Snow Leopard Conservation Grants Program

Fuzzy Logic modelling of Snow Leopard populations in response to threats from climate change

University of Cumbria, Central Queensland University, The Kazakh National University & Almaty State Nature Reserve

Final Project Report

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This report should be cited as:

Convery, I., Baibagysov, A., Baiturbayev, K., Deecke, V.B., Harpley, D., Holt, C., Janyspayev, A.D, Nevin, O.T., Nurtazin, S, Smith, D.J. van der Velden, N.K. (2015) Fuzzy Logic Modelling of Snow Leopard Populations in Response to Threats from Climate Change. Centre for Wildlife Conservation, University of Cumbria, Ambleside, UK (2015).

EXECUTIVE SUMMARY

The snow leopard population in Kazakhstan represents a small but important component of the species range, making up around 2.7% of the global range, of which 18,673 km^2 lies within protected areas. The most recent population estimate, by Jackson et al. (2008), suggests that there are around 180-200 individuals. Prior to this study there were no reliable estimates of snow leopard numbers in Almaty State Nature Reserve, one of the only two stable populations of snow leopards in Kazakhstan.

In total 40 camera traps were deployed for a total of 5152 traps nights and yielded 50 independent capture events of snow leopards (with between 1 and 10 images per event), 275 capture events of primary prey and 68 capture events of secondary prey. The study capture rate of 0.97 independent capture events per 100 trap nights is at the higher end of the range experienced by other studies (see McCarthy et al., 2008) and mark-recapture modelling estimated 11-18 individual snow leopards in the study area which suggests density between 4.4 and 7.2 individuals per 100km^2. Our population estimate for the whole reserve is 39.6 individuals, with a standard error of 5.44536 individuals and a 95% confidence interval of 39 to 64. Analysis of movement patterns suggests that individuals frequently crossed valley bottoms and used densely forested habitat in winter, which may indicated prey switching from ibex to forest ungulates.

The University of Cumbria has developed a fuzzy logic model which aggregates a wide range of socio-economic and ecological data and provides a tool that can be used to inform the sustainable natural resource and landscape management decision-making process. Our model predicts the consistent negative impact of climate change (warming) at elevations below the tree line; this is particularly significant as the potential positive impacts for snow leopards at high elevation are slower to kick in thereby increasing the habitat squeeze associated with climate change in mountain habitats.

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ACKNOWLEDGEMENTS

We thank the Snow Leopard Network for their generous support in funding this research, and in particular Rakhee Karumbaya, the Program Coordinator for Snow Leopard Network, for her unstinting assistance. We also thank our respective institutions and in particular the support and hospitality provided by Professor Sabir Nurtazin from KazNU, and the staff of Almaty State Nature Reserve. Dr Convery, Dr Deecke, Dr Holt and Dr Smith would like to thanks Dr Elspeth Lees and Ms Nicola Martin for all their assistance in managing this project. The Lakeland Wildlife Oasis kindly provided access to their 4 captive individuals to collect photographs to test the pattern recognition software.

LIST OF ABBREVIATIONS

ASNR Almaty State Nature Reserve

CWT Cumbria Wildlife Trust

CQU Central Queensland University

IPCC - Intergovernmental Panel on Climate Change

KazNU – Kazakh National University

UoC – University of Cumbria

1. INTRODUCTION

The snow leopard (*Panthera uncia*) is categorized as Endangered on the IUCN Red List and is listed in Appendix I of CITES. The population in Kazakhstan represents a small but important component of the species range, making up around 2.7% of the global range, of which 18,673 km^2 lies within protected areas. The most recent population estimate, by Jackson et al. (2008), suggests that there are around 180-200 individuals. Comparatively little is known about this population, however, and this project, based in Almaty State Nature Reserve (ASNR) Southern Kazakhstan, was developed to address two specific research/information needs. *First, Snow Leopard Population Size*, and second, the development of *Snow Leopard Monitoring Techniques*. The project was also developed to address two major snow leopard threats (Snow Leopard Network, 2014): *Institutional Capacity* and *Climate Change*.

