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POPULATION STATUS AND DISTRIBUTION OF SNOW LEOPARDS IN WANGCHUCK CENTENNIAL NATIONAL PARK, BHUTAN

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TECHNICAL REPORT

OCTOBER 2016

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Snow Leopard *(Panthera uncia)*
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CONTENTS

ACRONYMS

BWS	Bumdeling Wildlife Sanctuary
CMR	Capture-Mark-Recapture
DNA	Deoxyribonucleic Acid
GIS	Geographic Information System
GPS	Global Positioning System
JDNP	Jigme Dorji National Park
NiMh	Nickel–metal Hydride
SECR	Spatially Explicit Capture-Recapture
USAID	United States Agency for International Development
USD	United States Dollar
WCNP	Wangchuck Centennial National Park
WWF	World Wildlife Fund

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EXECUTIVE SUMMARY

Information about snow leopard (*Panthera uncia*) population status and distribution is required to secure the future of these endangered cats, since these factors affect virtually all other aspects of snow leopard ecology and conservation. Consequently, this study was undertaken to determine the population size, density, and distribution of snow leopards and their prey species in Bhutan's Wangchuck Centennial National Park (WCNP). Notably, this study is the first systematic assessment of snow leopard abundance and density in WCNP. As such, it provides baseline data that will inform future initiatives to conserve this endangered big cat. The survey was conducted in three parts as follows: 1) in Autumn 2011 and Spring 2012 in the upper Chamkar Chu River basin in WCNP's Central Park Range (Survey Area: 797 km^2), 2) in Autumn 2012 and Spring 2013 in the upper Nikka Chu River basin in WCNP's Western Park Range (Survey Area: 621 km^2), and 3) in Spring 2014 in the upper Yangrigang Chu River basin in WCNP's Eastern Park Range (Survey Area: 418 km^2)

The survey featured systematic placement of Reconyx HC500 passive infrared motion-detector camera traps across potential snow leopard habitat. Basing our identification process on the unique spot patterns on the dorsal part of the tail and on the lower limbs, we detected, nine, five, and one adult snow leopard individuals in the Central, Western, and Eastern Park Ranges, respectively. Applying closed population Capture-Mark-Recapture (CMR) models, we estimated that snow leopard abundance in the Central Park Range varies between 9 and 11 individuals (Mean: 9 individuals) and varies between 5 and 17 individuals (Mean: 6 individuals) in the Western Park Range. However, we were unable to estimate how many snow leopards reside in the Eastern Park Range survey area since only one individual was captured which is insufficient for running the population models employed.

In order to estimate snow leopard population density in the study area, we used Spatially Explicit Capture-Recapture (SECR) models and then analyzed our data in the SPACECAP program. We found mean snow leopard density to be 2.39 individuals/100 km^2 in the Central Park Range survey area and 3.36 individuals/100 km^2 in the Western Park Range survey area. Integrating the output from SPACECAP with ArcGIS 10.1, we mapped relative densities of snow leopard populations across both sites and identified key activity centers within them.

Blue sheep, the snow leopard's main prey in Bhutan, were counted using a fixed vantage point counting method in all three survey areas in WCNP. We counted 638 blue sheep in the Central Park Range, with an estimated population density of 1.8 individuals/km^2. In the Western Park Range we counted 330 blue sheep, with an estimated population density of 2.4 individuals/km^2. However, in the Eastern Park Range there were no confirmed sightings of blue sheep.

In addition, during the course of the survey we collected a number of carnivore scat samples which were sent to laboratories for DNA analysis in order to genetically identify the species that produced each sample and estimate the number of snow leopard individuals represented by the samples. In total, five snow leopard individuals were identified in WCNP in this manner.

Our findings indicate that snow leopard population density in the three WCNP survey areas is low compared to neighboring snow leopard range areas in Nepal and India, presumably due to a relative scarcity of prey species and the presence of a higher number of co-predator species. To gain deeper insight into snow leopard ecology, further research into the processes and patterns of interspecific interaction among predators is essential, particularly on interactions between snow leopards and Tibetan wolves since they have similar body sizes and ecological requirements.

We would also like to note here the importance of ecological connectivity between snow leopard populations. Snow leopard populations in the Eastern Himalayas need to be assessed with a meta-population structure in mind. Only in that way can we devise effective conservation strategies and ensure this big cat's long-term survival in Bhutan as well as in the Eastern Himalaya region as a whole. Such an approach becomes all the more critical given that snow leopards are wide-ranging creatures and that climate change is severely impacting their alpine habitat. Unfortunately, human-induced snow leopard habitat fragmentation and loss is also occurring in the Eastern Himalayas and beyond.

Based on the strength of our field survey findings, and in consultation with the various stakeholders, we also provide a list of key recommendations for improving snow leopard conservation in WCNP and elsewhere in Bhutan. These include building the capacity of protected area field staff for snow leopard survey data analysis, assessing interspecific interaction between co-predators, examining snow leopard spatial ecology, and scaling up community-based snow leopard research and conservation activities in WCNP.

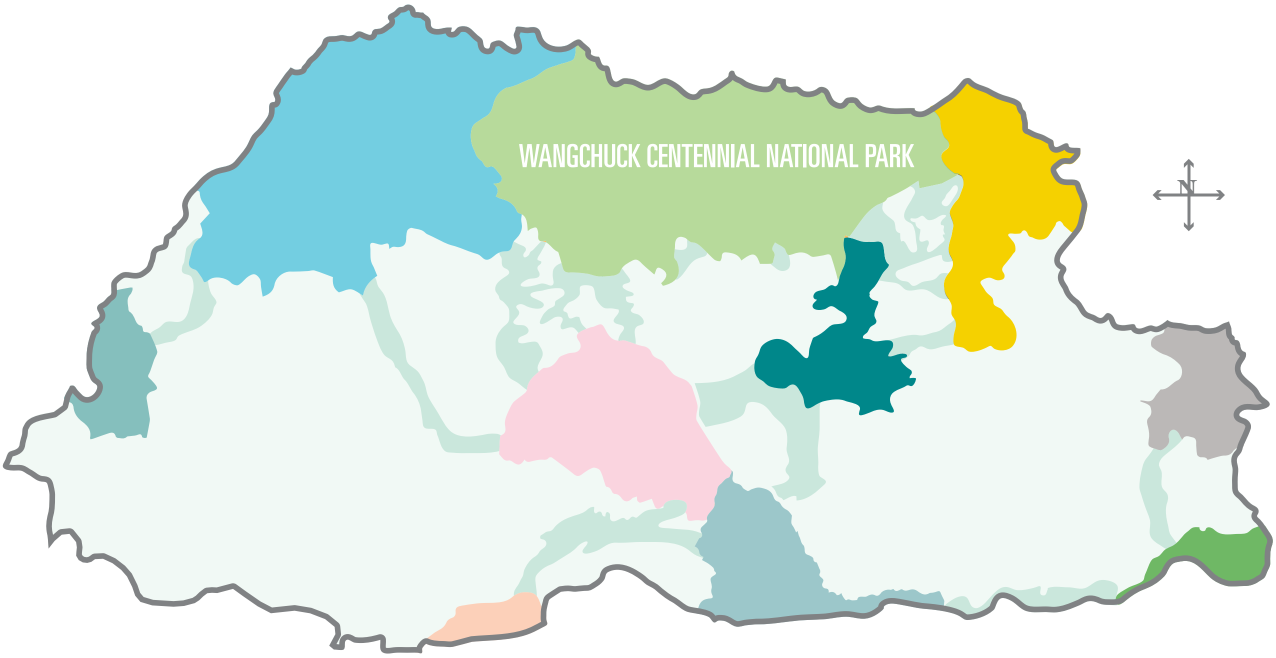
INTRODUCTION

Assessing population size of the endangered snow leopard is a notoriously challenging task, mainly because of this big cat's elusiveness, the remoteness of its habitat and its sparse distribution. Yet determining how many snow leopards there are — and equally importantly, whether their numbers are increasing, stable or decreasing — is essential for securing snow leopard populations across their range. Recent advances in wildlife monitoring techniques, such as camera trapping and molecular genetics, offer the prospect for more precisely estimating populations of elusive animals such as the snow leopard (Jackson et al. 2006; Wang and Macdonald 2009; Janecka et al. 2008; Wegge et al. 2012).

