many of the engineering challenges therefore deal with the maintenance of the permafrost. For areas of permafrost that are not very fragile, an embankment of large rocks is sufficient. Meanwhile in the most fragile areas, the rail bed must be elevated like a bridge. Chinese engineers dealt with this problem in the areas of weakest permafrost by building elevated tracks with pile driven foundations sunk deep into the ground. Similar to the Trans-Alaska Pipeline System portions of the track are also passively cooled with ammonia based heat exchangers. Despite the government's best efforts, the integrity and strength of the railroad is not fully secure. Due to Climate change, temperatures in the Tibetan Plateau will increase by an estimated two to three degrees Celsius. This small change, although minute, is sufficient to melt the permafrost and thereby affect the integrity of the entire system. The effects of climate change have yet to be seen. With limited industrial capacity in Tibet, the Tibetan economy heavily relies on industrial products from more developed parts of China. Transport of goods in and out of Tibet was mostly through the Qingzang Highway connecting Tibet to the adjacent Qinghai province. The length and terrain have limited the capacity of the highway, with less than 1 million tons of goods transported each year. With the construction of the Qingzang railway, the cost of transportation of both passengers and goods greatly reduced, allowing for an increase in volume. It is projected that the amount of transferred goods will increase. In 2010, 2.8 million tons carried to and from Tibet, with over 75% carried by the railway. This is expected to help support the Tibetan economy. The environmental impact of the new railway is an ongoing concern. The increase in passenger traffic will result in greater tourism and economic activity on the Tibetan Plateau. Wood is the main fuel source for rural inhabitants in certain regions of Tibet.

The damage to the ecosystem caused by cutting trees for fuel takes years to recover due to slow growth caused by Tibet's harsh environmental conditions. The railway would make coal, which is not produced in Tibet, an affordable replacement. However, the increase in fuel combustion due to increased human activity in an already-thin atmosphere may affect the long term health of the local population. China has been criticized by Tibetan Independence groups for having built the railway to strengthen its political control over Tibet. In particular, groups such as the International Campaign for Tibet have alleged that the railway will marginalize Tibetans in the Tibet Autonomous Region by encouraging further Han migration from the rest of China. The Qinghai–Tibet Railway stretches over 632 km in the permafrost zone, of which about 275 km goes through warm permafrost zone, 221 km across permafrost zone of high ice content and 134 km across warm permafrost zone with high ice content. So, the dominant design principle of Qinghai–Tibet Railway is to protect permafrost from thawing. There exists the deformation discrepancy on different slope orientations of embankment. As for the temperature field diversity between the shadowy slope and the sunny side slopes along the Qinghai–Tibet Railway, there is different settlement on the each side of the shoulder at the same time. The observations show that the settlement happened on the shoulder of the sunny slope is greater than that of the shadowy slope, and the vast majority of diversity settlement is not more than 2 cm. There are concerns from the China Meteorological Administration that melting, due to global warming, of the permafrost in Tibet on which part of the railway is placed could threaten the railway within this century. The effects of this railway on wild animals such as Tibetan antelope and plants are currently unknown. Thirty-three wildlife crossing railway bridges were constructed specifically to allow continued animal migration.

5.2 Migration patterns

The satellite tracking of the migrating Tibetan antelopes was successful, showed the exact locations of summer (calving), intermediate and winter pastures; temporal distribution patterns; association of summer habitat selection with conditions of pastures and so on. Analysis of distances, durations and other specifics of migration of Tibetan antelopes were made.

The analysis of data obtained, showed that 7 of the 9 observed females migrated in the similar way to each other, following a latitudinal gradient **(Figs. 5.1 and 4.1**) and shared the same area for calving **(Fig. 5.2)**. Two individuals did not migrate **(Fig. 4.13, 4.14).** Two of the 7 migrating individuals, (ID36 and ID38), used the southward habitation area. When the migration began, they crossed a hill through a valley (altitude 4700 m) **(Figs. 5.1)** before joining the main migration corridor **(Fig. 6.4 a).**

The features of migration dates and the position of the calving ground from the main pastures are shown in the **(Table 5.1 and Fig. 5.1).** The main habitation areas were commonly used for 8-9 months from mid-August to mid-May. The average period of migration is 83±5 days with 24±3 days spent on the calving ground, 22±4 days on the migration route to the calving place and 31±8 days on the migration route from the calving place, including 12±10 days spent near the highway, delaying migration and looking for a proper time and place to cross it **(Table 5.1).** All antelopes crossed under particular bridges in a specific way, according to the highway traffic load, river banks circulations, number of Tibetan antelope groups (lines), especially after the calving season during the migration. It appears that the timing of the giving birth is very important. The migration started on the beginning of June in 2008 and 2009, in late-May in 2010, approximately in the middle of May in 2011 and in early-May in 2012. The terminations of migration were in the end of August in 2008 and 2009, in the middle of August in 2010 and in the beginning of August in 2011 and 2012. Hence, the period of migration shifted to the earlier dates from 2010 for about 2.5 weeks **(Table 5.1).** ID44 began migration at 4^{th} -8^{th} of June in 2011. This individual (and ID36) spent more time on main pastures, in comparison with others, in spite of relatively long distance from calving place, and the average speed of migration was lower but the antelope returned from calving to core area in a short period **(Table 5.2).** Other individuals used more time for returning and average speeds were lower - in a case of delaying on intermediate areas of a migration route. Tibetan antelopes ID38 and ID39 spent more time in a calving ground. All animals investigated had lower averages of moving speeds on the way back to main pastures, when young followed the females. On the way back from the calving ground the Tibetan antelope with collar ID35 spent from 21 to 35 days in 2008 moving along the highway upward before crossing it. ID36 also had a delay in migration for around 13 days in 2008 before crossing the highway and railway and reaching the wintering area. All migrating Tibetan antelopes delayed their migration for 5-12 days, staying near the highway. ID41 started migration from calving ground on July 14th in 2011 and appeared near the highway on July 22nd (93.84 km), stayed there until July 30th (8 days) and reached the main pasture on August 3rd; on the next year, in 2012, this antelope initiated migration earlier, on about May 17th (comparing with approximate May 31st in 2011) and refused to come back to its main area of habitat, stayed near the calving ground for wintering. The Tibetan antelope ID40 moved to NNE from the calving ground on July 3rd 2011 and stayed on alternative pasture for 20 days, from July 10th until the July 30th, 2011. On August 3rd it appeared near the highway and reached the main, wintering pasture on August 11th.

The detailed relief and the proximity of rivers of the narrow area of migration route near the calving ground at the Huiten Nur Lake was shown on the calving ground map **(Fig. 5.2).** Also, the layout of core areas and calving area location of all monitored Tibetan antelopes are seen on the topographic model **(Fig 5.1),** and the hull of migration route of ID44 which almost corresponds to other samples, represents the model of corridor of migration route, made by the LoCoH home range method **(Fig.6.4a).**

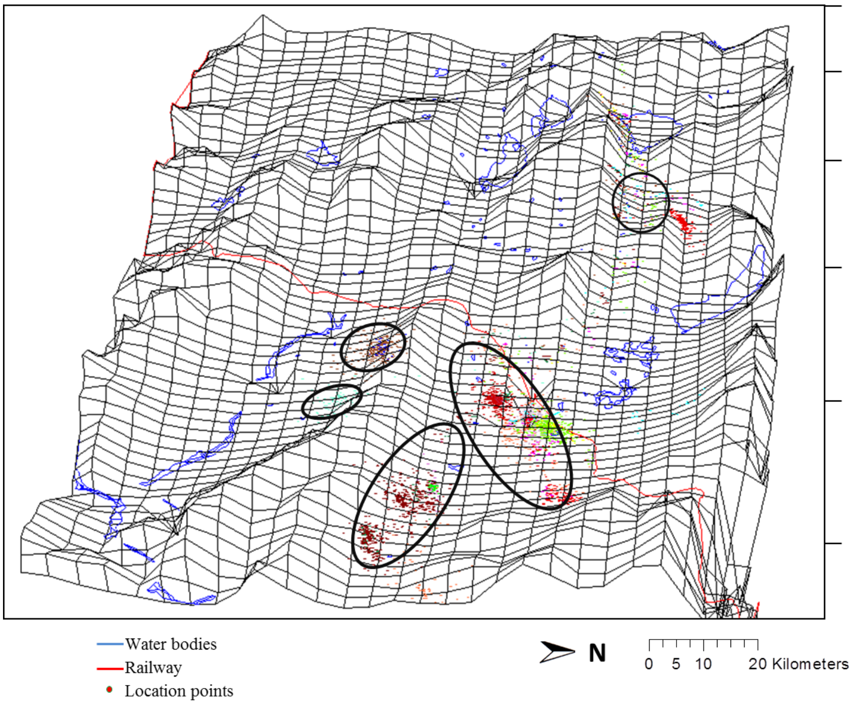


Fig. 5.1. Positions of wintering places of 9 tracked Tibetan antelopes and locations during the migrations and calving (PTTs locations, Aster DEM, by ENVI).

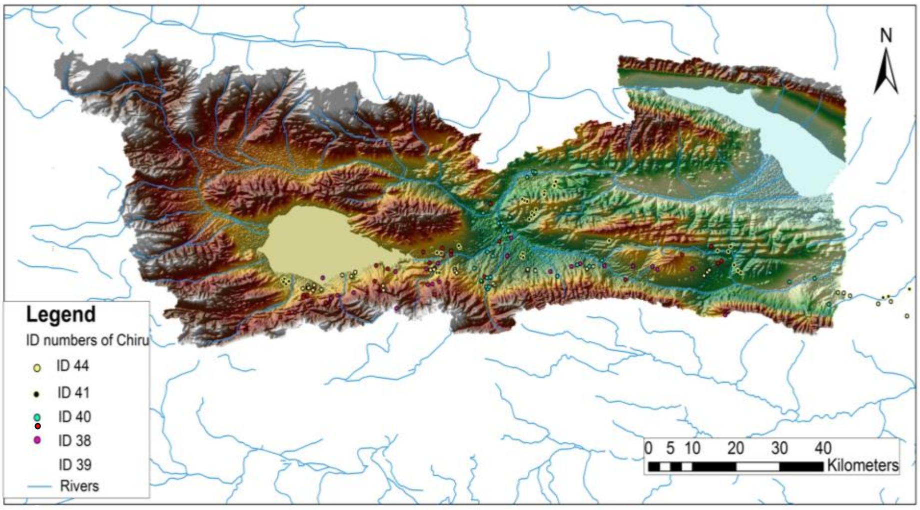


Fig. 5.2. Migration routes and the calving ground with locations of studied Tibetan antelopes at the Huiten Nur Lake, Hoh Xil Nature reserve, Qinghai, China. The details of slope, aspect and shaded relief from the satellite based on the digital topographic model.

Table 5.1. Length of stay on main pastures and migration periods (days) of studied Tibetan antelopes.

Identifier	Year	Main Pasture	Way to calving ground	Calving ground	Way from calving ground	Stop near the highway	Period of migration
ID35	2008	205	32	8	44	30	84
	2009	276	28	20	40	12	88
	2010	276	24	17	24	12	68
	2011	232	-	-	-	-	-
ID36	2008	272	16	20	32	13	72
	2009	280	12	31	32	9	80
	2010	256	-	-	-	-	-
	2011	254	-	-	-	-	-
ID38	2010	254	16	28	40	10	88
	2011	266	12	28	23	-	68
	2012	268	28	28	24	-	88
	2013	244	-	-	-	-	-
ID39	2011	258	10	40	20	7	72
	2012	272	36	32	16	10	88
	2013	240	-	-	-	-	-
ID40	2011	274	-	32	39	-	72
	2012	-	NE pasture	20	-	-	-
	2013	-			no migration from 2012		-
ID41	2011	274	12	28	50	9	64
	2012	288	24	308		stayed on calving ground	
ID44	2011	288	20	16	24	5	64
	2012	284	32	12	24	-	80
	2013	246	-	-	-	-	-
Average		262	22	24	31	12	83

Table 5.2. Enumeration of Tibetan antelope migration parameters.

Identifier	Distance of main pasture (km)		Average speed (per day, km)	
	from calving ground	from railway	to the calving ground	from the calving ground
ID75836	172±3	37.2±1.3	7±1.0	4.9±1
ID75837	not migrating	35.0±1.0	-	
ID75838	116±1	12.5±2.0	6.3±0.8	4±1.
ID75839	113±1	0.3±0.2	6.5±1.2	4±1
ID75840	109±1	-	6±2.0	11±6
	124±2	11.4±0.5		
ID75841	139±2	8.7±0.5	8.5±1.5	6.4±2
	151±2	2.8±0.3		
ID75842	not migrating	1.0±0.2	1.3±0.6	
ID75844	227±2	4.5±1.0 57.8±1.4	5±1.0	5.2±1

Distant tracking and on-site field observations showed that the migrating Tibetan antelope mostly used a relatively small (200 meters in size) underpass Wu-Bei (N35° 15'; E93° 09'; altitude 4597 m) and also an underpass at the river Chumaer (a total of 33 under and overpasses are exists along the railroad) (Hoshino et al., 2011). The frequency of the underpasses usage of the studied individuals is shown in (**Table 5.3**). The Tibetan antelopes which uses Wu-Bei underpass reveal the longer delay in their movement back to the main pasture. The dates of migration differs because of the big amount of animals collected nearby the underpasses, the herds has to cross in turn. The order of the linear barriers area crossing contains several stages (**Appendix C):** a) arranging in groups to cross the river, b) choosing the area for rest and collect all members (e.g. calves) before crossing the highway, it depends on the amount of herds in the area, c) crossing the highway, d) arranging the groups and grazing before crossing the railway, e) crossing under the railway.

Table 5.3. The frequency of the underpasses usage.

	Frequency of usage (times)	ID numbers of animal, used
Wu-Bei	11±4	ID35, ID36, ID38, ID41, ID44
Chumaer river bridge	6	ID35, ID38, ID39, ID44
Chumaer river bridge, long (2.55 km)	6	ID35, ID38, ID39, ID44

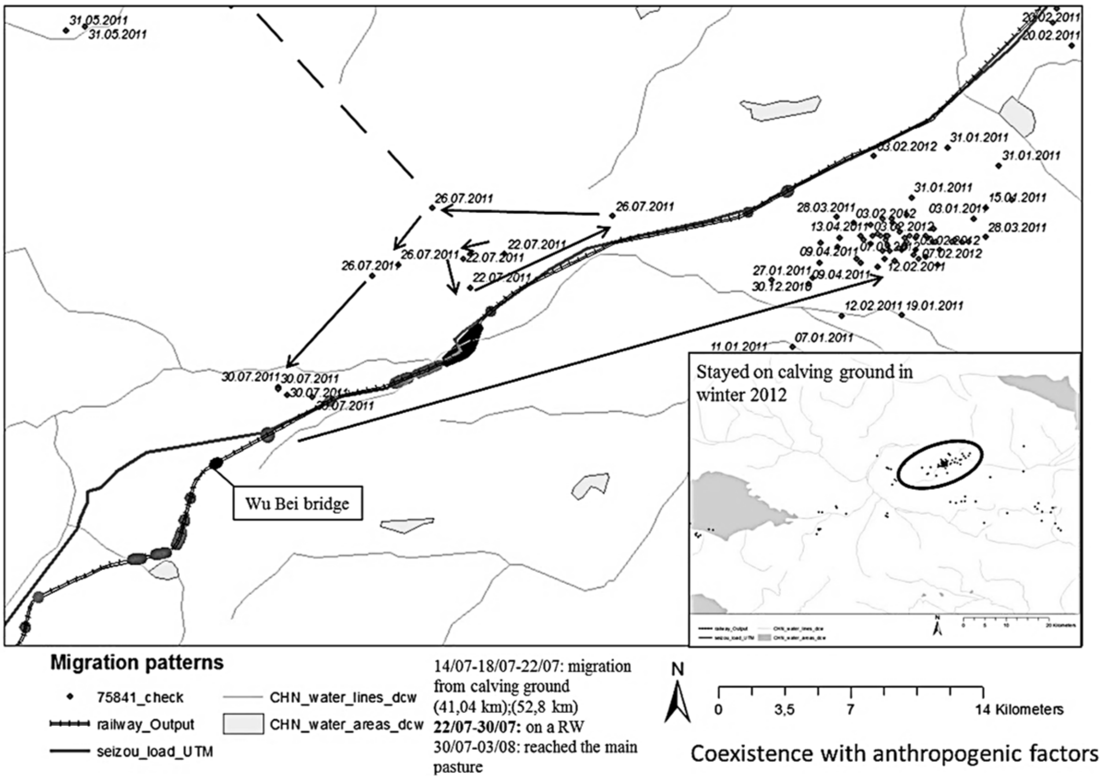


Fig. 5.3. The migration patterns of the Tibetan antelope ID41, delays in migration.