In the Himalayas, the Kingdom of Bhutan lies in the eastern distributional range of the snow leopard and provides an excellent environment for safeguarding wildlife. Nature conservation is not only embedded in the local traditions and religious practices, but forms a fundamental part of government policy too, since Bhutan's constitution stipulates that at least 60 percent of national territory must be maintained under forest cover (Royal Government of Bhutan 2014). At the same time, 39.6 percent of Bhutan's national territory is covered by a network of protected areas that by percentage is the most extensive in the world (Royal Government of Bhutan 2009). The protected area system is also exceptional in the sense that it provides relatively uninterrupted habitat connectivity for snow leopards across the northern arc of Bhutan. Consequently, Bhutan's snow leopard habitat can be regarded as some of the best protected among the 12 snow leopard range nations.

This study was undertaken in Bhutan's Wangchuck Centennial National Park (WCNP) and primarily focused on a series of camera trap surveys (Fig. 1). The objectives of the study were to estimate the snow leopard's population size and density in WCNP and to map their distribution in the park. Ours is the first systematic assessment of snow leopard population size and distribution in the park, which is Bhutan's largest protected area. We feel confident that our methodology will facilitate similar work in other snow leopard range areas of Bhutan, as well as help guide preparations for Bhutan's much anticipated national action plan for snow leopard conservation.

PROTECTED AREAS OF BHUTAN



LEGEND

International Boundary

PROTECTED AREAS

Bumdeling Wildlife Sanctuary
Phibsoo Wildlife Sanctuary
Phrumsengla National Park
Jigme Dorji National Park
Wangchuck Centennial National Park
Jigme Khesar Strict Nature Reserve
Jigme Singye Wangchuk National Park
Royal Manas National Park
Biological Corridor
Jomotshangkha Wildlife Sanctuary
Sakteng Wildlife Sanctuary

Figure 1. Map of the protected areas of Bhutan. Wangchuck Centennial National Park (WCNP) is shown in green on Bhutan's northern border.

STUDY AREA

Established in 2008, Wangchuck Centennial National Park (WCNP) has an area of 4914 km² and, together with neighboring Jigme Dorji National Park (JDNP) and Bumdeling Wildlife Sanctuary (BWS), contributes to safeguarding ecological connectivity along the entire length of the Bhutan Himalaya (Fig. 1). Notably, WCNP's northern boundary forms Bhutan's international border with China's Tibetan Autonomous Region. WCNP is hydrologically important since it is the location of several permanently snow-covered peaks, namely Gangkhar Puensum, Rinchen Zoegila and Jazayla, as well as numerous glacier lakes (Fig. 2). Therefore the park serves as the source area for Bhutan's major river systems, namely the Punatsang Chu (Sankosh), Mangde Chu, Chamkar Chu and Kuri Chu Rivers.

WCNP contains three distinct ecological zones, temperate, sub-alpine and alpine, which in the park occur at elevations of about 2500-3000 m, 3000-4000 m, and 4000-7570 m, respectively. Nearly 85 percent of WCNP's territory lies in the sub-alpine and alpine zones, which remain under snow cover for at least four months per year. As with other mountain ranges, slope, aspect and altitude determine the composition and structure of vegetation communities in WCNP.

One distinctive feature of the Eastern Himalayas is that this region has some of the highest treeline elevations in the world, which often occur at an elevation of 4200 meters or higher (Miehe et al. 2007). Treeline vegetation typically consists of shrubby mixed birch-rhododendron communities while just below, forest line vegetation is predominantly mixed fir-juniper forests (Figs. 3 and 4). Above treeline, slopes with south-facing aspect are dry and dominated by scrubland and xeric vegetation. However, slopes with north-facing aspect are relatively moist and foster mesic grasslands. Alpine meadows form important grazing areas for blue sheep, the snow leopard's main prey, and are patchily distributed in moist areas on valley floors, around glacier lakes and along riparian corridors (Shrestha and Wegge 2008). Vegetation in these meadows is predominantly various sedge species of the genera Kobresia and Carex. Above 5000 m, sparsely vegetated talus, cliff and scree slopes are the predominant land cover.

Figure 2. Gangkhar Puensum, elevation 7570 m, Bhutan's highest mountain and the northern boundary of our survey area.

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Figure 3. Snow leopard habitat above treeline in WCNP's Central Park Range.

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Figure 4. Mixed fir-juniper forest that forms the forest-line vegetation community in WCNP's Central Park Range.

WCNP harbors a remarkable diversity of mammalian carnivores. In addition to the snow leopard (*Panthera uncia*), Asian golden cat (*Pardofelis temminckii*), Himalayan black bear (*Ursus thibetanus*), common leopard (*Panthera pardus*), leopard cat (*Prionailurus bengalensis*), manul or Pallas's cat (*Otocolobus manul*), red fox (*Vulpes vulpes*), Tibetan wolf (*Canis lupus chanco*), Asiatic wild dog or dhole (*Cuon alpinus*), and possibly a marbled cat (*Pardofelis marmorata*) were all recorded in WCNP during the course of this study (see Annex). Among large wild ungulates, blue sheep (*Pseudois nayaur*) are the only species present in core snow leopard habitat (Fig. 5). However, musk deer (*Moschus chrysogaster*), Himalayan serow (*Capricornis thar*), and takin (*Budorcas taxicolor taxicolor*) have all been sighted near treeline in WCNP at the edge of the snow leopard's primary habitat. Pika (*Ochotona sp.*), yellow-throated marten (*Martes flavigula*) and weasel (*Mustela sp.*) were some of the smaller mammals recorded during this survey.

Figure 5. Blue sheep (*Pseudois nayaur*), the snow leopard's main prey in Wangchuck Centennial National Park.

The maximum and minimum temperatures recorded in the study area during our research were about +20°C in April and -20°C in November. As elsewhere in the Himalayas, the seasons are sharply defined. Winter normally starts in November, lasts until February and is generally cold and dry. The spring thaw sets in during March and April. The month of June brings mists and the warm summer monsoon rains as well as an explosion of plant life that draws herders and medicinal plant collectors to the park's alpine pastures. September brings the end of the summer monsoon and the beginning of autumn cooling.

The pastoral communities that live in and around the park subsist primarily on yak husbandry with households typically owning 85 to 90 yaks and 2 to 10 horses (Fig. 6). Most herders have given up rearing smaller livestock such as goats and sheep due to the many predators in the park that prey on these animals and also due to a decline in the demand for wool. Dogs, mostly Tibetan mastiffs, are kept to guard livestock. Animal slaughter is infrequent because of the strong Buddhist belief prevalent among local communities that all killing is wrong.

Herders in WCNP follow transhumant herding practices, moving their livestock to higher altitude pastures in summer and lower altitude pastures in winter, stopping at intermediate altitude grasslands en route. The WCNP survey area discussed in this report is used for livestock grazing primarily during summer and autumn, from about May to November. Each herder possesses the exclusive right to use his or her designated pastures, and moves his herd three to eight times a year. Herders occasionally burn certain pastures to maintain or improve the quality of the grasses and check the growth of undesirable plant species such as woody shrubs.

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Figure 6. Domestic yak *(Bos grunniens).*

In 2004, collection of caterpillar-fungus (*Ophiocordyceps sinensis*), known locally as *yartsa gunbu*, was legalized in Bhutan and it is now an important economic activity for upland communities in WCNP. From April to June each year, as many as one-thousand people converge on alpine meadows in WCNP to harvest this medicinal plant. Caterpillar fungus is in high demand in China and fetches a correspondingly high price. Certain households are known to earn as much as USD 2000 in a single season. This is nearly the equivalent of Bhutan's annual per capita income, which in 2013 was USD 2362.60, earned in a short two-month period (UN Data 2016). Although economically benefiting diligent gatherers, the caterpillar fungus harvest also has a destructive side, which includes disturbance to local wildlife, rampant cutting of firewood, and the piling up of herder refuse in alpine areas (Thukten 2014). All of which leads us to speculate that the alpine ecosystem as a whole may be adversely affected. It is also possible that caterpillar fungus collectors are having adverse impacts on snow leopards and their prey species since these collectors set up camp in prime snow leopard habitat for months at a time.

Actual fieldwork for this survey was carried out between November 2011 and June 2014 in the upper reaches of three watershed complexes in WCNP, namely the Nikka Chu (27°45′ N, 90° 18′ E), Chamkar Chu (27°51′ N, 90°39′ E) and Yangrigang Chu (27°54′ N, 90°54′ E) River basins in WCNP's Western, Central and Eastern Park Ranges, respectively (Fig. 7). The three survey areas selected covered various habitat types in WCNP and took into account considerations of potential habitat connectivity with the two protected areas adjoining WCNP, namely Jigme Dorji National Park (JDNP) to the west and Bumdeling Wildlife Sanctuary (BWS) to the east. Table 1, below, provides a summary of the general features of the three selected survey areas in WCNP's three park ranges.

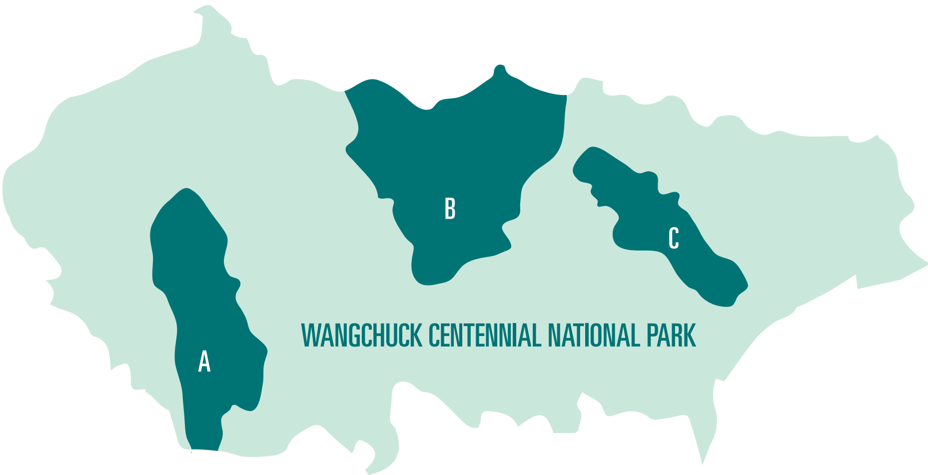

Figure 7. Map of Wangchuck Centennial National Park showing the location of the three survey areas in the upper catchments of the A) Nikka Chu, B) Chamkar Chu, and C) Yangrigang Chu River basins in WCNP's Western, Central and Eastern Park Ranges, respectively.

Table 1. General features of the three selected survey areas in WCNP

	Western Park Range	**Central Park Range**	**Eastern Park Range**
Location	27°45′ N, 90°18′ E	27°51′ N, 90°39′ E	27°54′ N, 90°54′ E
River Basin Name	Nikka Chu	Chamkar Chu	Yangrigang Chu
Survey Area Altitudinal Range (m)	2800–5600	3600–5600	2200–5400
Survey Period	Autumn 2012 and Spring 2013	Autumn 2011 and Spring 2012	Spring 2014
Survey Area Size (km²)	621	797	418
Number of Herding Households Present	507	554	217
Herding Villages Present	Baynil, Dangchu, Sephu and Thangyul	Dhur, Nasiphel, Zhabjithang, Khangdang and Tang	Khangdang
Number of Yaks and Dzo (Yak-Cow Hybrids)	2188	2580	130
Number of Sheep and Goats	26	299	0

FIELD SURVEY METHODOLOGY

To ensure consistency in data collection, WCNP field staff received practical training on both snow leopard and blue sheep survey methods before the field survey got underway (Fig. 8). Afterwards, pilot surveys were undertaken to ascertain snow leopard presence and blue sheep abundance in the survey areas. During these pilot surveys, we also tested the performance of our photographic equipment, Reconyx HC500 HyperFire camera traps activated by passive infrared motion-detectors that were equipped with 4GB SD data cards and rechargeable nickel–metal hydride (NiMh) batteries (Fig. 9). These cameras are capable of taking as many as 15,000 images over a two-month sampling period without any need for changing batteries or data cards. Next, likely snow leopard activity centers and habitat areas were identified based on pilot survey findings and herder consultations, and a formal survey framework for these areas was developed. Only then did we start on systematic camera trap surveys.

Although our fieldwork, including the above mentioned pilot surveys, was conducted from November to June in each of the survey areas, effective camera trap sampling sessions only took place over a total of 45 days between late March and mid-June. We followed the methodology in Jackson et al. (2005) in selecting and preparing the trap sites. On the basis of sign encounter rates, one to three camera trap stations were set up in each 4 x 4 km survey grid cell, with camera traps stations being placed 2 to 4 km apart (Figs. 10-12). One to two cameras were set up at each camera trap station. This approach ensured that each snow leopard present in the survey areas had a good chance of being photographed.

The camera setting mode used depended on the peculiarities of the trap site. Next to wildlife trails, the camera mode used took 3 pictures per trigger at 1 second intervals with no delay. Next to snow leopard scrape sites, the camera mode used produced 5 pictures per trigger, rapid fire with no delay. Camera sensitivity was set at "high" in sites with little or no vegetative cover. To reduce the number of false triggers in densely vegetated sites caused by vegetation blowing in the wind, we switched the sensitivity setting to "medium." We did not move the cameras at any given site during the course the survey period for that site. All trap stations were given unique identifiers and the images were digitally coded. GPS locations of each trap station were taken and later linked to the camera trap images. Camera trap deployment details are summarized in Table 2, below.

As a secondary means of estimating snow leopard populations, predator scat samples found in the survey areas were collected for laboratory DNA analysis to determine the species type and number of snow leopard individuals represented by these samples. At the same time, blue sheep, the primary wild prey species of snow leopards in WCNP, were counted using a fixed vantage point counting method, with observers counting blue sheep through both binoculars and spotting scopes. These counts served as the primary method for gauging the amount of wild prey available for snow leopards in WCNP.


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Figure 8. WCNP field staff during a training session for this survey.


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Figure 9. A typical camera trap station setup used during this survey.

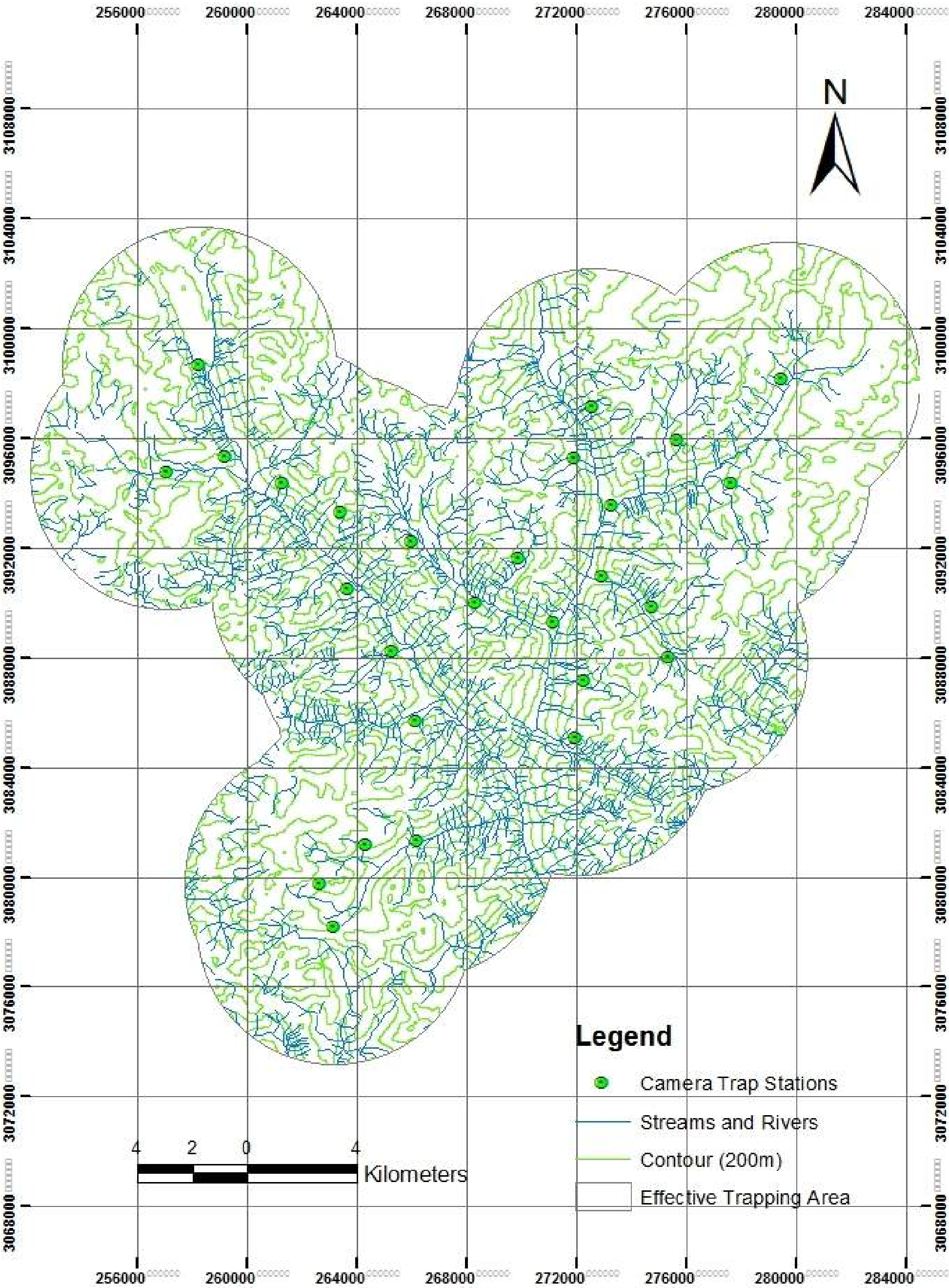

Figure 10. Map showing the distribution of camera trap locations (green dots) in the Central Park Range survey area. Each grid cell is 4 km on a side for a cell area of 16 km².