The evidences of the highway and the railway influences are clearly shown in the dates of migration, its shifts and delays near the railway and the highway **(Fig. 5.3, 5.4).** The Tibetan antelope ID41, had a one week delay in migration in 2011, locating next to the railway, the Tibetan antelope ID35, had from 25 to 31 days delay in migration in 2008.

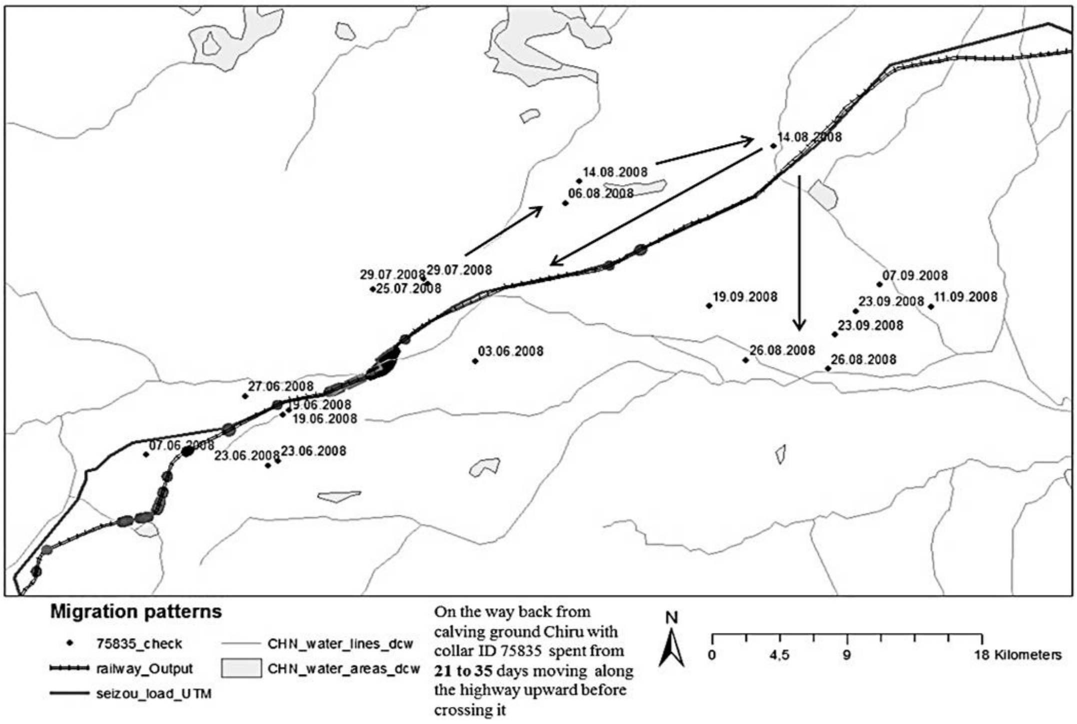


Fig. 5.4. The migration patterns of the Tibetan antelope ID35, delays in migration.

The spatial and temporal features of ID40 and ID41 individuals' parameters are shown in **(Fig. 5.5).** The Tibetan antelope ID 40 went to the alternative pasture after the calving ground and before crossing the artificial barriers, delaying the migration for 1 month; on the next year this antelope stayed at the wintering ground without initiating the migration. The Tibetan antelope ID 41 had delay in migration before the artificial barriers for 8±6 days in 2011 and in 2010 stayed at the calving ground for wintering.

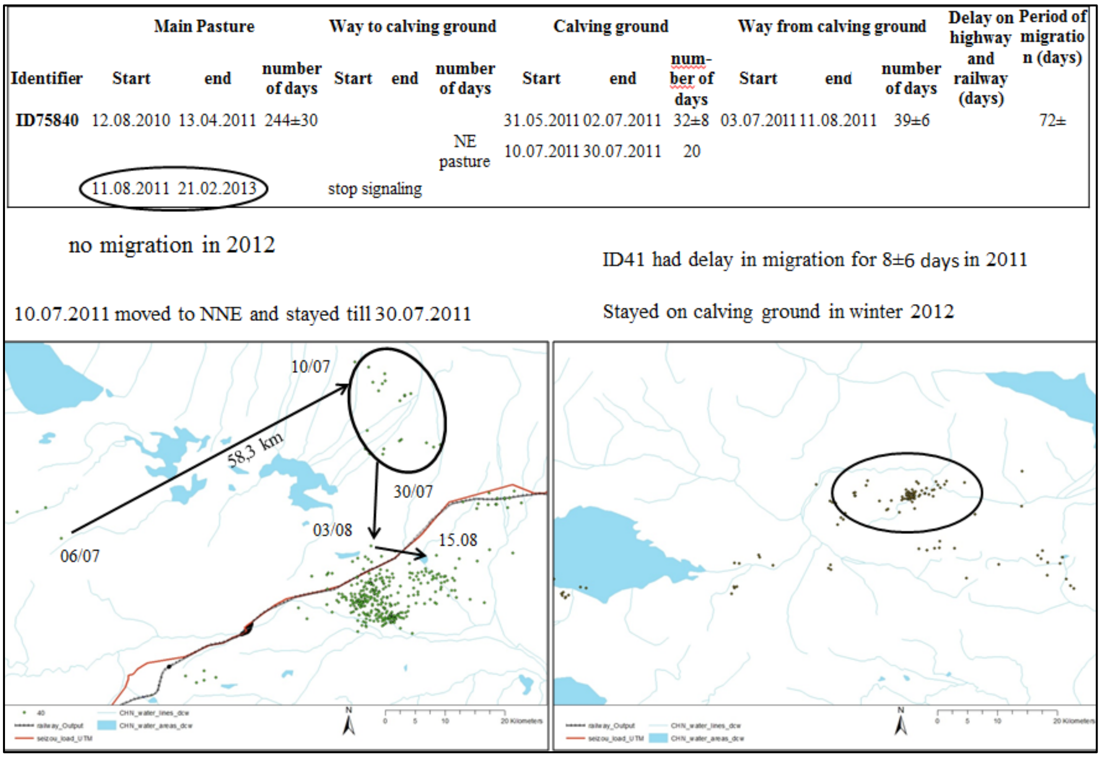


Fig. 5.5. The spatial and temporal features of the individual parameters.

5.3 Discussion

Numerous factors could be stimuli for the beginning of migration, such as the changes of day length, precipitation, pregnancy term or physiological mechanism of motherhood. Until now, there were no significant data to support the hypotheses of the stimulus for the beginning of migration. The reasons of migration includes the dependence on surface characteristics, climate conditions, stable fresh water resource, escape from predators, protection of newborns, probable seasonal changes in diet etc. “Nutritious way” could play an important role (the high vegetation value on the migration route, when females are on gestation and lactation).

The dates of migration were shifted to earlier dates from 2010 for about 2 weeks. The Tibetan antelope spent more time on the way back from calving, compared to the way forward. The necessity of the accession to the mutual migration route, as well as the similar timing of migration was shown. The long-term monitoring of the Tibetan antelope's movement is clearly depicts the unique nature of the "Huiten Nur" calving ground and the migration corridor.

Indirect division into classes leads to the separate analysis of the migrating and non-migrating, (ID37 and ID42), individuals. Individuals, which came from different valleys and had to cross the hill (ID36 and ID38), showed the importance of one mutual migration corridor, as well as similar timing of migration to the mutual calving ground. The direction of migration corresponds to the common topography. Females move to the calving ground towards the valley. The number of calving grounds are limited, (Ginsberg et. al., 1999); therefore, Tibetan antelopes inhabiting in the neighboring valleys had to cross the natural barriers, such as hills and rivers to form large herds and migrated in groups by the same migration route to the calving area. The calving ground location continues to be stable while wintering places changes easily. Understanding of details of female Tibetan antelopes` migration into particular sites on definite time to high altitude severe area and the sizes and positions of home ranges, the behavioral features and preferences has an important implication in Tibetan antelope general biology and conservation.

The migration discontinuance may be caused by barrenness of females, health conditions and so on. We estimate evidence of negative influences of the highway and the railway constructions in interaction on female and offspring seasonal migration for breeding, such as migration of 1 individual during 2 years of observation and its stay near the calving ground in winter 2012-2013 and long stops near the highway and the railway. The railway and highway in combination has an effect on delays of the migration (up to 23±8 days), causing stress and becoming a serious obstacle for migrating females. Animals stay next to the linear barriers before crossing it, and the dates of migration had been shifted to earlier dates. However, the degree of that influence remains unclear; according to the available information it could be concluded that the adaptation is satisfied, and even though animals tolerate the inconveniences and has to adjust and shift, being under the continuous stress.

Tibetan antelopes spent more time on the way back from the calving ground. Females with calves concentrate next to the highway, form herds of several thousands (observed during the field survey). Such bunching and later fragmented crossing of the obstacles by small groups may cause the reshuffle of primary families in parcels and companions, and change in hierarchy of herds, which constitute mainly by kinship. Further survey of Tibetan antelope herds' hierarchy is required for estimation of its influence on reproduction, grazing, movement and so on. In addition, the larger sizes of herds cause the less pronounced behavioral aspects of formation and dynamics of herds' units. Due to exposure of anthropogenic factors complex on the Tibetan antelope and its habitat, the spatial arrangement of population (ways, terms and intensity of migration, areas of wintering and calving) is changed and fragmented. It leads to intrapopulational and interpopulational ties violations, food competition growth and to irrational usage of forage recourses (overgrazing in some places and underutilization in another). All these must be considered in the development of measures to preserve the population of such stenobiontic and endemic species as the Tibetan antelope.

The increase of highway and railway traffic complicates its intersection and normal course of ungulates migration. Naturally to expect, that traffic volume will increase significantly in future. To prevent the migration delays and the concentration of big-sized herds and mixing of herds, it is necessary to provide the faster and safer crossing of artificial barriers. Therefore, the construction of special transitions for migrating wildlife, which will ease the transportation ways crossings, should be provided. The optimum construction of such transition for cautious and timid ungulates of open spaces (flatlands and plateaus) might be the laying of road sections in shallow underground tunnel, slightly recessed metro-like, in wildlife migration routes intersections. Wherein the ground surface of transport tunnel occurrence will look like untransformed. The construction has to be considered with the relative locations of frequently used by Tibetan antelope passes under the railway. To estimate a definite frequently used railway underpasses, for advising the location and structures of the crossing construction, further survey is required.

The population is under the threat from habitat loss and gaps in ecological knowledge. A better understanding of the drivers of Tibetan antelope migration at multiple scales is a key step towards addressing these threats. As far as the region economic development increases (including tourism), it requires strong conservation strategy of species and arrangement of its less stressful migration way. The preservation of Tibetan antelope habitat, including migration routes, by minimizing of anthropogenic influences, has a significant role for survival of this endemic species.

Chapter 6 Home ranges of the Tibetan antelopes

6.1 Introduction

Parametric kernel methods currently dominate the literature regarding the construction of animal home ranges (HRs) and utilization distributions (UDs). These methods frequently fail to capture the kinds of hard boundaries common to many natural systems. Recently a local convex hull (LoCoH) nonparametric kernel method, which generalizes the minimum convex polygon (MCP) method, was shown to be more appropriate than parametric kernel methods for constructing HRs and UDs, because of its ability to identify hard boundaries (e.g., rivers, cliff edges) and convergence to the true distribution as sample size increases. (Getz et al., 2007)

Comparative study on African buffalo in the Kruger National Park, South Africa demonstrates that LoCoH methods are superior to parametric kernel methods in estimating areas used by animals, excluding unused areas (holes) and, generally, in constructing UDs and HRs arising from the movement of animals influenced by hard boundaries and irregular structures (e.g., rocky outcrops). It also been demonstrated that "adaptive sphere-of-influence," or a-LoCoH (kernels constructed from all points within a radius a such that the distances of all points within the radius to the reference point sum to a value less than or equal to a) is generally superior to the original "fixed-number-of-points," or k-LoCoH (all kernels constructed from k-1 nearest neighbors of root points) and "fixed sphere-of-influence," or r-LoCoH (kernels constructed from all points within a fixed radius r of each reference point).

Home-range analysis has evolved from early attempts to identify an area via minimum convex polygons (Blair, 1940; Odum and Kuenzler, 1955) to methods that describe the animal's home range as a utilization distribution: a multi-dimensional relative frequency distribution of animal locations (Jennrich and Turner, 1969; Van Winkle, 1975; Worton, 1989; Getz and Wilmers, 2004; Keating and Cherry, 2009). Since the publication of Worton's (1989) seminal paper, density estimation techniques such as kernel smoothing have become the method of choice for quantifying utilization distributions (Kernohan et al., 2001; Laver and Kelly, 2008). As elaborated in more detail in Getz and Wilmers (2004), the k-LoCoH method begins by constructing the convex hull associated with each point (the root) and its k-1 nearest neighbors. The union of all these hulls is finite and can be used to represent the home range of the associated individual. To obtain a UD, the hulls are ordered from the smallest to the largest, where the smallest hulls are indicative of frequently used areas. By progressively taking the union of these from the smallest upwards, until x% of points are included (with some rounding error), the boundaries of the resulting union represents the x% isopleth of the densest set of points in the UD. Depending on convention the HR can be defined as the area bounded by the 100% isopleth of the UD or, for purposes of comparison, the 95% isopleth which is the one most commonly used for UDs constructed from more traditional, particularly noncompact, kernels such as the symmetric bivariate Gaussian excluding individuals.

In summary, LoCoH methods are superior to bounded and, especially, unbounded parametric kernel methods for constructing UDs and HRs because they directly draw upon the actual spatial structure of data that may well be influenced by hard boundaries and irregular exclusionary areas in the environment.

The aim of this Chapter is to clarify the home ranges of the Tibetan antelope using the satellite tracking data derived from Argos transmitter collars. High-resolution presence data were combined with environmental factors to create the models of species occurrence, which will be extrapolated to a projection area. To estimate the parameters of home ranges, the linear minimum convex polygons method had been used in previous study and represented the approximate habitation area of two individuals, distinguishing the main wintering place, migration route and a calving area from each other; in this study the method of estimation of the home ranges improved and the analysis was made on all investigated antelopes.