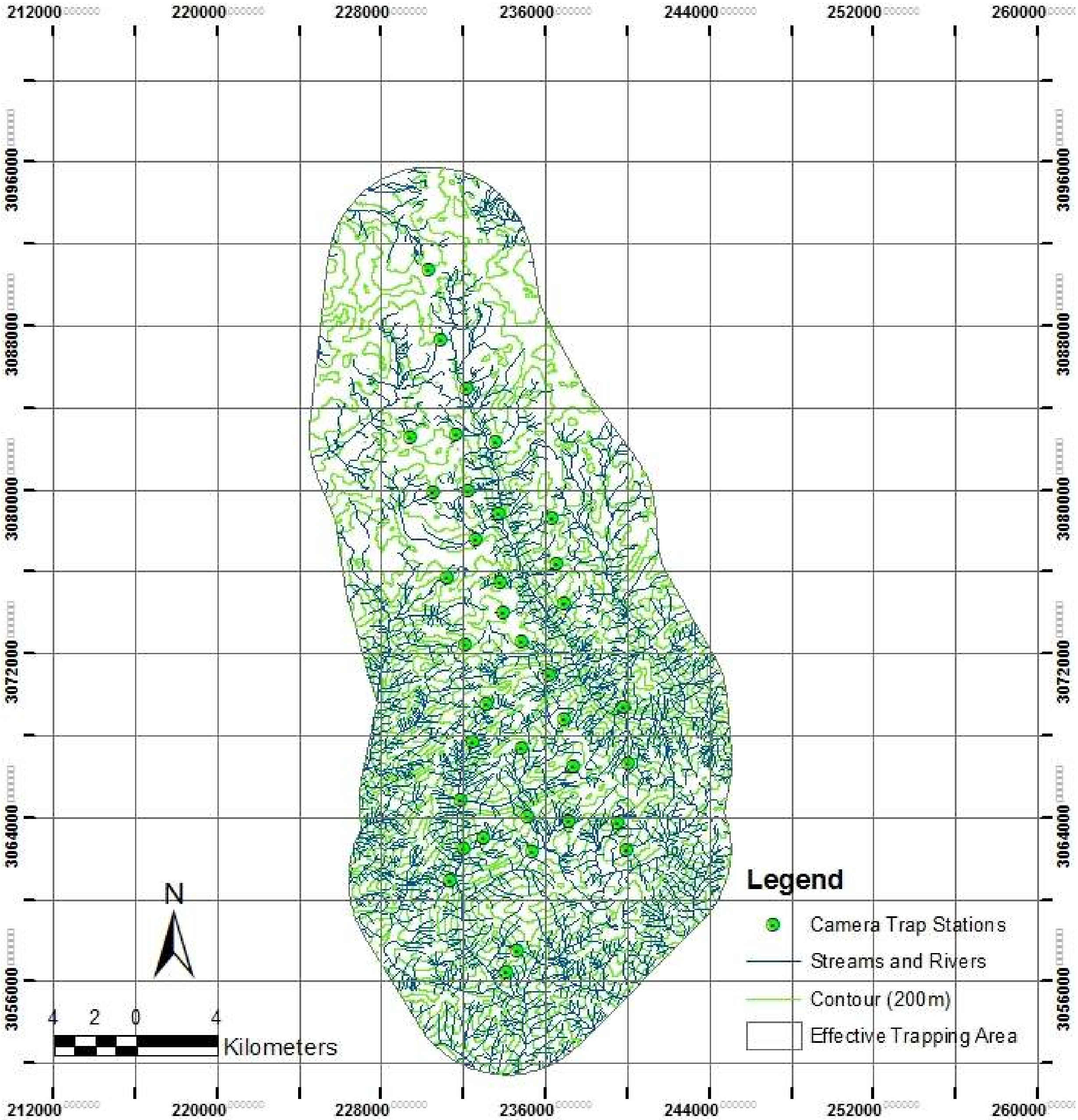

Figure 11. Map showing the distribution of camera trap locations (green dots) in the Western Park Range survey area. Each grid cell is 4 km on a side for a cell area of 16 km².

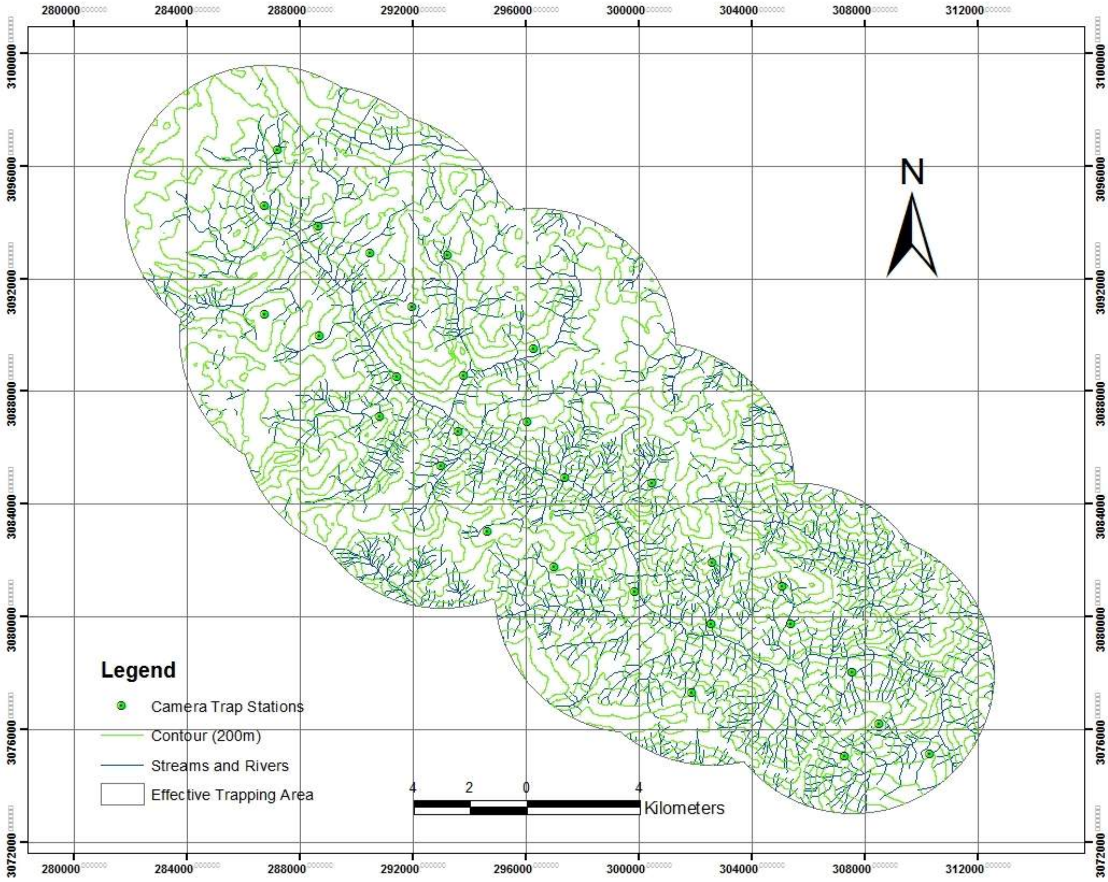

Figure 12. Map showing the distribution of camera trap locations (green dots) in the Eastern Park Range survey area. Each grid cell is 4 km on a side for a cell area of 16 km².