6.2 The LoCoH Hull home range models

The actual sizes and locations of main habitation home ranges, migration and calving areas of each individual had been calculated **(Figs. 6.2 and 6.4).** According to the home range model, the annual habitation area, including migration and calving ground of all 9 monitored antelopes varies from 2024 to 4111 km^2, with an average of 2652 km^2. Therefore, the annual habitation areas vary in 2 times. The area will vary from 2024 to 2908 km^2 with an average of 2409 km^2 if to exclude the habitation area of the Tibetan antelope ID35, which changed its main pastures **(Fig. 6.2B).**

The wintering place was located in a valley, with an elevation about 4500±100 m **(Fig. 6.1).** The calving place was highly elevated, it rises further for about 400 m and locates near the Huiten Nur Lake, on a flat area and it is surrounded by hills. The migration corridor lied on a rising valley with average slopes of 15-20 degrees and had a narrow area between the hills, closer to the calving ground.

The average home range of wintering places **(Fig. 6.2A)** was 441 km^2, with minimal of 246.39 and maximal of 644.07 km^2, the area of ID35 had been excluded because it consists of two core areas and has a size of 1939.32 km^2. The isopleths area of the home range of ID35, seen on the graph **(Fig. 6.2A)** has higher value of two different core areas used. In addition, the areas of ID37 and ID42 were excluded, due to that the both animals did not migrate and the areas are smaller than the other's migrating ones: 46.65 and 138.01 km^2. The most intensively used areas, showed on maps by more intensive grey colors (**Fig. 6.4**), characterizes of its locations appearing near the riverbanks in valley on elevation 4300- 4600 m. The isopleths of value from 10 to 50 represents the most intensive used area and could be named as a core area, it has a small diameter; the isopleths of value from 60 to 100 shows less intensively used area. Percentages of value 50, 70, 80 isopleths from the value 100 isopleths of wintering areas are shown in **(Table 6.1).**

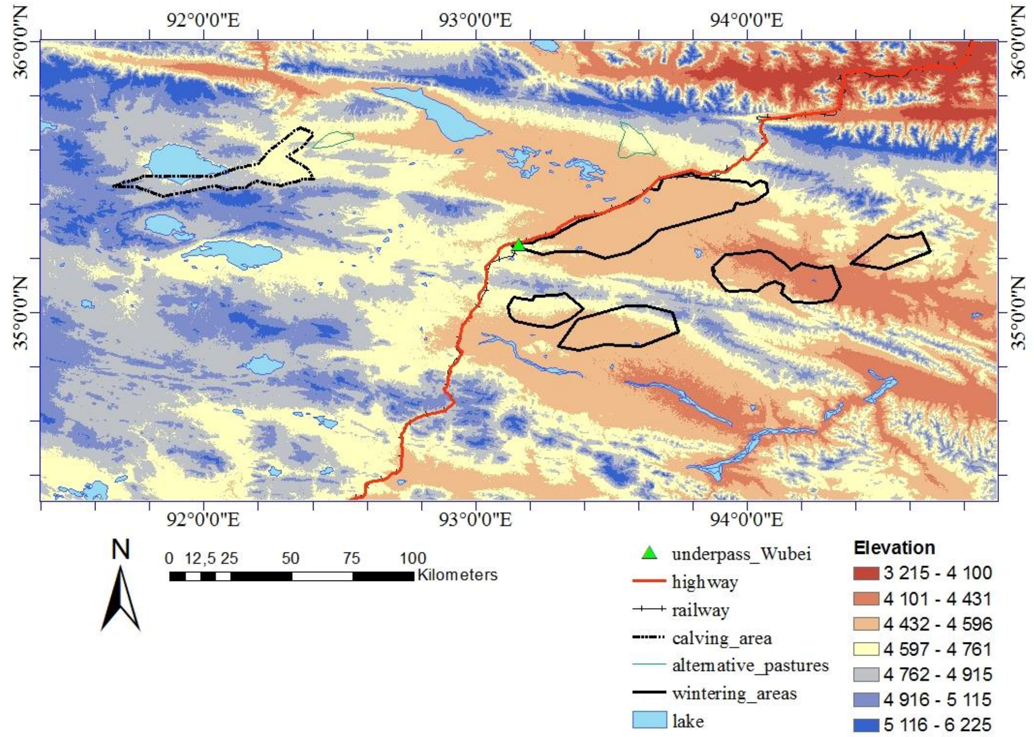


Fig. 6.1. Home range polygons and range of the calving ground.

The percentages of wintering HRs isopleths from the annual ones and the sizes of isopleths are shown in (**Table 6.2**). Wintering HR isopleths are from 21.97 to 55% in average from annual HR (which includes calving ground and migration route) with more percentages of low value (10-50) isopleths.

The HR locations could be divided into 3 groups **(Fig. 6.1)** – the first locates near the highway and railway, second locates in the valley 35-40 km eastward from the railway, and the third is beyond the hill, in another valley. Also some individuals changed their main habitation areas within the wintering, 9-month period and in different years. Other classification could be made by migration, dividing on migrating and non-migrating individuals. Therefore, the caught samples appear to be representational and illustrate the different types of HRs.

The antelope ID37, which didn't migrate, shared almost the same area with ID44 in winter, which located in a distance of 35-40 km eastward from the railway **(Fig. 6.4i)**; the core area of the second non-migrating, ID42, is near the railway, 1.2 km from Wu-Bei underpass, on the southern part of main pastures of ID35 (in 2008 and 2011), ID39, ID40, ID41 **(Figs. 6.4c-f and 6.4i).** ID44 used two areas for pasture: one used in autumn and spring, which located more far (to the East) and one - in winter time, and the distance between two pastures is around 12 km **(Fig. 6.4g).** ID41 also used a different habitation area for autumn and spring, of which altitude is higher than on winter pasture. This area was located northeastward from place used in winter, the distance between two places is 25 km, and also, ID41 spent some time between two zones in late autumn and early spring. Antelope ID41 stayed near the calving ground on winter 2012-2013 and have not come back to the previous wintering pasture area **(Fig. 6.4f).** The core area of ID35 located near the highway in winter 2007-2008 and 2010-2011; in winter seasons 2008-2009 and 2009-2010 antelope changed its core area and inhabits more far to the East, the distance between two different areas is around 62 km **(Fig. 6.4c).** Table 3 shows the distances of wintering HRs from the railway and the highway. Hence, 1:3 of samples changes its wintering pastures, irregularly, could adjacent to different groups. The reasons of ID35, ID41 and ID44 instability could be the changes in environment and adaptation, especially to the railway construction and surrounding area dynamics.

The shapes of home ranges are commonly round or oval, with most frequently used areas in the middle, tend to southward. Except the home ranges of ID35 and ID41, that changed their core areas in different years; its HRs has S-shape. In addition, the HR of ID44 is divided on 2 core areas, because this representative changed the main pasture within the seasons (autumn-spring and winter).

The HRs located near the artificial barriers – railway and a highway had the parallelepiped shape, which clearly shows the dependence of the distribution on the limiting barriers **(Fig.6.1).** Also, the valley, surrounded by hills and the close locations of rivers to the most frequently used areas are seen on the LoCoH HR maps **(Fig. 6.4).** The individuals, located at the other valley, beyond the hill could use that valley for their migration. However, the accession to the primary migration route is necessary in case of the sharing the one mutual calving ground. (The local people questionnaire data tells, that previously Tibetan antelopes inhabited in another, southern valley, followed another route and united to the main migration stream farther, to the northwest. However, the railway construction changed their route, making them getting together before crossing the railway-highway in more convenient place (e.g. Wu-Bei underpath).)

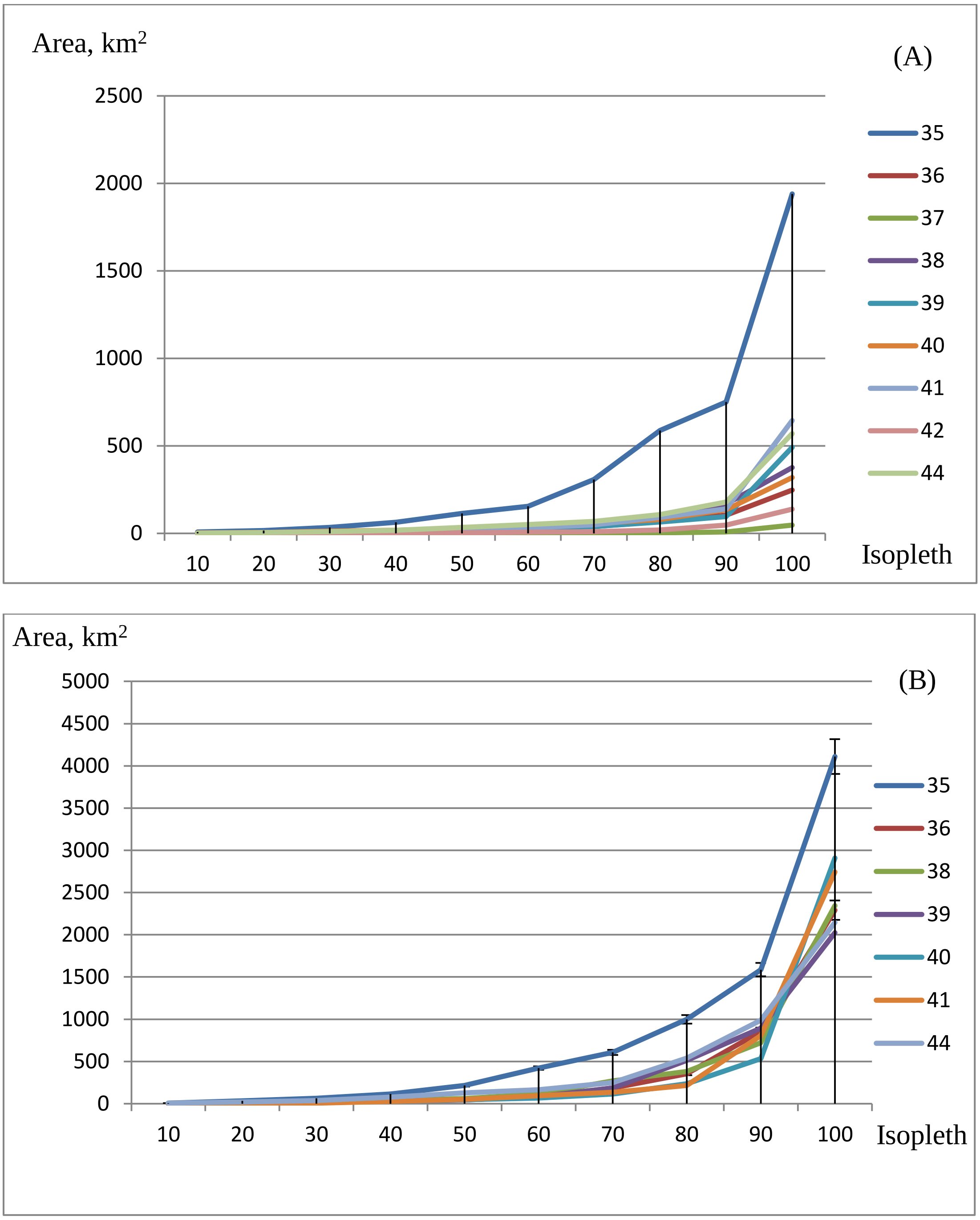


Fig. 6.2. Areas of wintering HRs (A) and annual HRs (B) isopleths of studied Tibetan antelopes (Hull LoCoH).

Table 6.1. Percentages of frequently used area isopleths of wintering area home ranges (Hull LoCoH).

Isopleth	ID35	ID36	ID37	ID38	ID39	ID40	ID41	ID42	ID44	Average	Average -ID35	Average - ID 35,37,42
50	5.83	10.26	0.41	6.92	4.35	8.46	2.32	2.19	5.81	5.53	5.33	5.58
70	15.81	15.55	81.24	17.23	7.87	17.15	7.56	6.62	12.00	13.98	12.73	11.84
80	30.33	27.62	4.54	27.52	13.07	24.91	14.02	13.48	18.85	23.51	18.84	19.37

Table 6.2. Percentages of isopleths of wintering home ranges from annual home ranges (Hull LoCoH).

Isopleth	ID35	ID36	ID38	ID39	ID40	ID41	ID44	Average
10	100.00	-	57.36	31.92	94.26	24.40	22.06	55.00
20	48.24	35.11	56.16	40.40	61.12	35.20	22.63	42.69
30	53.09	43.47	58.68	49.67	60.84	47.84	25.82	48.49
40	56.02	45.72	33.73	44.57	72.26	31.76	22.44	43.78
50	52.72	52.30	43.31	49.16	58.83	28.94	26.16	44.49
60	36.53	48.59	40.76	35.76	59.21	32.91	30.50	40.61
70	50.40	20.77	24.01	21.00	48.17	35.80	27.52	32.52
80	58.88	19.19	27.08	12.52	33.51	42.02	19.89	30.44
90	47.32	12.11	23.02	10.73	25.31	17.27	18.01	21.97
100	47.17	10.75	16.03	24.30	10.94	23.47	26.58	22.75

At the home range of the Tibetan antelope ID35 **(Fig.6.3),** the area of the migration route closer to the highway and the railway is wider due to the distribution behavior during the crossing- barrier process. This estimates as another evidence of the highway and railway constructions influences.

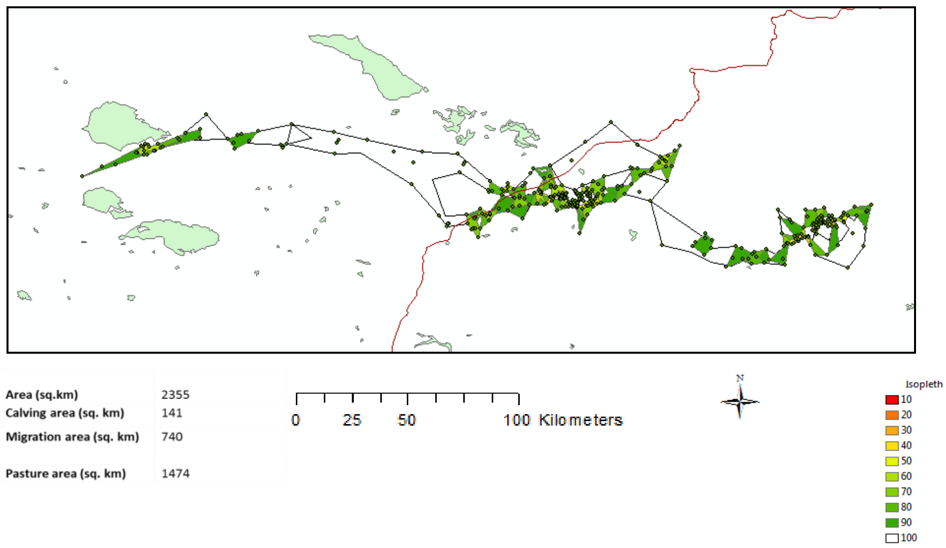
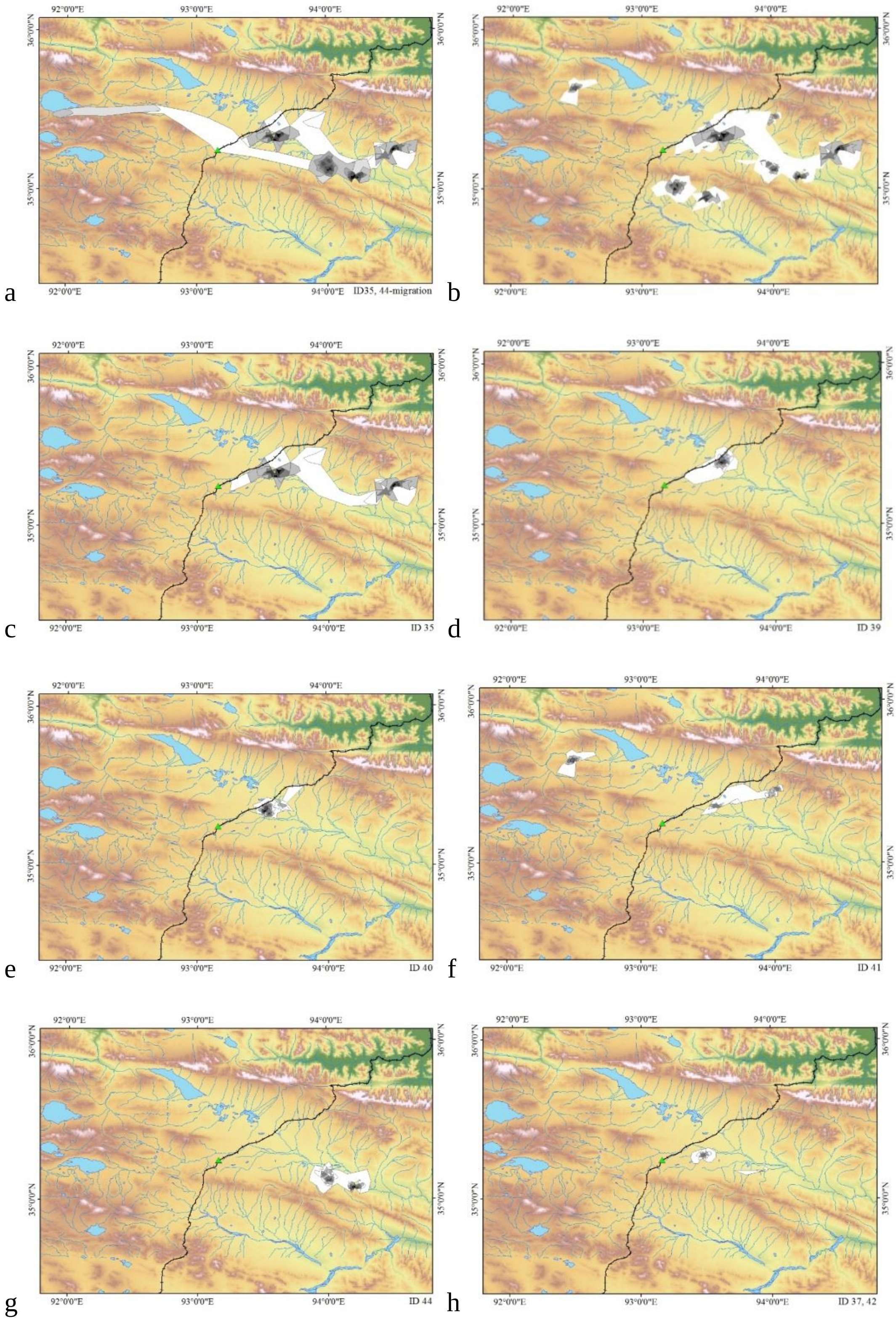


Fig. 6.3.LoCoH Hull home range of the Tibetan antelope ID35.


a
b
c
d
e
f
g
h
92°0'0"E
93°0'0"E
94°0'0"E
36°0'0"N
35°0'0"N
ID35, 44-migration
ID 35
ID 39
ID 40
ID 41
ID 44
ID 37, 42

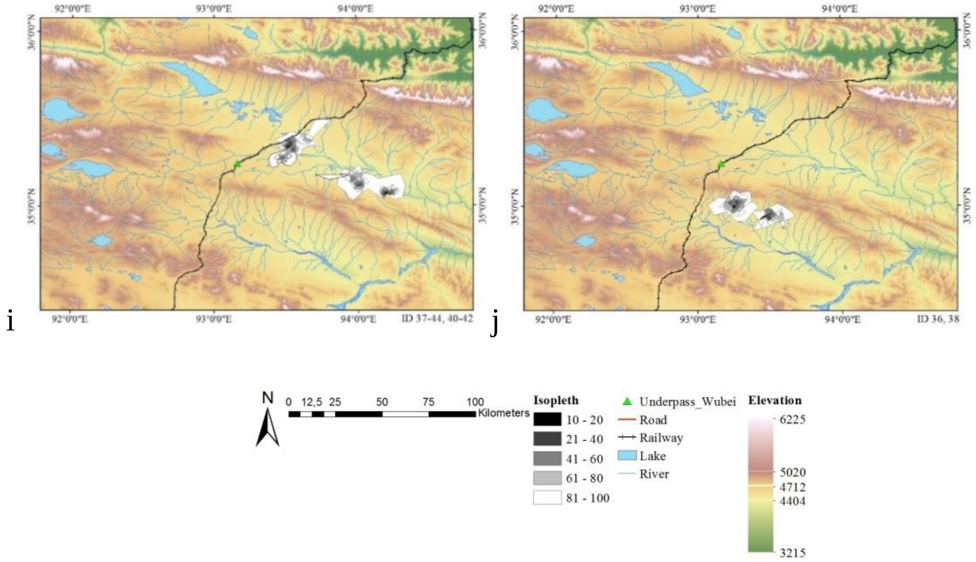


Fig. 6.4. Hull LoCoH home ranges of wintering pastures of the Tibetan antelope. (a) Annual home ranges of ID44 (migration included) and ID35; (b) home ranges of all studied individuals; (c-g) home ranges of each individual, inhabits near the Qinghai-Tibet railway and highway (d, e, f), in valley (g) and in both places (c); (h) non-migrating individuals; (i) home ranges of non-migrating individuals locates in the similar area with migrating individuals; (j) home ranges of individuals, inhabits beyond the hill.

6.3 Discussion

Some of observed Tibetan antelopes used pastures with different conditions, such as altitude, in autumn and winter; some of them can change the main habitation area and then, after 2 years, return to the previous place. Argos telemetry monitoring provides a year-round and remote data, the knowledge of the species in spatial and temporal scale.

The LoCoH Hull home range (HR) analysis showed that the calving ground location continues to be stable while wintering places changes easily. One-third of samples changed its wintering pastures and could be adjacent to different groups. The annual habitation area varies from 2024 to 2908 km^2 with average of 2409 km^2, and the wintering place locates in a valley with the average HR of 441 km^2. The HRs could be divided into 3 groups by locations, and other classifications were made by migration existence and stability of HRs within the seasons and years. The HRs located near the artificial barriers (railway and a highway) had the parallelepiped shape, which shows its dependence on those factors. Therefore, the reduction of fragmentation of migration from the main habitation area and the establishment of more satellite tracking on Tibetan antelopes, especially on non-migratory females and males requires. The LoCoH model shows that the area along the highway and railroad remained the main hindering factor for the antelope’s seasonal migration.

Chapter 7 Estimation of the habitat selection

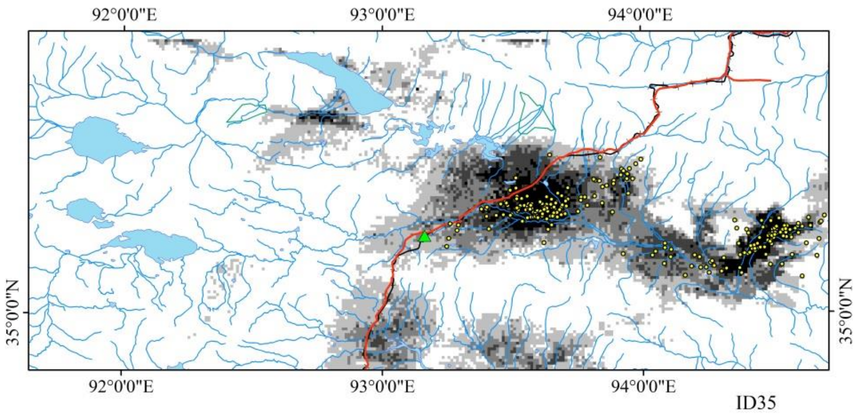
7.1 Introduction

Maximum entropy modeling is a machine learning approach that has been adapted to model species distributions (Phillips et al., 2006). The assumption is that the true, but unknown distribution of a species is a probability distribution p over a set of locations X (i.e., all cells in the study area). This distribution p is approximated by deriving a probability distribution ^p that respects constraints inferred from environmental variables associated with the occurrence data. The Maximum entropy modeling supposed to be well-suited for mapping the Tibetan antelope habitat selection in the Tibetan plateau as it is relatively robust against false negatives. Such approaches are crucial for species occupying only a portion of their potential habitat (Engler et al., 2004). Moreover, maximum entropy models perform well with small sample sizes (Wisz et al., 2008), frequently outperforming traditional approaches (Elith et al., 2006). MaxEnt analysis had been used in various studies and approved to be relevant.

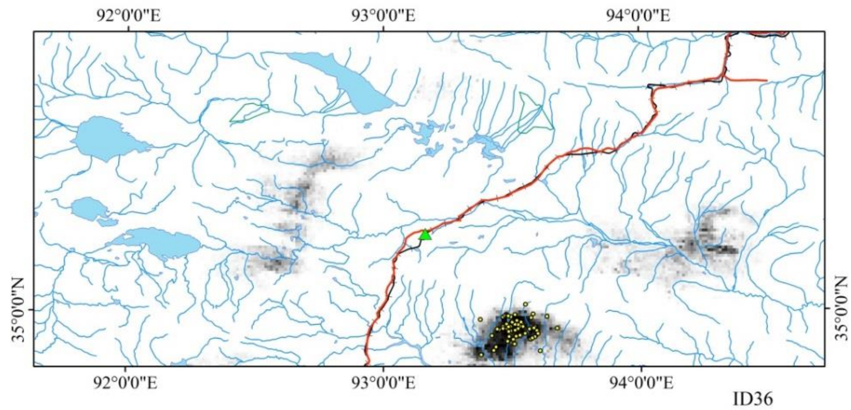
7.2 Results

From the environment variable and position data of Tibetan antelopes in wintering grounds, the habitat selection was estimated **(Fig.7.1).** The variables used were as follows: distances, digital elevation data (DEM), surface angles (Slope), shadows (Shaded Relief), slope directions (Aspect), distances from river, distances from lake, snow cover.

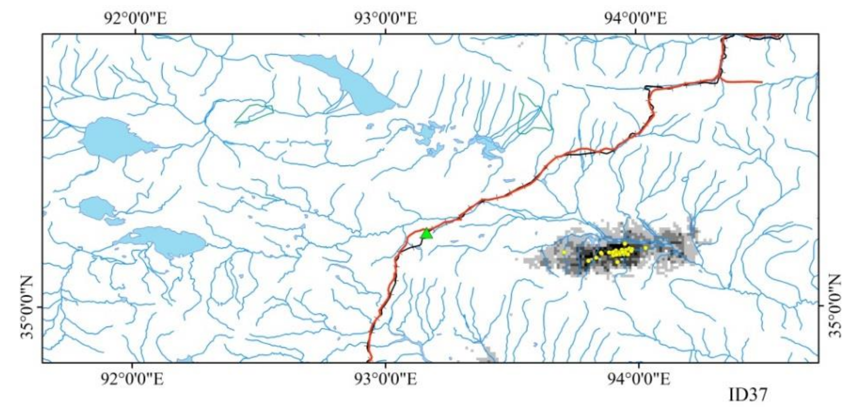
According to the MaxEnt models, the antelopes ID35 and ID41 had the different wintering grounds in different years and has wider predicted suitable area, as the result **(Fig. 7.1 a, g).** Antelope ID36, in addition to the wintering ground area has the other suitable area, which is currently not used but has the similar parameters. The current wintering grounds of the studied Tibetan antelopes had been interpreted as areas of suitable habitat with high probability; however, the predicted areas were wider than the current home ranges **(Fig. 7.1 a-i).**


92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
35°0'0"N
92°0'0"E
93°0'0"E
94°0'0"E
ID35

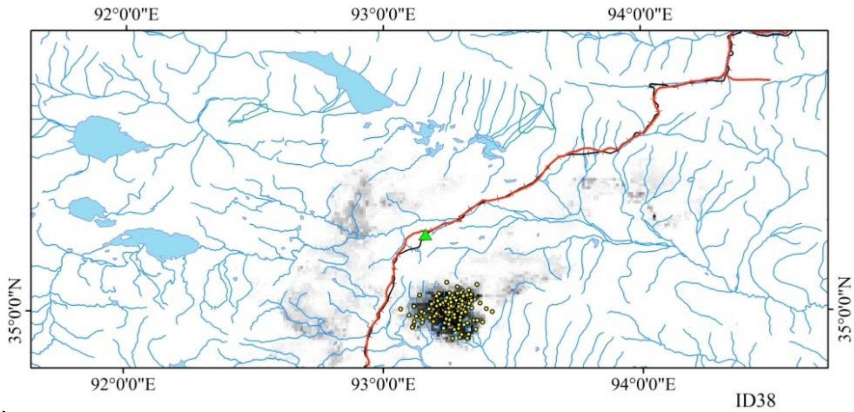
a


92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
35°0'0"N
92°0'0"E
93°0'0"E
94°0'0"E
ID36

b

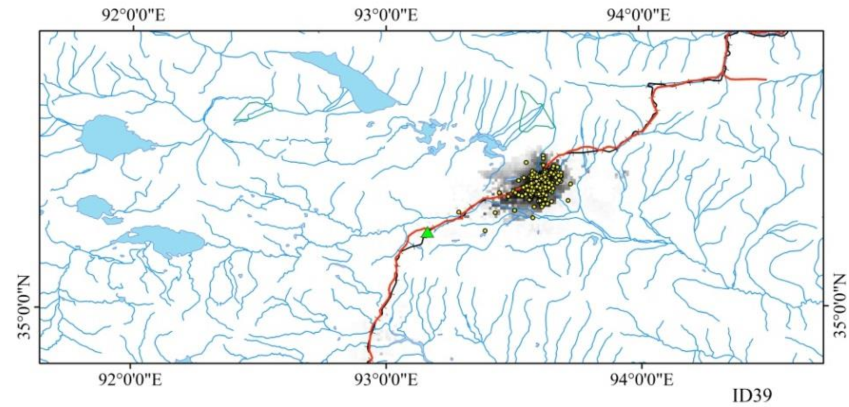

92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
35°0'0"N
92°0'0"E
93°0'0"E
94°0'0"E
ID37

c



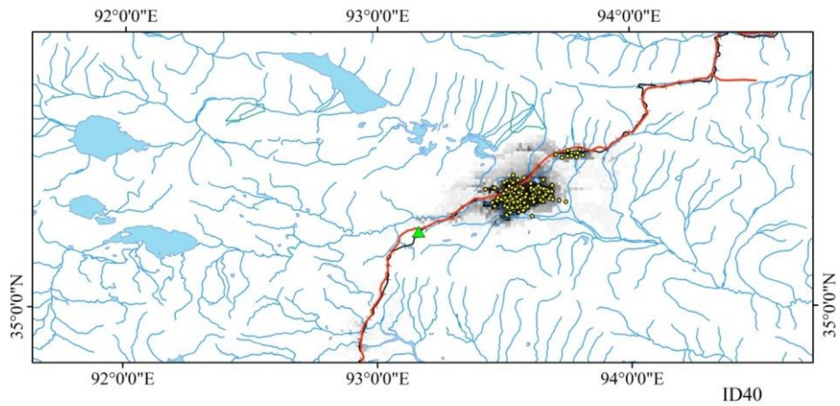
92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
ID38