Table 2. Summary of camera trap deployment details for the three survey areas in Wangchuck Centennial National Park

	Western Park Range	Central Park Range	Eastern Park Range
Total Number of Trapping Days/Camera trap	45	45	45
Number of Trap Stations	38	27	32
Sampling Occasions*	9	9	9

*Note: A sampling occasion is defined here as a period of five consecutive days.

DATA ANALYSIS METHODOLOGY

IDENTIFYING SNOW LEOPARD INDIVIDUALS FROM CAMERA TRAP PHOTOS

The shapes and pattern of the snow leopard's spots are unique to each animal, making positive identification of individual snow leopards possible. However, even the slightest variation in a snow leopard's body posture when captured by camera traps can make identification of individuals from a set of photos very difficult if not impossible. Therefore, for identification of individuals we relied mainly on the spot patterns on the dorsal surface of the tail and also on the lower limbs, where spots tend to appear more distinct on photos (Fig. 13). We used Picasa software (version 3) to organize, sort and compare the various images, while photo sequences of up to 135 pictures per encounter event greatly facilitated the identification process. Due to the inherent subjectivity of this process, all identifications were independently cross-checked by three trained volunteers at WWF-Canada's headquarters in Toronto. Final identification was based on group consensus. We believe this approach reduced observer bias and resulted in more precise identification of individuals. Notably, images that were deemed to be of poor quality and/or produced ambiguous results were not used for identification of individuals. In addition, for this survey, only adult snow leopards were considered in population estimates since smaller cubs can pass under a given camera trap's photographic field of view. Cubs and sub-adults also have a higher mortality rate which could introduce bias into population estimates.

ESTIMATING TOTAL POPULATION SIZE AND DENSITY USING STATISTICAL MODELS

To estimate the total number of snow leopards in a survey area, we employed widely used Capture-Mark-Recapture (CMR) models under the assumption of a closed population, with a closed population being defined as one with no snow leopard births or deaths and no movement of snow leopards into or out of a survey area during the data collection period.

To this end, the computer programs CAPTURE (version 1995) and MARK (version 7.1) were used to estimate snow leopard population sizes in WCNP's Central and Western Park Ranges using camera trap data from these two survey areas (Otis et al. 1978; White et al. 1982; Phidot.org 2016). Given that only one snow leopard was camera trapped in the Eastern Park Range, there was insufficient input data for running the population models for this survey area. To estimate snow leopard population density, we used Spatially Explicit Capture-Recapture (SECR) models in the SPACECAP program (version 1.1.0)(Gopalaswamy et al. 2012). For the Central Park Range only, population density estimates from SPACECAP were verified using maximum-likelihood-based SECR models in the DENSITY program (Efford et al. 2004).

Input data for SECR models consisted of three different types: 1) camera trap deployment details, including dates, locations, and operational status of trap sites; 2) capture details of individual snow leopards that were camera trapped, namely date, time, location, and ID codes of positively identified individuals; and 3) potential snow leopard habitat for a given survey area. Potential habitat represents possible snow leopard activity sites and was generated by overlaying a grid consisting of 0.25 km^2 pixels across the respective survey areas, after which potentially unsuitable habitat areas were clipped out, including water bodies, human settlements, and areas above or below general snow leopard elevation range, which in WCNP is from about 3800 m to 5000 m. Finally, Arc GIS software (version 10.1) was used to produce pixel maps of SPACECAP results showing snow leopard population densities across the Central and Western Park Range survey areas as divided into three population density categories: 1) Low Density: ≤0.020 individuals/km^2, 2) Moderate Density: 0.021 to 0.040 individuals/km^2, and 3) High Density: ≥0.041 individuals/km^2 (Fig. 14 and 16).

RESULTS

CAMERA TRAP PHOTO IDENTIFICATION AND STATISTICAL MODELS

Central Park Range

In the Central Park Range, the camera trapping effort amounted to 1116 trap nights (total number of camera traps deployed multiplied by the total number of nights each individual trap was functioning) and yielded 1013 photos of snow leopards including 9 individuals that were identified from photos (Table 3, Fig. 13). The snow leopard capture rate for this survey area was 8.17 individuals per 100 nights and the population during the survey period is likely to have been closed as per our close test results (Stanley and Burnham 1999). Due to the small sample size, the effect of individual heterogeneity (e.g. differences in age and sex, inquisitiveness, and social status of individuals) could not be examined. Results of camera trap data analysis in CAPTURE provided total population estimates for the Central Park Range ranging from 9 to 11 snow leopard individuals (Table 5). The mean population estimate of 9 individuals was found to be consistent with the population estimates obtained through other maximum-likelihood-based approaches obtained using both the DENSITY and MARK programs. A SPACECAP analysis of camera trap data yielded a mean population density estimate for potential habitat areas in the Central Park Range of 2.74 snow leopards per 100 km^2 while at the 95 percent confidence interval, the density estimates in this study area ranged from 2.67 to 2.97 individuals per 100 km^2 (Table 5). By comparison, the DENSITY program gave a slightly lower population density estimate but wider range of densities at the 95 percent confidence interval. Notable centers of snow leopard activity in WCNP's Central Park Range survey area were found to occur at four principal sites, the Gurphu, Dhirup, Chachena, and Tolegang pasture areas which are all located in an altitudinal range of 4000 to 5000 m (Fig. 14).

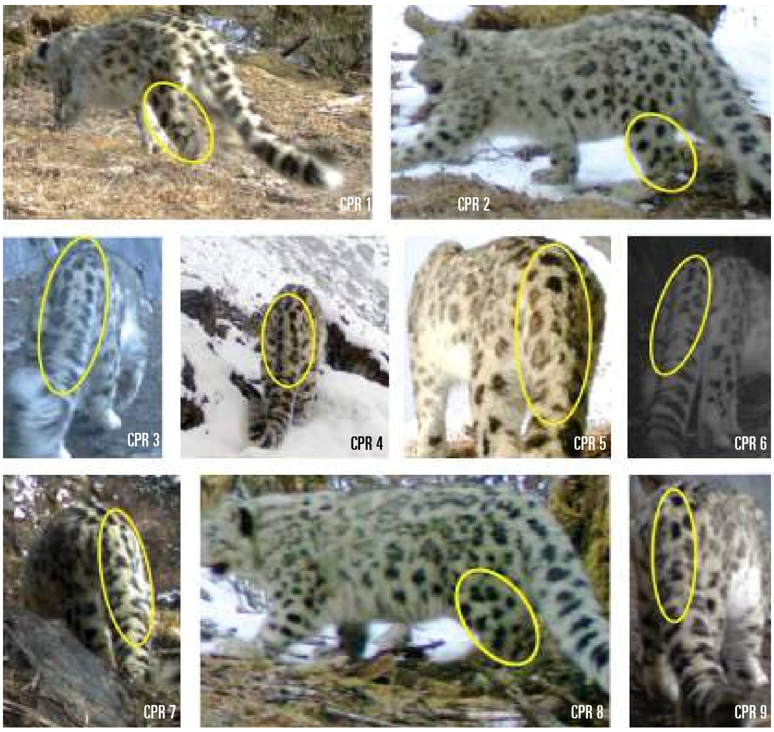

Figure 13. Camera trap photos of nine different snow leopard individuals taken in WCNP's Central Park Range.

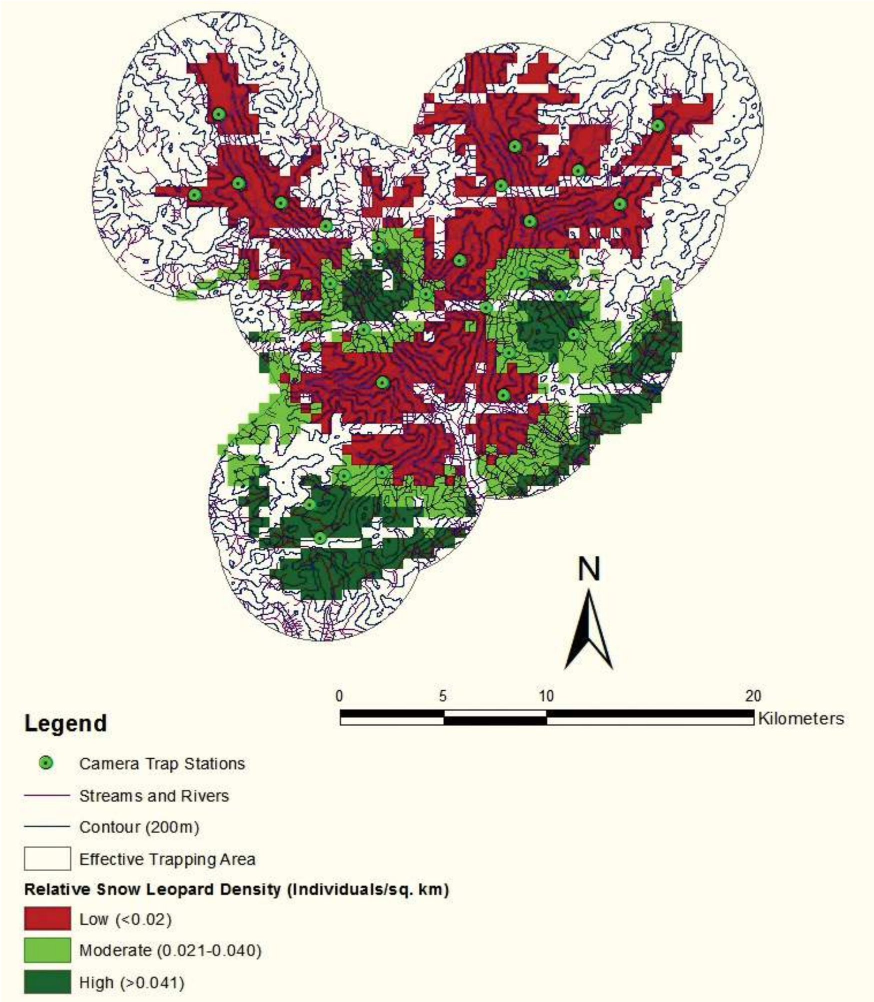

Figure 14. Map of relative snow leopard population density in WCNP's Central Park Range survey area as generated by the SPACECAP program using camera trap survey data.

Western Park Range

In the Western Park Range, the camera trapping effort amounted to a total of 610 trap nights and yielded 249 photos of snow leopards, including 5 adult and 2 sub-adult individuals (Table 3, Fig. 15). The snow leopard capture rate for this survey area was 15.56 individuals per 100 nights and the population during the survey period is likely to have been closed. In line with standard protocol, population modeling analysis was only performed for the five adult individuals identified due to higher mortality rates and a higher likelihood of being missed by camera traps for sub-adult snow leopards. Again, we could not test the effect of individual heterogeneity because of the small sample size. Results of camera trap data analysis in CAPTURE provided total population estimates for the Western Park Range that ranged from 5 to 11 snow leopard individuals with a mean of 6 individuals (Table 5). A SPACECAP analysis of camera trap data yielded a mean population density estimate for potential habitat areas in the Western Park Range of 3.36 snow leopards per 100 km^2 while at the 95 percent confidence interval, population density in this survey area ranged from 1.14 to 8.91 individuals per 100 km^2 (Table 5). Notable centers of snow leopard activity in WCNP's Western Park Range survey area were found to occur at four principal sites, the Umtasho/Tampela, Balla/Tsokar, Yaktsha, and Dotosongpan pasture areas which are located in an altitudinal range of 3900 to 5000 m (Fig. 16).

Figure 15. Camera trap photos of seven different snow leopard individuals taken in WCNP's Western Park Range.

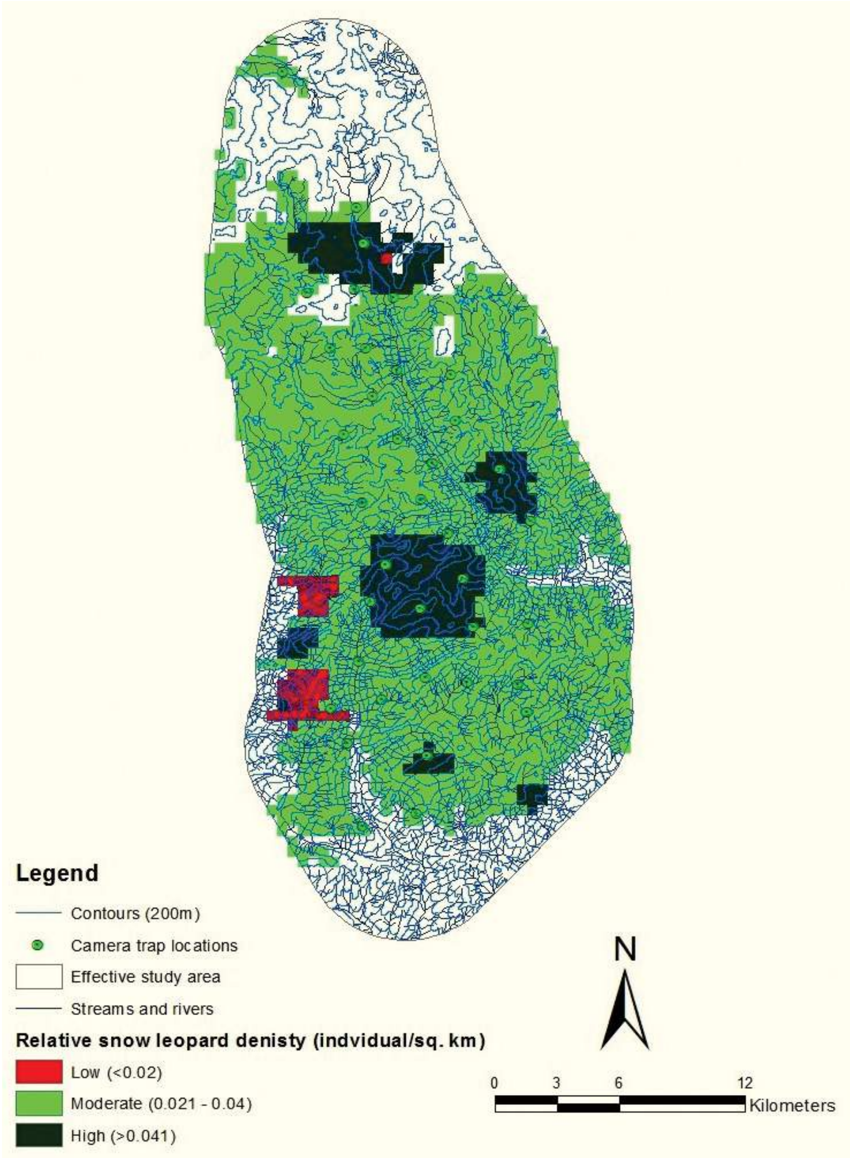

Figure 16. Map of relative snow leopard population density in WCNP's Western Park Range survey area as generated by the SPACECAP program using camera trap survey data.

Eastern Park Range

In the Eastern Park Range, only one snow leopard was photographed (Table 3, Fig. 17). Consequently, we did not have sufficient input data for using the statistical models to estimate snow leopard population size and density in the Eastern Park Range. In addition, the three camera trap photos obtained of this animal were of such poor quality that it could not be determined if it had been photographed earlier in the Central and Western Park Ranges.

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Figure 17. Camera trap image of the only snow leopard photographed in the Eastern Park Range survey area of WCNP.

Table 3. Summary of camera trapping deployment data and results for the three survey areas in Wangchuck Centennial National Park

	Western Park Range	Central Park Range	Eastern Park Range
Total Number of Trap Nights	610	1116	893
Number of Trap Stations that Captured Snow Leopard Images	8	16	1
Total Number of Snow Leopard Images	249	1013	3
Snow Leopard Capture Rate (Captures per 100 nights)	15.56	8.17	0.11
Total Number of Snow Leopards Individuals Identified	5 Adults 2 Sub-adults	9	1*

* Note: Although one snow leopard was camera trapped in the Eastern Park Range, the photos were of too low quality to be used for further comparative identification of individuals.

SCAT SAMPLE DNA TESTING

Central Park Range

During the autumn 2011 pilot survey of the Central Park Range, 50 predator scat samples were collected for genetic analysis as another method for estimating snow leopard population size in this survey area. These samples were sent to the National Center for Biological Sciences in Bangalore, India for DNA analysis. Of these 50 samples, 11 were determined to be snow leopards. However, due to the poor quality of these scat samples, identification of snow leopard individuals could not be made.