d



92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
ID39

e



92°0'0"E
93°0'0"E
94°0'0"E
35°0'0"N
ID40

f

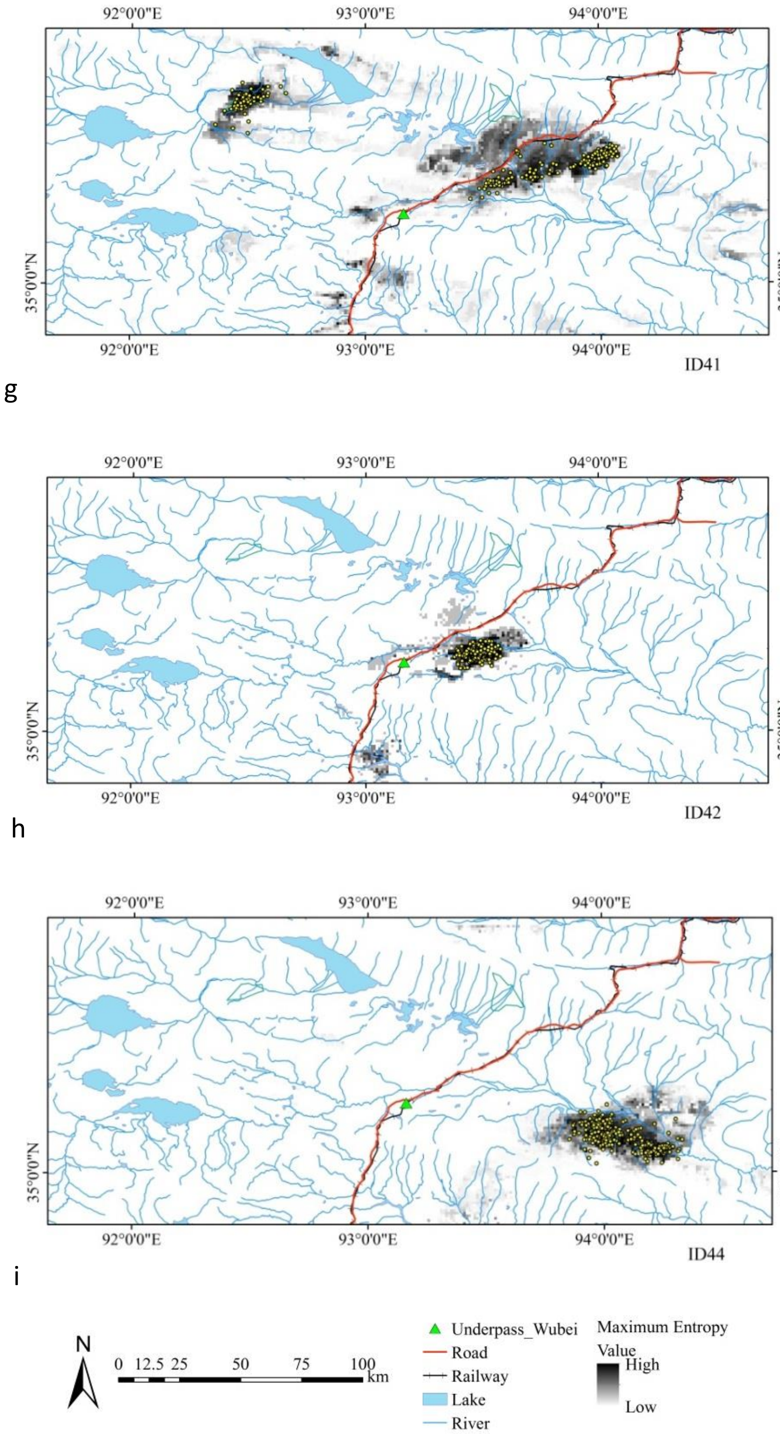


Fig.7.1. Estimation of the habitat selection of the Tibetan antelopes in wintering site (main pasture) using MaxEnt Model (the main pastures distributions were shown by yellow dots).

The jackknife test of regularized training gain for Tibetan antelope ID35 in a calving site showed the influence of environment variables for habitat prediction **(Fig. 7.2)** in wintering grounds. This trend is similar for all individuals.

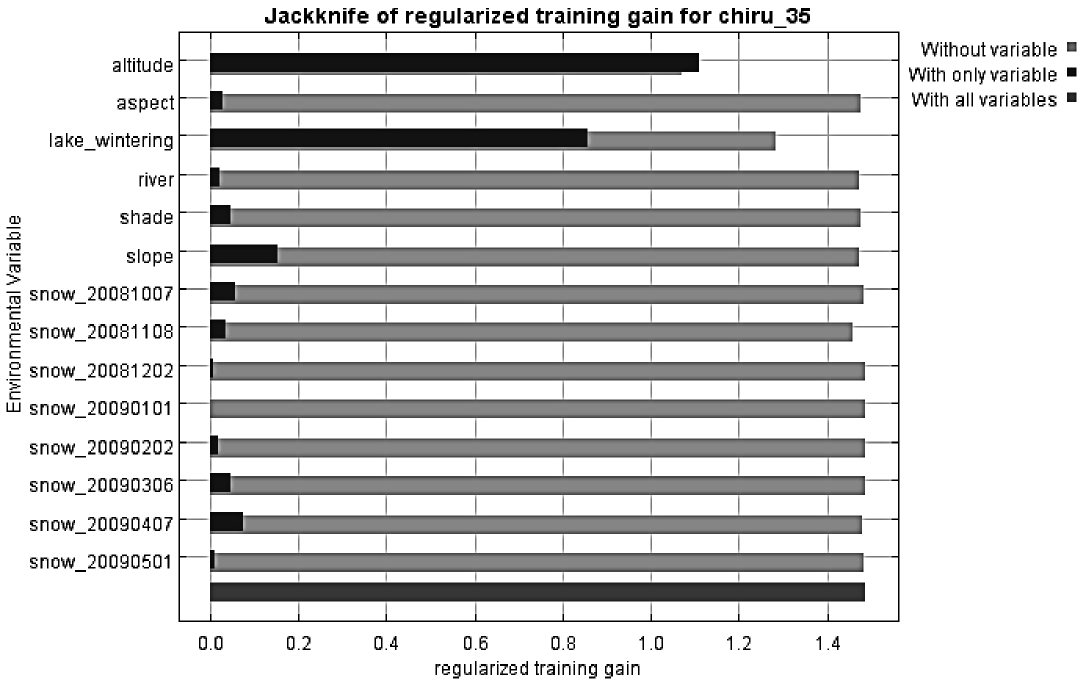


Fig.7.2. Jackknife test of training gain for Tibetan antelope ID35 in a calving site.

The dark graphs show the influence of environment variables for Tibetan antelope habitat possibility. This jackknife shows that the lakes presents and altitude of the area pays a higher role for the distribution at the wintering grounds.

Permutation importance contribution to the habitat probability, percentage of the contribution to model per environmental variable was shown in **(Table.7.1).** The influence of the altitude and distances to the lakes, its contribution rate to the probability of habitat selection appeared to be high in the model.

Table7.1. Analysis of each variable contribution for the habitat selection at the wintering site (main pasture).

Variable	Percent contribution	Permuttion importance
Elevation	51.2	31.8
Lake_wintering	44.1	60.5
Snow_20081108	1.6	0.8
Aspect	0.9	0.9
Slope	0.9	2.9
Snow_20090407	0.6	0.5
Hillshade	0.3	1.3
River	0.2	1.0
Snow_20081007	0.1	0.1
Snow_20090501	0	0.3
Snow_20090202	0	0
Snow_20090101	0	0
Snow_20081202	0	0
Snow_20090306	0	0

The suitable altitude for Tibetan antelopes habitat was 4400 m – 4500 m above the sea level, as shown in the graph **(Fig. 7.3)** Also, the antelopes preferred the flat area, as far as the most area with elevation of 4500 m above the sea level were at the flat highlands, surrounded by steep mountains, therefore the selectiveness of the Tibetan antelope to use the flat area was estimated.

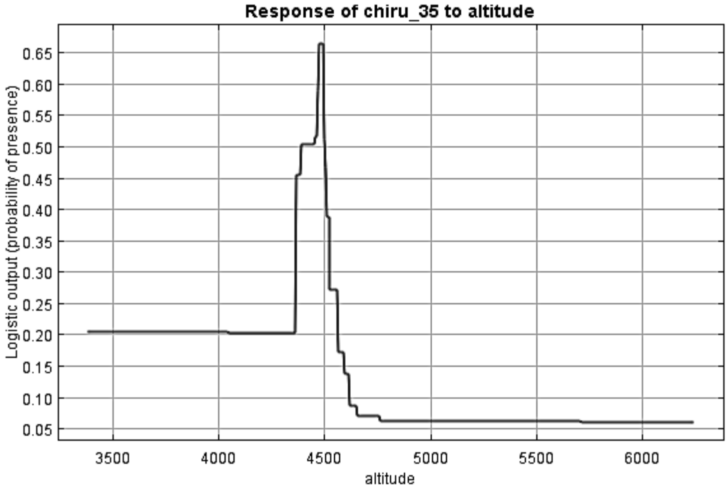


Fig.7.3. Response of the Tibetan antelope ID35 to altitude (the horizontal axis shows altitude).

The distance from the lakes of antelope ID35 locations **(Fig.7.4)** shows the high rank of useful area in the distance ranged from 0m to 400m. It shows that the Tibetan antelopes selected the area very close to the lakes as a wintering ground. It indicates the importance of the lake for the antelopes' habitat, on a calving ground, as a source of the fresh water, the wide and flat area and the "side of confidence" from where no predators are expected to come and therefore, only particular area left to observe, being aware of predators.

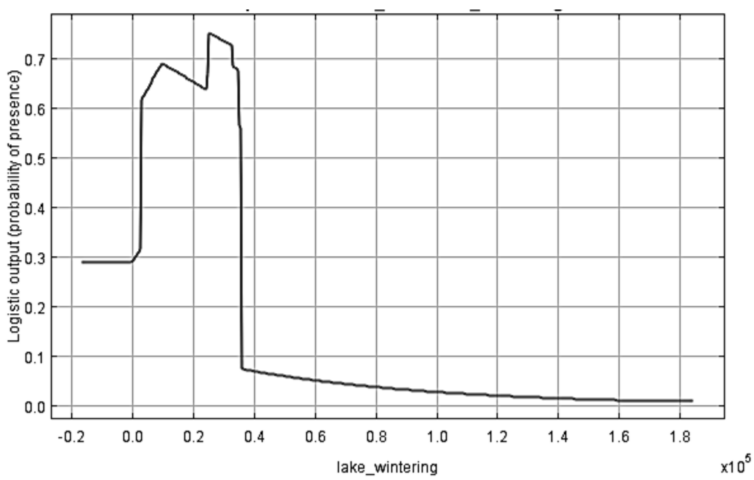


Fig. 7.4. The lake area usage of the Tibetan antelope ID35; the horizontal axis shows the distance from the lake.

Estimation of the environmental relevance of the breeding ground showed that the useful area locates at the lakesides and flat area at the surroundings. It predicted the possibility of population extending. However, having a wide area that fit for a calving, according to this model, the Tibetan antelope females use only the area near the Huiten Nur Lake.

The following environmental variables were used, along with the positional data of Tibetan antelope in the breeding grounds to estimate the habitat selection **(Fig.7.5):** digital elevation data (DEM), slope, shadows (Shaded Relief), slope aspect, the distance from river, the lake environmental variables (distance from lake), vegetation index (NDVI).

The influence of environmental variables on habitat selection in breeding grounds of the Tibetan antelopes is shown in **(Fig.7.6).** The dark columns represent the influence of environmental variables for the habitat selection of the Tibetan antelopes, the most valuable are the distance from the lake or lake appearance and the altitude. NDVI in August had more influence on the habitat selection at the time the Tibetan antelopes being at the calving ground and migrated back to the main pastures.

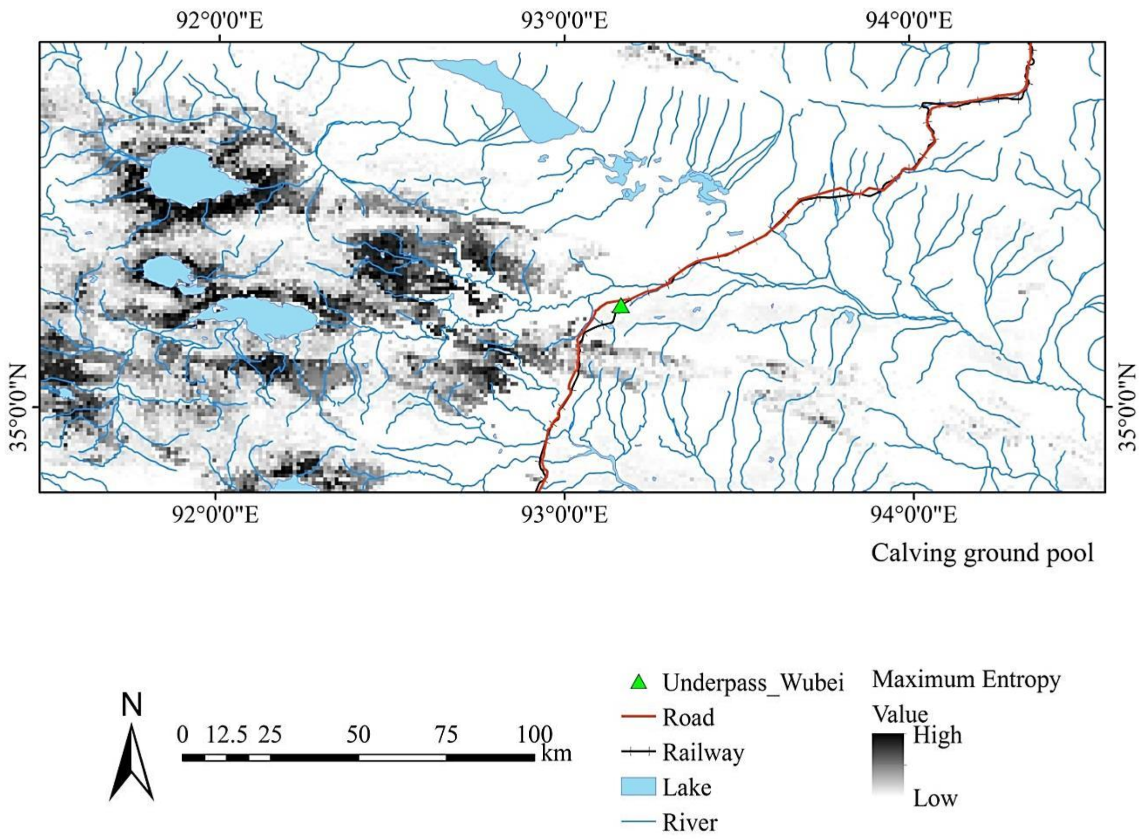


Fig.7.5. Estimation of the habitat selection of the Tibetan antelope in the calving site using MaxEnt Model.

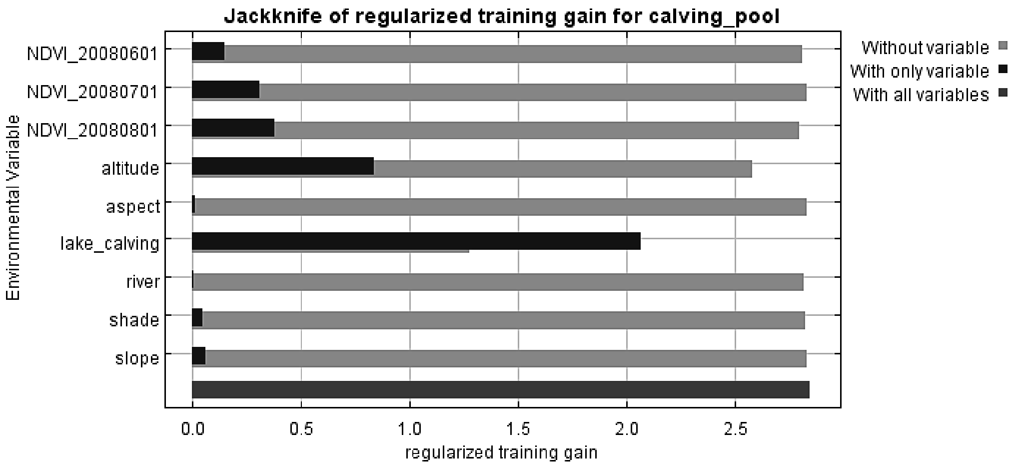


Fig.7.6. Jackknife test of regularized training gain for Tibetan antelopes in calving site.