Western and Eastern Park Ranges

During the autumn 2012 and spring 2014 surveys of the Western and Eastern Park Ranges, respectively, a total of 36 predator scat samples were collected. These samples were sent to the Aaranyak Wildlife Genetics Laboratory in Guwahati, Assam, India for DNA analysis. In total, 11 scats were identified genetically as being from snow leopards while the remainder of the samples were from red fox (*Vulpes vulpes*), Asiatic wild dog (*Cuon alpinus*), and wolf (*Canis lupus*). Of these 11 scat samples, further genetic analysis revealed 5 unique snow leopard individuals in the Western Park Range while Aranyak reported that scat from 3 of these 5 individuals was later collected in the Eastern Park Range (Table 4). If these results are accurate, it would clearly demonstrate a high degree of connectivity between the three park ranges with respect to snow leopard migration. However, further study is needed to confirm these findings. Notably, individual identity for one snow leopard scat sample collected on December 14, 2012 in the Western Park Range could not be made.

Thus, in total, of 86 scat samples collected in WCNP, only 5 snow leopard individuals were identified, a figure much lower than was obtained through camera trapping.

Table 4. Details of individual identification snow leopards from DNA analysis of scat samples from WCNP's Eastern and Western Park Ranges

Snow Leopard Individual Lab ID	Western Park Range Scat Collection Date	Eastern Park Range Scat Collection Dates
WCP_SL1	Dec. 14, 2012	April 23, 2014
WCP_SL2	Dec. 17, 2012, Dec. 18, 2012	April 22, 2014, April 23, 2014
WCP_SL3	Dec. 21, 2012	April 22, 2014
WCP_SL4	Dec. 17, 2012	N/A
WCP_SL5	Dec. 19, 2012	N/A

BLUE SHEEP POPULATION SURVEY

Blue sheep are the single most important wild prey species for snow leopards in WCNP. Given their importance, during the course of this survey we also counted blue sheep in the survey areas to estimate their population size and density. Using a fixed vantage point counting method, potential blue sheep habitat was systematically scanned in the morning from about 8 AM to 11 AM and again in the evening from about 3 PM to 7 PM, the times of day when blue sheep are known to be most active. Results of these counts are provided below.

Central Park Range

From October 21 to November 21, 2011, a blue sheep count was conducted in WCNP's Central Park Range. This survey covered a 355 km^2 area of the park's upper Chamkar Chu watershed. In total 638 blue sheep were counted in the Central Park Range during the survey period (Table 5). Of these 638 animals, 409 individuals were classified to sex and age categories which revealed a sex ratio of 102 males per 100 females and an autumn survival rate of 70 young per 100 females. Of 35 blue sheep groups that were completely counted, the average group size was 11.7 individuals although nearly two-thirds of these groups had less than 10 individuals. Average blue sheep population density in the Central Park Range blue sheep survey area was estimated to be about 1.8 individuals/km^2, which is relatively low compared to other adjacent blue sheep range areas. This is possibly due to heavy predation following the recent cessation of goat and sheep herding in the range by local herders. Blue sheep in the Central Park Range were mainly distributed in an altitudinal range of 4000 to 5000 m.

Western Park Range

From November 19 to December 20, 2012, a blue sheep count was conducted in WCNP's Western Park Range. This survey covered a 135 km² area of the park with intensive observations being made in the Tsela, Somjithang, Yakta, Simley, Sinthapu, Balala, and Dortsho pasture areas of the Western Park Range. In total, 330 blue sheep were counted in the western range during the survey period (Table 5). Of these 330 animals, 120 individuals were classified to sex and age categories which revealed a sex ratio of 122 males per 100 females and an autumn survival rate of 60 young per 100 females. Of 12 blue sheep groups that were completely counted, the average group size was 11 individuals. Average blue sheep population density in the Western Park Range blue sheep survey area was estimated to be about 2.4 individuals/km² with these animals being mainly found on alpine pastures located between 4000 and 4500 m in elevation.

Eastern Park Range

From April 8-28, 2014 we conducted a snow leopard prey species survey in WCNP's Eastern Park Range. This survey covered an area of about 90 km². However, during the survey period only one animal was sighted that was possibly a blue sheep but was seen at such a long distance that it could not be positively identified. Small ungulate pellets were also found, but it was not be determined whether these were from blue sheep or from domestic animals.

Table 5. Estimates of snow leopard and blue sheep population sizes and densities in Wangchuck Centennial National Park obtained through various methodologies

	Western Park Range	Central Park Range	Eastern Park Range
Number of Adult Snow Leopards Individuals Identified from Camera Trap Photos	5 (also 2 Sub-adults)	9	1*
Estimated Total Snow Leopard Population Size**	Mean: 6 (Range: 5-11)***	9 (Range: 9-11) ***	N/A
Estimated Snow Leopard Population Density† (per 100 km²)	Mean: 3.36 (Range: 1.14-8.91) ***	Mean: 2.74 (Range: 2.67-2.97) ***	N/A
Snow Leopard Individuals Identified from DNA Analysis of Scat	5	0††	3†††
Total Blue Sheep Count	330	638	0
Estimated Blue Sheep Population Density (per km²)	2.4	1.8	0

Notes:

* Although one snow leopard was camera trapped in the Eastern Park Range, the photos were of too low quality to be used for further comparative identification of individuals.

** Total population size estimates are based on closed Capture-Recapture models. Heterogeneity model (Mh) and model average estimates were used for the Central and Western Park Ranges, respectively.

*** At the 95 percent confidence level.

† Population density estimates are based on Bayesian Spatially Explicit Capture-Recapture models.

†† Snow leopard scat samples collected were of too low quality to positively identify individuals.

††† According to the laboratory, these three individuals were not unique but also among the 5 individuals identified from the scat samples collected in the Western Park Range (see Table 4).

CONSERVATION IMPLICATIONS

Our findings show that breeding snow leopard populations exist in Wangchuck Centennial National Park (Fig. 18). Based on evidence gathered and evaluated, WCNP can now be considered a core snow leopard range area of the Eastern Himalayas. We have verified the presence of 9 adult snow leopards in the Central Park Range and 5 in the Western Park Range. In addition, we obtained evidence of another snow leopard adult in the Eastern Park Range. However, centers of snow leopard activity in the study areas are largely confined to the Gurphu, Dhirup, Chachena, and Tolegang pasture areas in the Central Park Range and the Umtasho/Tampela, Balla/Tsokar, Yaktsha, and Dotosongpan in the Western Park Range. Considered spatially, snow leopard population density appears to increase from east to west in WCNP. This comes as no surprise, given the lack of blue sheep, the primary wild prey of snow leopards, in the Eastern Park Range while blue sheep population densities were estimated to be 1.8 and 2.4 individuals per km^2 in the Central and Western Park Range study areas, respectively (Table 5)(Shrestha et al. 2012). Even if we set aside the question of prey availability, the snow leopard's range appears to be relatively limited in the Eastern Park Range study area where the landscape is dominated by extensive forests. We therefore conjecture that prime snow leopard habitat in the Eastern Park Range is located farther north, in the unstudied alpine areas along the international border with China.

In comparison with other Himalayan snow leopard range areas to the west of WCNP, such as Bhutan's Jigme Dorje National Park (JDNP), the Phu Valley in Nepal, and Hemis National Park in Ladakh, India, snow leopard density estimates in WCNP are fairly low (Thinley 2014; Wegge et al. 2012; Jackson et al. 2006). This could be due to the prevalence of many co-predators in WCNP combined with low prey numbers in the park. Based on the results of the autumn 2011 blue sheep survey of the Central Park Range, we conclude that the blue sheep population in this area is suppressed, with groups occurring in smaller sizes and having an apparent preference for habitat close to escape cover (Shrestha et al. 2012). This may indicate a higher degree of predation pressure on the blue sheep population in WCNP. In addition, domestic sheep and goat numbers in WCNP are in sharp decline due to local herders giving up rearing of small stock, which may eventually lead to improved alpine pasture conditions and an increase in blue sheep numbers. However, at present, the rate of predation on blue sheep by both snow leopards and Tibetan wolves would be expected to rise as these predators necessarily turn from domestic sheep to wild prey (Wegge et al. 2012). Given this situation, snow leopards and wolves are likely to compete for prey resources as both have similar body sizes and ecological requirements (Jumabay-Uulu et al. 2013).