The contribution percentage and the permutation importance of the environmental model variables for the calving site are shown in **(Table 7.2).** The average NDVI in August 2008, elevation, distance from the lakes variables showed the high percentage of contribution, the distance to the lake had the highest permutation importance.

Table 7.2. Analysis of each variable contribution to the habitat selection of the Tibetan antelopes at the calving site.

Variable	Percent contribution	Permuttion importance
Lake_calving	72.4	89.5
NDVI_20080801	12.1	3.7
Elevation	10.9	4.6
Slope	1.4	0.2
NDVI_20080701	1.3	0.6
Hillshade	0.8	0.4
NDVI_20080601	0.5	0.9
River	0.4	0.1
Aspect	0.3	0.1

The altitude of the preferable area at the calving ground of the Tibetan antelope **(Fig.7.7)** has the range between 4800m and 4900m above sea level. In comparison with the altitude in wintering grounds, it is 300-400 m higher. The impact of parasites and predators is lower in such altitude and it can be considered as the reason of such selection.

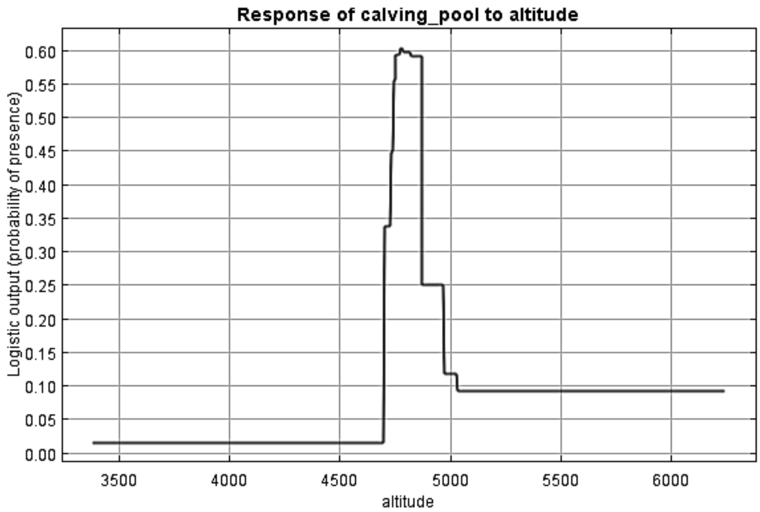


Fig. 7.7. The altitude of the preferable area at the calving ground of the Tibetan antelope (the horizontal axis shows altitude).

The calving ground basin MaxEnt model for all studied Tibetan antelopes showed the predicted suitable area for the calving. The limited area of the Huiten Nur Lake was chosen to take into account the Tibetan antelope historical preference of the calving grounds **(Fig. 7.8).** The jackknife of regularized training gain for studied Tibetan antelopes shows the importance of the elevation and slope. The preferred area characterizes of the low slope flat and open space.

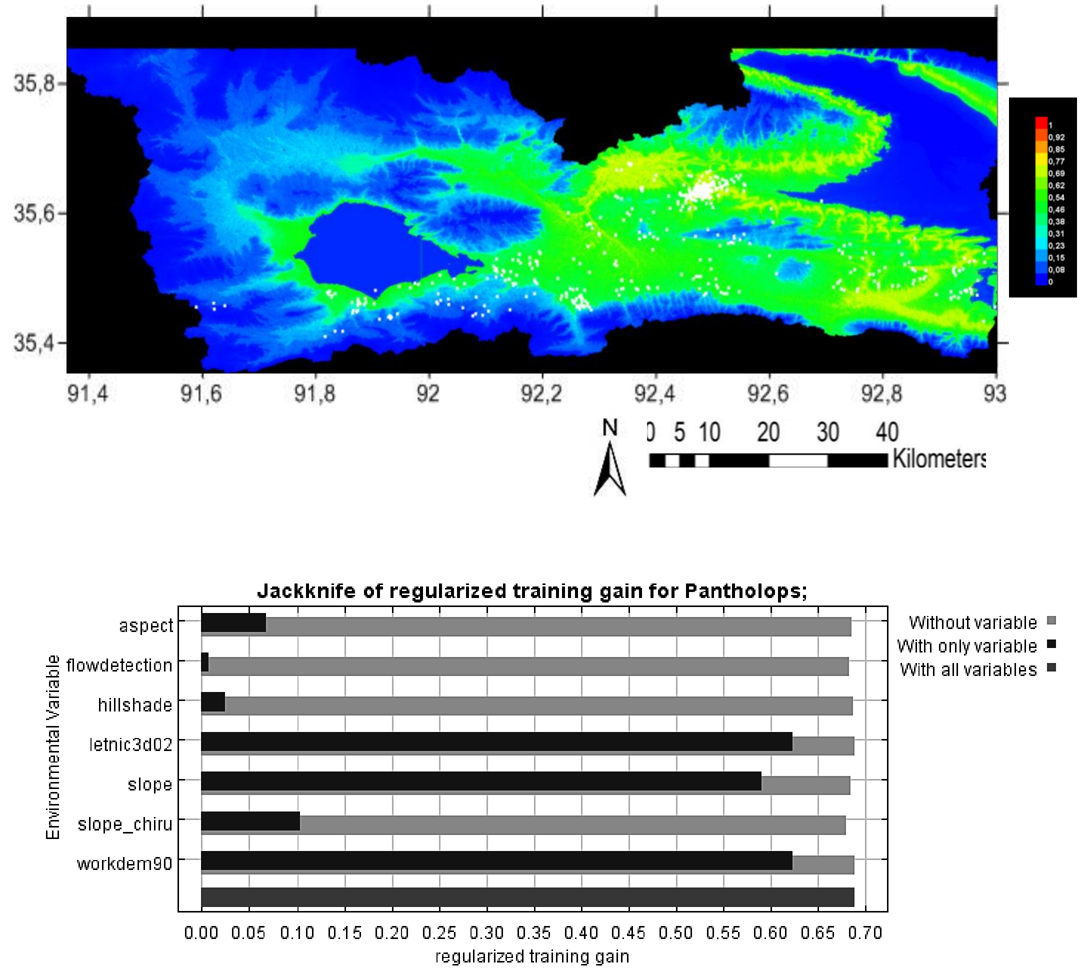
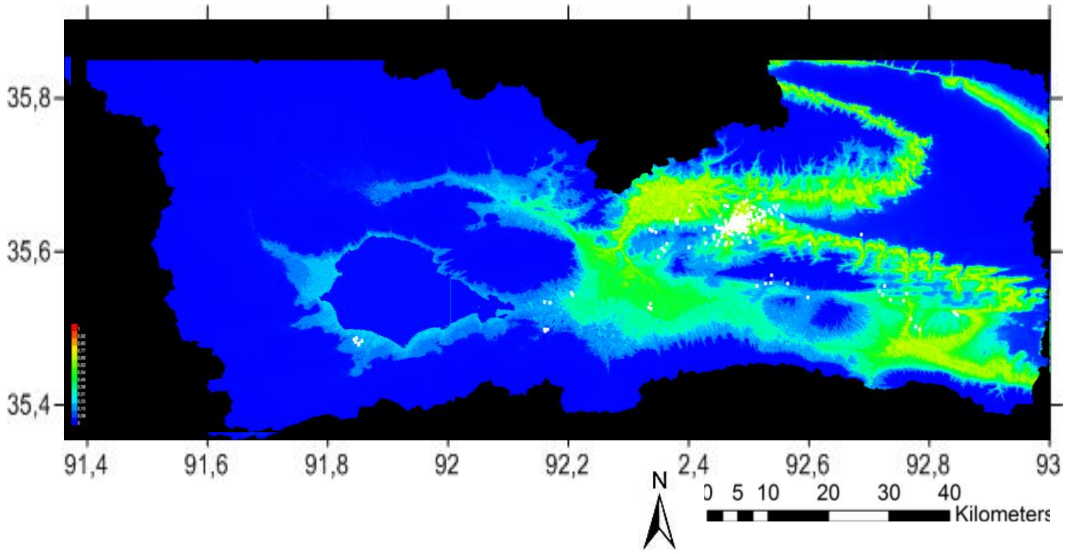


Fig. 7.8. The calving ground basin MaxEnt model and the jackknife of regularized training gain for all studied Tibetan antelopes. Yellowish color shows the most suitable area.

The calving ground basin MaxEnt model for the locations of Tibetan antelope ID 41 showed more narrow habitation area as a suitable for this individual`s distribution **(Fig. 7.9).** Slope variable has the bigger influence on the prediction.



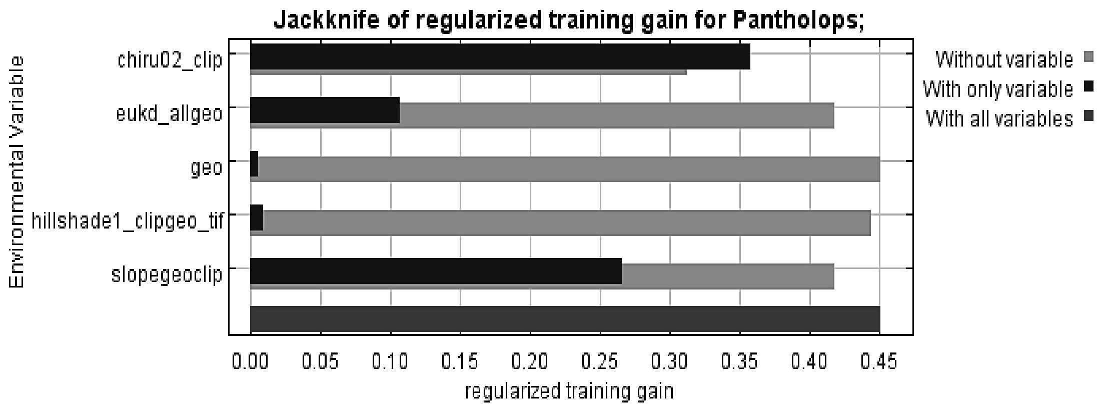


Fig. 7.9. The calving ground basin MaxEnt model and the jackknife of regularized training gain for the Tibetan antelope ID 41.

Analyzing the MaxEnt model for the locations of all studied individuals, including the altitude, slope, aspect, hillshade, distance to the lake and the proximity of rivers, average NDVI in June, July and August, snow cover variables, and excluding the highway and the railway possible influences, the wide suitable area of distribution was predicted **(Fig.7.10).** All main pastures area is relatively smaller comparing with the predicted suitable area.

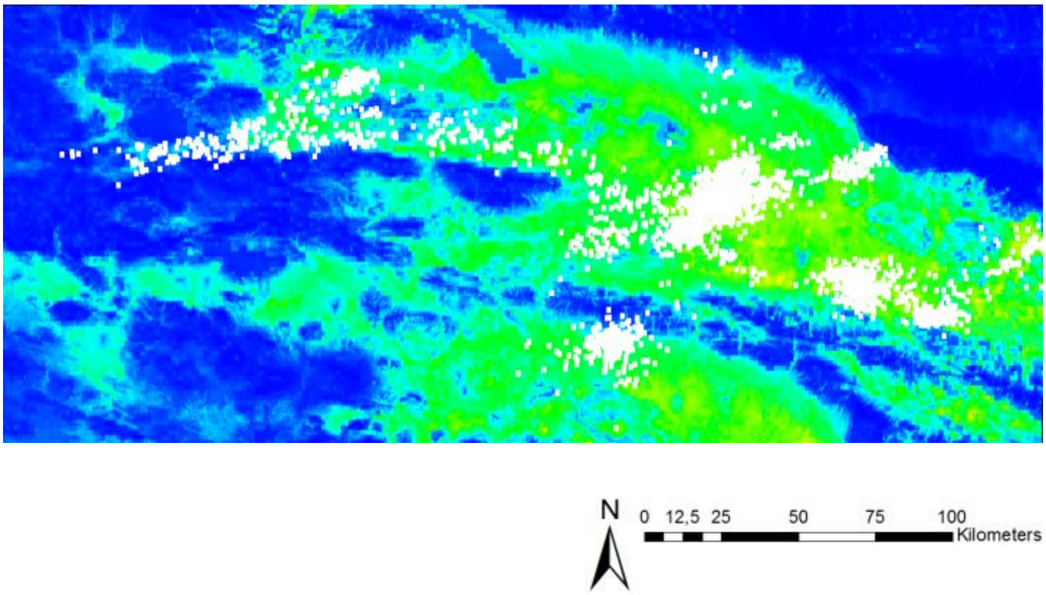


Fig. 7.10. The Maximum Entropy of the studied Tibetan antelopes without the railway and the highway variables.

The Maximum Entropy of the studied Tibetan antelopes with the railway and the highway variables **(Fig. 7.11)** shows the estimated suitable area; the most suitable area (red color) locates at the valley with more of Tibetan antelopes actual locations and at the Western side of the railway and the highway. However, antelopes' main pastures located only on the Eastern part of the suitable area, beyond the railway, which is probably due to the artificial constructions. The railway and highway itself has the less suitable qualities in this model and clearly separates the predicted preferable suitable habitation area. The most preferable slope were about 1 degree, flatland. The preferable distance from the railway was 7- 10 km, the distance from the highway was shorter – about 6 km. The most contributive variable for the habitat choice was the elevation 4400- 4500 m.

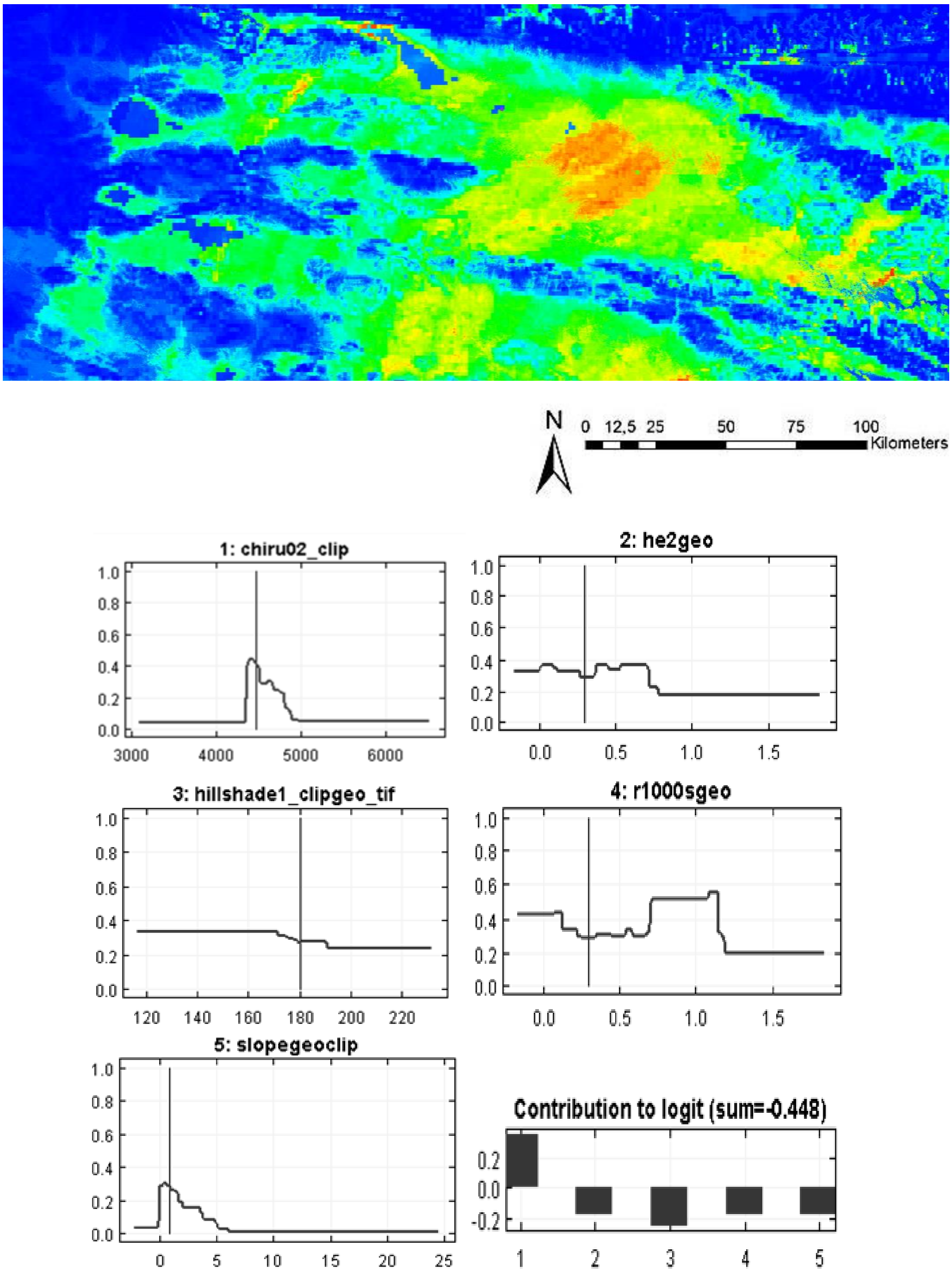


Fig. 7.11. The Maximum Entropy of the studied Tibetan antelopes with the railway and the highway variables and the features of the variables (1: elevation, 2: distance to the highway, 3: hillshade, 4: distance to the railway, 5: slope).

The analysis of each variable contribution to the habitat selection of the Tibetan antelopes at the whole habitation area showed the high percent of the contribution of the elevation (42.7), railway (41.3) and slope (35.2), The permutation importance of the highway was dramatically high (151). The actual distribution of the studied antelopes locates only at the Eastern part of the predicted suitable area; however the highway locates on the Western side when the railway line lies on the Eastern side of the suitable area, this cause the differences in permutation importance and contribution values **(Table 7.3).**

Table 7.3. Analysis of each variable contribution to the habitat selection of the Tibetan antelopes.

Variable	Percent contribution	Permutation importance
Elevation	42.7	33
Slope	35.2	23
Railway	41.3	28.2
Highway	6.4	151
Hillshade	1.4	0.7

Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

Table 7.4. Thresholds and corresponding omission rates.

Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate
1.000	0.050	Fixed cumulative value 1	0.694	0.008
5.000	0.158	Fixed cumulative value 5	0.517	0.038
10.000	0.245	Fixed cumulative value 10	0.420	0.083
0.000	0.000	Minimum training presence	0.994	0.000
11.725	0.263	10 percentile training presence	0.395	0.100
30.359	0.459	Equal training sensitivity and specificity	0.233	0.233
27.377	0.440	Maximum training sensitivity plus specificity	0.251	0.209
1.449	0.066	Balance training omission, predicted area and threshold value	0.657	0.011
5.574	0.172	Equate entropy of thresholded and original distributions	0.503	0.045

It is clearly seen the border line of habitat, which became parallelepiped shaped, caused by the railway and highway constructions. However such shape could be interpreted as intention to inhabit closer to construction, on the other hand, another groups of the Tibetan antelopes preferred the area not related to the railway and highway. So far, the construction may alter the normal distribution. **(Fig. 7.12)**

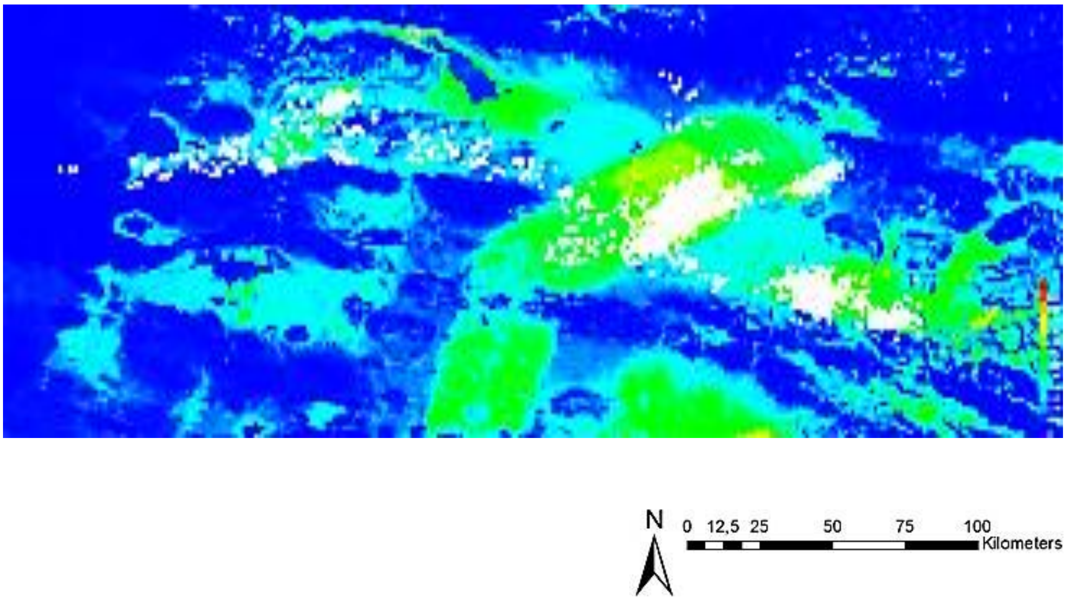


Fig. 7.12 The Maximum Entropy Model of the Tibetan antelope ID 35.

The Maximum entropy model of the Tibetan antelope ID 35 shows the usage of habitat, according to the proximity of railway, slope, aspect NDVI values, snow cover, distance to the lakes and rivers and altitude variables of study area **(Fig. 7. 13).** The altitude and the proximity or the railway - are the more important variables. The most of locations were at the 1 and 6 km from the railway **(Fig. 7.14).** The close location shows that the railway and highway constructions are situated at the most preferable and suitable area and separates the potential suitable area for the main pastures.

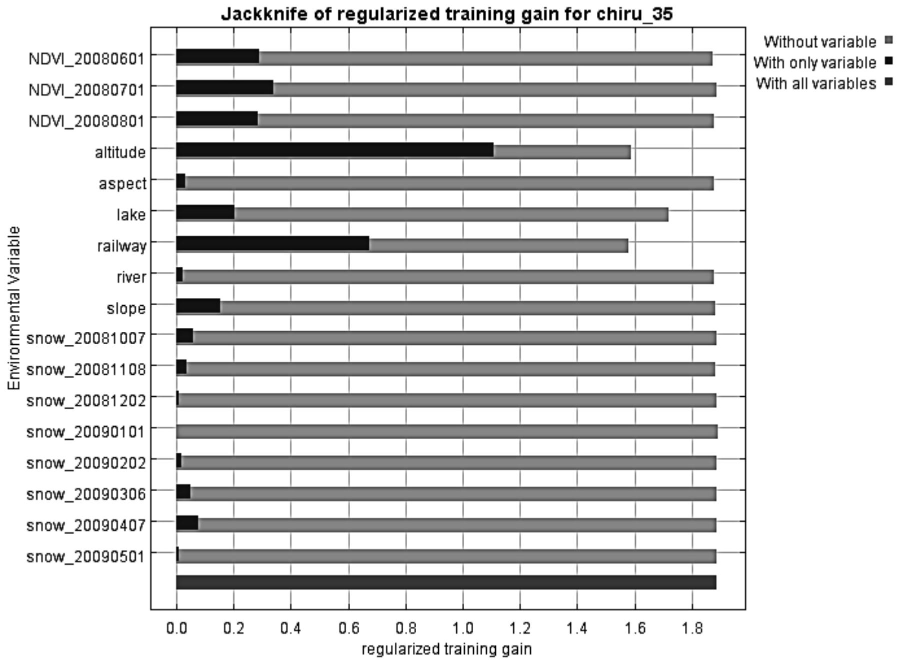


Fig.7.13. The jackknife of regularized training gain for the Tibetan antelope ID 35.

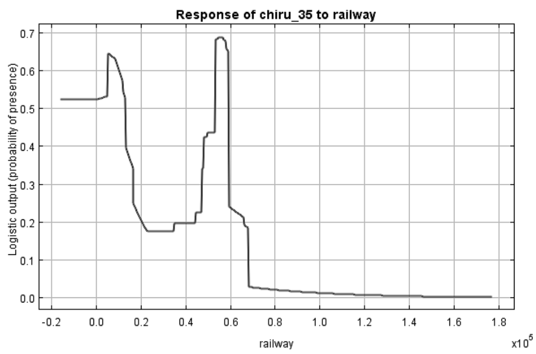


Fig. 7.14. The response of the Tibetan antelope ID35 distribution to the railway variable.

7.3 Conclusions

The Maximum Entropy analysis shows the area, estimated as suitable for habitation, however, almost half of the most suitable area is out of the identified home ranges. Artificial barrier lies in the most suitable area and separates the potential pasture in the middle, giving the opportunity to use only half of it. Antelopes graze closer to railway in winter time, preferred to choose open, flat landscape with the lower altitude. It revealed that water bodies (rivers and lakes) pay a very important role in animal distribution, along with the slope.

The Maximum Entropy models was performed for the each wintering places of the studied Tibetan antelope; for the calving place and for the calving place, restricting the area of Huiten Nur Lake basin as the antelopes` only calving ground; for the whole distribution of the antelopes, including its migration route, as this route is the preferable for the antelopes and showed the higher NDVI value, in comparison with the main pasture and the calving ground.

Chapter 8 Summary

Using 6 years of indirect monitoring and 2 seasons of observations, the differences between the Tibetan antelope distribution ranges in terms of environmental parameters (precipitation, seasonal productivity etc.) and topographical variables were underlined. The hypotheses concerning the drivers of migration to their seasonal ranges and the impact of peak and average values were assessed and the predictability of drivers of habitat use within the seasonal ranges was estimated.

For the first time ever, the Argos tracking had been made on the Tibetan antelope and the location data received provided of the detailed information about spatial and temporal patterns of the movements of this rare endemic animal. The exact migration route and the features of habitat were clearly shown. Received information gave an opportunity to understand some of the reasons of migration, influences of artificial obstacles, stability of migration. Estimating the Argos system accuracy (Chapter 3) in high-mountain area revealed the less accurate and rarer signals during the winter season. Location errors were concentrated in the latitudinal direction, 67.52% of locations were succeed. Average altitude difference between Argos positional data and DEM satellite image data was 58.7 m, no significant difference between seasons revealed. Argos data showed lower value of altitude. The maximum length of usage was 1809 days. Mean 3 signals per each session were received from later established collars, after 2010, when Argos revised their settings. Environmental characteristics of habitat (Chapter 4) shows that the average slope of the migration is 17-22^0, with a big range from 3 to 37^0, NDVI value appears to be lower in a calving place; the highest value was on the migration route. Chapter 4.1 "Calving ground" contains information about the calving ground topography and hypotheses about the reasons of migration to that particular area. The study enlightens the question of the reasons of migration. Since vegetation index is lower in calving place, but the peak of vegetation growth falls on the migration route it tells that foraging during the travel is important. To prevent the shortage of food in very important period of reproduction, males stay on main pastures while females migrate foraging during the way. Water resources availability plays a vital role, during the summer time there are many rivers and a stable fresh water resource on Huiten Nur Lake - the calving ground; in addition, this area is wide and flat giving an opportunity to observe more, being aware of predators. Chapter 4.2 contains the fieldwork results. During the field survey in 2012 the female/offspring ratio was 78/21%. Only 27% of adult females were with offspring. The peak of the linear barriers crossing held on 2nd of August, when number of migrating animals was accounted for approximately 30% of the total population. Chapter 5 describes the features of migration and influence of the linear barriers. The females shifted their migration dates for 2 weeks earlier, and the delays (up to 30 days) in common migration schedules occurred, due to the artificial obstacles. The Tibetan antelope mainly used the Wu-Bei underpass, however it reveals the longer delay in their movements back to the main pasture. Dates of migration differs for different antelopes` groups because of the big amount of animals, groups has to cross in turn.

The distance between Wu-Bei underpass and the highway was the shortest in surroundings of the migration route which could be the reason to prefer this underpass, along with the better observation of the highway and existence of the wide area for collecting and grazing next to it. The frequency of Wu-Bei usage by monitored animals was 11±4 compare with other bridges frequency of 6. The Tibetan antelope spent more time on the way back from calving (aver. 31 days), compared to the way forward (aver. 21 days) within the migration, started in the middle of May until the middle of August. Average period of migration is 83 days, period of stay at the main pasture is 262 days and time, spent on the calving ground is 24 days. The average delay next to the linear barriers was 12 days. The direction of migration corresponds to the common topography and the fresh-water bodies play an important role in a route choice. The necessity of the accession to the mutual migration route, as well as the similar timing of migration was shown. Chapter 6 shows the analysis of the home ranges. The studied females had been divided into three groups by their main pasture locations. The results of monitoring and LoCoH Hull home range (HR) analysis showed that the calving ground location continues to be stable while wintering places changes easily; one-third of samples changed its wintering pastures and could be adjacent to different groups. The annual habitation area varies from 2024 to 2908 km² with average of 2409 km², and the wintering place locates in a valley with the average HR of 441 km². The most intensively used areas characterizes of its locations appearing near the riverbanks in valley on elevation 4300 - 4600 m. The HRs classifications were made by migration existence (2 of studied Tibetan antelopes are non-migratory) and stability of HRs within the seasons and years. One studied individual stayed on a calving ground on the last year of our survey. The HRs, located next to the artificial barriers (railway and a highway) had the parallelepiped shape, which shows its dependence on those factors. The width of the migration corridor was wider in neighboring to linear barriers area, evidencing that the artificial constructions influenced on the migration behavior. The Maximum Entropy models and the area difficulties analysis had been performed in Chapter 7. The Maximum Entropy analysis shows the area, estimated as useful for habitation, however, almost half of that suitable area is out of the identified home ranges. It revealed that the water bodies (rivers and lakes) play a very important role in animal distribution, along with the slope. Artificial barrier lies in the most suitable area and separates the potential pasture in the middle, giving the opportunity to use only the half of it. Antelopes grazed closer to the railway in winter time, preferred to choose open, flat landscape with the lower altitude.

The results suggest the reduction of fragmentation of migration from the main habitation area and the establishment of more satellite tracking on Tibetan antelopes, especially on non-migratory females and males.

References cited

Bernard Y and M Belbeoch. No date. Improving Argos doppler location with Kalman filtering - advantages for Argos floats. http://www.argossystem.org/files/ pmedia/public/r283_9_new_argos_location_for_argo.pdf>.

Blair WF. 1940 Notes on home ranges and populations of the short-tailed shrew. Ecology, 21: 284・88.

Bleisch WV, PJ Buzzard, H Zhang, D XU, Z Liu, W Li and H Wong. 2009. Surveys at a Tibetan antelope *Pantholops hodgsonii* calving ground adjacent to the Arjinshan Nature Reserve, Xinjiang, China: decline and recovery of a population. Fauna and Flora International, Oryx, 43(2): 191–196.