We do not know of any work that has quantified the processes and outcomes of competition between wolves and snow leopards except for the single paper by Jumabay-Uulu et al. (2013). While this article does note significant overlap in the diets of snow leopards and wolves, a dietary overlap does not in and of itself denote competition, except possibly when the common prey of these two predators is in short supply. We feel that further research into prey requirements, prey availability and the population dynamics of both snow leopards and Tibetan wolves is needed to gain an understanding of the nature and extent of interactions between these two predators. To this end, established techniques such as non-invasive molecular DNA sampling, telemetry studies, and study of the dietary habits of these two predators could provide insight into the degree of competition for prey between snow leopards and Tibetan wolves in WCNP.

Another fundamental requirement for the conservation and management of snow leopards is the need for implementation of pro-active conservation initiatives for their long-term survival. The loss, degradation and fragmentation of snow leopard habitat resulting from anthropogenic as well as climatic stressors are widely recognized as key threats to the continued existence of this species. A recent study by Forrest et al. (2012) predicts that as the climate of the eastern Himalaya gets warmer and wetter, Bhutan could lose nearly 50 percent of its current snow leopard habitat to an advancing treeline, including snow leopard range areas in and around WCNP. Given that WCNP adjoins Jigme Dorje National Park (JDNP) and the Bumdeling Wildlife Sanctuary (BWS), loss of habitat in WCNP could also lead to a loss of connectivity between these two adjacent protected areas. Given that snow leopards require large areas over which to roam, maintaining connectivity between these three protected areas with respect to snow leopard migration is crucial for maintaining the ecological resilience of these reserves in the face of a rapidly changing climate (McCarthy et al. 2005; Wangchuk 2007; Hannah et al. 2002). We therefore recommend undertaking snow leopard satellite telemetry studies to examine routes used by snow leopards to move between these three protected areas. Such studies would not only help us better understand the spatial requirements of snow leopards in the Bhutan Himalaya, but would also contribute to better identifying and mapping habitat refugia, including core snow leopard range areas and biological corridors. Ultimately, this will make it possible to devise science-based, landscape-scaled, climate-integrated conservation strategies for the protection of snow leopards and their prey.

Figure 18. A snow leopard family camera trapped in a forested section of the Central Park Range study area in Wangchuck Centennial National Park.

KEY RECOMMENDATIONS

Based on our 2011-2014 snow leopard field studies and interactions with a diverse group of stakeholders, we provide the following recommendations to guide snow leopard conservation and research initiatives in WCNP.

Capacity-building for WCNP Staff

In the course of project implementation, we trained WCNP staff on how to gather field data on snow leopards and blue sheep, the snow leopard's primary prey species in WCNP. Their newly acquired skills can now be utilized to conduct similar surveys in other ranges in Bhutan. However, further training on data analysis, interpretation of results, and scientific reporting is required to enable the WCNP research team to function independently.

Snow Leopard Spatial Ecology

Now that a population assessment for snow leopards in WCNP has been carried out, there is a need to determine whether there is sufficient habitat in the park to maintain and/or increase current snow leopard numbers. It is also important to know how the local snow leopard populations in WCNP are connected to those in JDNP in the west and BWS in the east, as well as to snow leopard populations in Tibet to the north. Protecting the connectivity between these populations will be crucial to safeguarding the long-term survival of snow leopards in the region as a whole, which is becoming more urgent in the light of looming climate change threats. Satellite telemetry and/or further non-invasive genetic study of snow leopards could provide useful answers to these questions. Work on this front is already ongoing in other snow leopard range countries, and the results from Bhutan will be critical in bridging the existing information gap with respect to habitat connectivity in the snow leopard's eastern distributional range.

Co-predator Interaction in WCNP

In terms of predator species richness, Bhutan's snow leopard habitat is unique in the sheer number of predators that snow leopards share their habitat with, which include Tibetan wolves, Asiatic wild dog, and common leopards. As discussed above, the predator species richness may be contributing to a suppressed blue sheep population. We therefore recommend undertaking further studies to gather more information about the processes, patterns and outcomes of interaction between snow leopards and other predators present in WCNP, especially those mentioned above. Such studies could prove valuable in improving effectiveness of conservation plans.

Caterpillar Fungus Collection

Since 2004, hundreds of local residents have collected caterpillar fungus (Dzongka: *yartsa gunbu*) in WCNP's alpine meadows each spring, providing a large boost to the local economy. However, we do not know how this large annual influx of humans into snow leopard range areas affects snow leopards, their prey, and habitat. Elsewhere, human activity and disturbance is known to significantly affect the normal activity patterns of both snow leopards and their prey (Wolf and Ale 2009, Namgail et al.

2007). Notably, caterpillar fungus collection occurs each June, coinciding with the annual blue sheep parturition period. Therefore, it is likely that the increasingly high levels of human activity in WCNP's alpine meadows during this period could be adversely affecting blue sheep in the process of giving birth. Further research on disturbance of snow leopards, their prey, and habitat by caterpillar fungus collectors is a key need if one is to devise a sound conservation strategy for securing both local livelihoods and local biodiversity.

Community-based Research and Conservation Activities

As elsewhere, community-based conservation activities have enormous potential to contribute towards improving snow leopard conservation effectiveness in WCNP. Given the large loss of livestock to wild predators that local herders currently face each year, involving these herders in snow leopard conservation work is imperative if retaliatory killing is to be prevented. Several areas where local herders, Buddhist monks, and others can easily participate in snow leopard conservation activities include snow leopard population monitoring, human-wildlife conflict mitigation, and anti-poaching activities.

WCNP field staff have been fully trained and are experienced on conducting snow leopard monitoring surveys, and they are also already equipped with the necessary camera traps and GPS units. Therefore, they should be able to train interested local herders and monks as citizen scientists to conduct community-based snow leopard and prey species population monitoring at minimal expense. During the course of field research, it was noted that Khangdang Village, located north of Jakar in WCNP's Central Park Range, could serve as a trial site for the setting up a pilot citizen scientist program.

With respect to human-snow leopard conflict mitigation, snow leopard range countries are increasingly acknowledging the importance of participatory human-snow leopard conflict mitigation programs targeting livestock herders in snow leopard range areas. These include education on conflict prevention, predator-proofing corrals, and setting up community based livestock insurance schemes as well as harmonizing conservation goals with livelihood improvement opportunities. Implementation of such measures in WCNP could provide benefits for both snow leopards and local herders (Gurung et al. 2011).

Finally, WCNP staff continue to report poaching problems in upland areas of WCNP, particularly poaching of musk deer near treeline. This is of concern for snow leopard conservation since snow leopards are known to occasionally descend below treeline, particularly in winter or when transiting between mountain ranges, while snares used for musk deer indiscriminately trap all wildlife that encounter them (Fig. 18). Therefore, one area of community conservation that locals can assist WCNP rangers with is anti-poaching work, including snare removal, joint anti-poaching patrols, and reporting movements of suspected poachers to WCNP authorities.

CONCLUSIONS

As elsewhere in the snow leopard's range, conducting this first snow leopard monitoring survey in WCNP proved extremely challenging due to the forbidding high altitude terrain snow leopards inhabit in WCNP, their elusive behavior, and their sparse distribution. In spite of these challenges, the survey was a success and definitively proved the existence of an important breeding population of snow leopards in WCNP. Through this process, a robust methodology for monitoring snow leopards that is anchored in the best available science was developed specifically for Bhutan that can be implemented elsewhere in the Kingdom. In addition, a core team of WCNP field staff was trained to independently conduct snow leopard monitoring activities who can lead this research work in Bhutan's other snow leopard range areas. Given that the status of snow leopards in the WCNP region was virtually unknown prior to this study, this research has made a significant contribution to our knowledge of snow leopard distribution in the eastern Himalaya. Consequently, the findings contained in this report will serve as the foundation for improving conservation efforts for this species in WNCP and will contribute towards the continued survival of the snow leopard in Bhutan and beyond.

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ANNEX: WILDLIFE CAMERA TRAP PHOTOS FROM WCNP

Snow leopard (*Panthera uncia*)

Asian golden cat (*Pardofelis temminckii*)

Himalayan black bear (*Ursus thibetanus*)

Common leopard (*Panthera pardus*)

Leopard cat (*Prionailurus bengalensis*)

Manul or Pallas's Cat (*Otocolobus manul*)

Tibetan wolf (*Canis lupus chanco*)

Red fox (*Vulpes vulpes*)

Asiatic wild dog or dhole (*Cuon alpinus*)

A photo of what may possibly be a marbled cat (*Pardofelis marmorata*), although better photos are needed for positive identification.

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