Block BA, D P Costa, GW Boehlert and RE Kochevar. 2002. Revealing pelagic habitat use: the tagging of Pacific pelagics program. Oceanologica Acta, 25: 255-266.

Bolis JS. 2013.Factors affecting the quantity and quality of Argos telemetry locations for wolverines in the northern Cascade Range in Washington, University of Washington.

Brito JC, AL Acosta, F Alvares and F Cuzin. 1999. Biogeography and conservation of taxa from remote regions: An application of ecological-niche based models and GIS to North-African Canids. Biological Conservation, 142 (2009) 3020・029, via Science Direct.

Campbell TA, DB Long and BR Leland. 2010. Feral swine behavior relative to aerial gunning in southern Texas. Journal of Wildlife Management, 74: 337-341.

Cao Y, J Su, X Lian, , T Zhang and Q Cui. 2008. Food habits of Tibetan antelope (*Pantholops hodgsonii*) in the Kekexili Nature Reserve. Acta Theriologica Sinica, 28: 14–19.

CLS 2007-2014. Argos user`s manual. Available at http://www.argos-system.org/manual/ Accessed 10 Apr. 2014.

Davis L S, RG Harcourt and CJ Bradshaw. 2001. The winter migration of Adelie penguins breeding in the Ross Sea sector of Antarctica. Polar Biology, 24: 593-597.

Du Y-R, S-C Guo, Z-F Wang, H-X Ci, Z-Y Cai, Q Zhang, J-P Su and J-Q Liu. 2010. Demographic history of the Tibetan antelope *Pantholops hodgsonii* (chiru). Journal of Systematics and Evolution, 48(6): 490-496.

Elith J, CH Graham, RP Anderson. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29: 129–151.

Ellis J E and J B Lewis. 1967. Mobility and annual range of wild turkeys in Missouri. Journal of Wildlife Management, 31: 568-581.

Engler R, A Guisan, L Reshsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J Appl Ecol, 41: 263–274.

Fancy SG, L F Pank, DC Douglas, CH Curby, GW Garner, SC Amstrup and WL Regelin. 1988. Satellite telemetry: a new tool for wildlife research and management. U.S. Fish and Wildlife Service Resource Publication 172, Washington, D.C., USA

Feng S, M Tang and D Wang. 1998. New evidence for the Qinghai-Xizang (Tibet) Plateau as a pilot region of climatic fluctuation in China. Chinese Science Bulletin, 43 (20): 1745-1749.

Feng Z. 1993. Wild animal resources in the Hoh Xil Region. Chinese Journal of Arid Land Research, 4: 3247–253.

Feng Z, B Fan, K Li, QD Zhang, QS Yang and B Liu. 2008. Molecular characteristics of Tibetan antelope (*Pantholops hodgsonii*) mitochondrial DNA control region and phylogenetic inferences with related species. Small Ruminant Research, 75(2): 236-242.

Gaubert P, M Papes and AT Peterson. 2006. Natural history collections and the conservation of poorly known taxa: Ecological niche modeling in central African rainforest genets (Genetta spp.). Biological Conservation, 130: 106・17.

Getz WM, S Fortmann-Roe, PC Cross, AJ Lyons and SJ Ryan. 2007. LoCoH: Nonparameteric Kernel Methods for Constructing Home Ranges and Utilization Distributions. PLoS ONE 2(2): e207. doi:10.1371/ journal.pone. 0000207.

Getz WM and CC Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography, 27: 489–505.

Ginsberg JR, GB Schaller and J Lowe. 1999. A Petition to List the Tibetan Antelope (*Pantholops hodgsonii*) as an Endangered Species Pursuant to the U. S. Endangered Species Act of 1973.

Guisan A and NE Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling, 135: 147–186.

Gyaco. 2005. Former director of the Communications Commission of the Tibet Autonomous Region. "Roads of change revitalize Tibet". Asia Africa Intelligence Wire, Business Daily Update. Retrieved 2012-04-07.

Harris RB and DJ Miller. 1995. Overlap in summer habitats and diets of Tibetan Plateau ungulates. Mammalia, 59(2): 197–212, doi: 10.1515/mamm.1995.59.2.197.

Hays GC, S ArKesson, BJ Godley, P Luschi and P Santidrian. 2001. The implications of location accuracy for the interpretation of satellite-tracking data. Anim. Behaviour, 61: 1035–1040.

Hoshino B, Z Jiang, C Liu, T Yoshida, M Halik, M Kaneko, M Asakawa, M Motokawa, K Kaji, H Wu, N Ohtaishi, S Ganzorig and R Masuda. 2011. Preliminary study on migration pattern of the Tibetan antelope (*Pantholops hodgsonii*) based on satellite tracking. Advances in Space Research, 48: 43-48.

IPCC (Intergovernmental Panel on Climate Change), official site: www.ipcc.cn

Ito TY, B Lhagvasuren, A Tsunekawa, M Shinoda and S Takatsuki. 2013. Fragmentation of the Habitat of Wild Ungulates by Anthropogenic Barriers in Mongolia. PLoS ONE, 8(2): e56995, doi:10.1371/journal.pone.0056995.

Jennrich RI and FB Turner. 1969. Measurement of noncircular home range. J. Theor. Biol., 22: 227–237.

Jin H, S Li and S Wang. 2000. Impacts of climatic change on permafrost and cold regions environments in China. ACTA Geographic China, 55 (2): 161– 173.

Kaji K, N Ohtaishi, S Miura and J Wu. 1989. Distribution and status of white-lipped deer (*Cervus albirostris*) in the Qinghai-Xizang (Tibet) Plateau, China. Mammal Review, 19(1): 35-44.

Keating K. and S Cherry. 2009. Modeling utilization distributions in space and time. Ecology, 90: 1971–1980.

Kernohan BJ, RA Gitzen and JJ Millspaugh. 2001. Analysis of animal space use and movements. In Radio tracking animal populations (eds J. J. Millspaugh and J. M. Marzluff), 125–166. San Diego, CA: Academic Press.

Knopff KH, AA Knopff, A Kortello and MS Boyce. 2010. Cougar kill rate and prey composition in a multiprey system. Journal of Wildlife Management, 74: 1435-1447.

Laver PN and MJ Kelly. 2008 A critical review of home range studies. Journal of Wildlife Management, 72: 290・98.

Le Munyan CD, W White, E Nyberg and JJ Christian. 1959. Design of a miniature radio transmitter for use in animal studies. Journal of Wildlife Management, 23:107–110.

Leslie DM and GB Schaller. 2008. *Pantholops Hodgsonii (Artiodactyla: Bovidae).* Mammalian Species, 817: 1 – 13.

Lian X, T Zhang, Y Cao, J Su and Simon Thirgood. 2007. Group size effects on foraging and vigilance in migratory Tibetan antelope. Behavioural Processes, 76(3): 192-197, doi: 10.1016/j.beproc.2007.05.001.

Lopez R and J Malard. 2011. Improving Argos doppler location using Kalman filtering. http://www.argos-system.org/files/pmedia/public/r282_9_technical_paper.pdf.

Ma W, G Cheng, Q Wu and D Wang. 2004. Application on idea of dynamic design in Qinghai–Tibet Railway construction State Key Laboratory of Frozen Soil Engineering, CAREERI, CAS, Lanzhou 730000, China.

Milakovic B, KL Parker, DD Gustine, RJ Lay, ABD Walker and MP Gillingham. 2012. Seasonal habitat use and selection by grizzly bears in northern British Columbia. Journal of Wildlife Management, 76: 170-180.

Odum EP and E Kuenzler. 1955. Measurement of territory and home range size in birds. Auk, 72: 128・37.

Papes M and P Gaubert. 2007. Modelling ecological niches from low numbers of occurrences: assessment of the conservation status of poorly known viverrids (Mammalia, Carnivora) across two continents. Diversity and Distributions, 13: 890–902.

Phillips SJ, M Dudík and RE Schapire. 2004. ICML '04 Proceedings of the twenty-first international conference on Machine learning, 83, doi:10.1145/1015330.1015412

Phillips SJ, RP Anderson and RE Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190(3): 231-259, doi: 10.1016/j.ecolmodel.2005.03.026

Przhevalsky NM. 1879-1880. From Zaisan across Khami to Tibet and the headwaters of the Yellow River. (In Russian)

Qiu L and Z Feng. 2004. Effects of traffic during daytime and other human activities on the migration of Tibetan Antelope along the Qinghai-Tibet high-way, Qinghai-Tibet Plateau. Dong wu xue Bao, Acta Zoologica Sinica, 50(4): 669-674.

Ridgeway R. 2003. 275 miles on foot through the Chang Tang. National Geographic, 4: 104-123.

Ruan X, P He, J Zhang, Q Wan and Sh Fang. 2005. Evolutionary history and current population relationships of chiru (*Pantholops hodgsonii*) inferred from mDNA variations. J. Mammalogy, 86: 881-886.

Schaller GB. 1998. Wildlife of the Tibetan Steppe. Wildlife Conservation Society and Tibetan Plateau Project, University of Chicago, USA

Schaller GB and R Junrang. 1988. Effects of a snowstorm on Tibetan antelope. J. Mammalogy, 69 (3): 631-634.

Schaller GB, A Kang, X Cai and Y Liu. 2006. Migratory and calving behavior of Tibetan antelope population. Acta Theriol. Sinica, 26 (2): 105-113.

Schaller GB, A Kang, T-D Hashi and X Cai. 2007. A winter wildlife survey in the northern Qiangtang of Tibet Autonomous Region and Qinghai Province, China.兽类学报, 27 (4): 309 -316.

Shanglin L. 2006. "Tibet's 1st railway to start unmanned operation". Xinhua.

Singh NJ, IA Grachev, AB Bekenov and EJ Milner-Gullanda. 2010. Saiga antelope calving site selection is increasingly driven by human disturbance. Conservation planning within emerging global climate and economic realities. Biological Conservation, 143(7): 1770-1779.

Travaini A, J Bustamante, A Rodriнguez, S Zapata, D Procopio, J Pedrana and R Martнnez Peck. 2007. An integrated framework to map animal distributions in large and remote regions. Diversity and Distributions, 13: 289–298.

Van Winkle W. 1975 Comparison of several probabilistic home-range models. Journal of Wildlife Management, 39: 118・23.

Weimerskirch H, M Salamolard, F Sarrazin and P Jouventin. 1993. Foraging strategy of wandering albatrosses through the breeding season: a study using satellite telemetry. Auk, 110: 325-342. Antarctica.

Wisz MS, RJ Hijmans, J Li, AT Peterson, CH Graham and A Guisan. 2008. Effects of sample size on the performance of species distribution models. Divers Distrib, 14:763–773.

Worton BJ. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology, 70: 164–168.

Wu G and Zhang Y. 1998. Tibetan Plateau Forcing and the Timing of the Monsoon Onset over South Asia and the South China Sea. Mon. Wea. Rev., 126: 913–927.

Wu Y. 2007. Adaptation of migration of female Tibetan antelope for precipitation distribution on the Qinghai-Tibet Plateau. Acta Theriologica Sinica, en.cnki.com.cn

Xia L, Q Yang, Z Lia, Y Wual and Z Fenga. 2007. The effect of the Qinghai-Tibet railway on the migration of Tibetan antelope, *Pantholops hodgsonii* in Hoh-xil National Nature Reserve, China. Oryx, 41: 352-357

Yang Q and L Xia. 2008. Tibetan wildlife is getting used to the railway. Nature, 452: 810–811.

Yang H, Q Lu, B Wu, H Yang, J Zhang and Y Lin. 2006. Vegetation diversity and its application in sandy desert revegetation on Tibetan Plateau. Journal of Arid Environments, 65(4): 619-631.

Appendices

Appendix A

The study object: Females of the Tibetan antelope at the Hoh Xil Nature Reserve

The Tibetan antelope (*Pantholops hodgsonii*), Hoh Xil Nature Reserve

Appendix B

The number of locations received, divided by months (Argos PTT).

ID	Dates	Mean	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
							Wintering						Migration	
ID35	28/08/2008-1/04/2011	352	39	34	31	35	31	15	16	24	23	28	27	47
ID36	20/08/2007-02/08-2012	119	20	12	10	11	8	7	10	8	8	7	10	8
ID37	12/8/2010-3/03/2012	49	12	21			1	2	4	1	6			
ID38	17/08/2009-16/04/2013	315	43	40	36	29	25	20	16	20	16	4	23	43
ID39	5/08/2010-14/04/2013	403	60	49	31	32	32	46	45	32	20	2	12	42
ID40	8/08/2010-17/03/2013	347	72	53	29	24	19	25	23	23	10	4	26	39
ID41	5/08/2010-14/04/2013	563	72	79	55	55	51	52	55	43	22	4	23	52
ID42	17/08/2009-14/03.2012	662	70	73	55	68	53	50	59	71	40	24	42	57
ID44	8/8/2010-14/04/2013	601	81	73	54	51	56	58	60	61	28	2	24	53
min			12	12	10	11	1	2	4	1	6	2	10	8
max			81	79	55	68	56	58	60	71	40	28	42	57
average			52	48	38	38	31	30	32	31	19	9	23	42
SD			25	24	16	18	20	21	22	23	11	10	10	15

The monthly difference of number of location points received from the already terminated transmitters.

Accurate locations													
ID	Dates	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
						Winter						Migration	
ID35	28/08/2008-1/04/2011	39	35	31	35	31	15	16	23	23	28	27	47
ID36	20/08/2007-02/08-2012	20	12	11	15	9	7	12	15	13	7	16	8
ID37	12/8/2010-3/03/2012	12	21	22	16	5	6	9	9	13	2	6	1
ID40	8/08/2010-17/03/2013	52	50	27	34	20	27	26	19	15	17	31	38
ID42	17/08/2009-14/03.2012	63	67	73	75	61	55	80	73	61	53	63	45
min		12	12	11	15	5	6	9	9	13	2	6	1
max		76	72	74	75	67	65	80	82	61	53	63	49
aver		31	30	23	25	16	14	16	17	16	14	20	24
SD		18	17	9	11	12	10	7	6	5	12	11	22

Appendix C

The order of transition through the linear barriers (highway and railway) by the Tibetan antelope females along with the calves, on the way back from the calving ground (August 2012).

a) **Crossing the river**

b) **Collecting near the highway**

(Antelopes running northward towards the Chumaer Bridge)

c) **Crossing the highway**

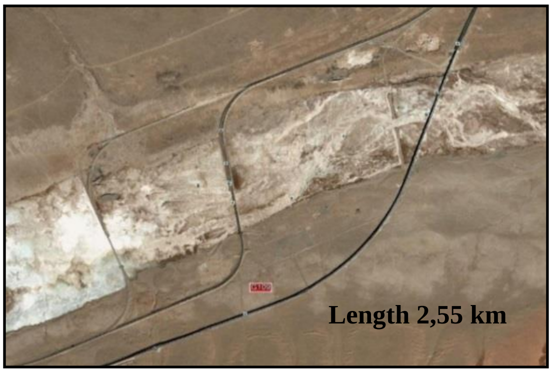
(in front of Wu-Bei underpass)

(in front of Chumaer bridge)

d) **Collecting next to the railway and crossing under it.**

(Wu-Bei underpass)

(Chumaer bridge)



Appendix D

The National Highway 109, Wudaoliang area.

Camera trap, Wu-Bei underpass. 24.06.2011 (H. Igota et. al.) The migration towards the calving ground.

Camera trap, Wu-Bei underpass. 03.08.2012 (T. Nakazawa et. al.) The migration from the calving ground.