1.1. Snow Leopard Population Size

Prior to this study there were no reliable estimates of snow leopard numbers in ASNR, one of the only two stable populations of snow leopards in Kazakhstan (Saparbayev & Woodward, 2008). The only significant recent research concerning snow leopard populations in ASNR was conduced by Saltore Saparbayev and Dilya Woodward (2005 - 2008)[1]. They identified that snow leopard habitat lies in the range of subalpine and alpine zones of 2500 m and higher, and that in winter the animal descends to the forest zone and river valleys following its main prey, Siberian ibex (*Capra sibirica*). They also noted a decline in the number of direct encounters with snow leopards: from an average of 1.6 encounters/year between 1975 – 2000, to 0.8 encounters/year over 2000 – 2008. During their research they encountered limited signs of snow leopard activity and were unable to produce a robust population estimate (Saparbayev, pers.comm. 2012).

1.2. Snow Leopard Monitoring Techniques Development

The University of Cumbria has developed a fuzzy logic model which aggregates a wide range of socio-economic and ecological data and provides a tool that can be used to inform the sustainable natural resource and landscape management decision-making process. The approach builds a hierarchical framework that illustrates the interactions and interdependencies between and within individual environmental descriptor components and their subsequent higher order descriptor domains. The method can also be employed in the construction of sustainability models that seek axiomatic guidance for the selection of rules regarding conservation and natural resource management in a

[1] There is an earlier estimate of 100-110 for Kazakhstan, including 30-35 in Almaty State Reserve: Zhiryakov, V.A. and Baidavletov, R.Zh. 2002. Ecology and behaviour of the snow leopard in Kazakhstan. *Selevinia* 2002: 1-4 (in Russian).

manner able to accommodate multiple relationships, many of which can often be characterised by conflicting needs and outcomes. In this work adopting a fuzzy logic-based approach enables the combination of snow leopard population and distribution modelling to be incorporated alongside a range of environmental indicators in a manner that allows for outputs to reflect the potential for climate related population change. Thus the fuzzy logic outputs provide a tool that can be used to inform and support climate smart adaptation of snow leopard conservation plans within and beyond the reserve.

1.3. Institutional Capacity

Almaty State Nature Reserve (ASNR) was established in 1931 and is situated in the central part of the Zailliysky Alatau range, in the most northern part of the Tian Shan mountain range, southern Kazakhstan. The reserve covers an area of 733 km^2, with an elevation range from 1200m to 4973m (Saparbayev & Woodward, 2008; Farrington, 2005). The current director of the reserve is Dr Kyat Baiturbayev; he leads a team of rangers working in the reserve and a detailed (though paper-based) programme of phenological data collection in place across this network of rangers. Reserve staff appear well trained, knowledgeable and committed and there was enthusiastic support for this project. The main focus of institutional capacity building was to provide camera traps and training to reserve staff to support existing snow leopard monitoring activities, and ultimately to establish a permanent network of trailcams in ASNR to monitor both snow leopard and prey species population numbers (after Rowcliffe et al., 2008).

1.4. Climate Change

Mountain habitats are in general highly vulnerable to environmental change and anthropogenic influences, and climate change in particular poses a range of serious threats, including melting glaciers, erratic and unpredictable weather conditions, changing rainfall patterns, and increasing temperatures. For mountain species like snow leopards, climate change has immediate impacts with temperature, competition from other predators, precipitation changes and increasing human activity fragmenting suitable habitat (Riordan et al., 2015).

A recent climate change mapping study by WWF has indicated that there is vulnerability in the suitable climate envelope for snow leopards up to 2100. For the nearest major basin to the study area – Lake Balkash – there is a predicted 60% loss as a percentage of the original climate envelope (Figure 1).

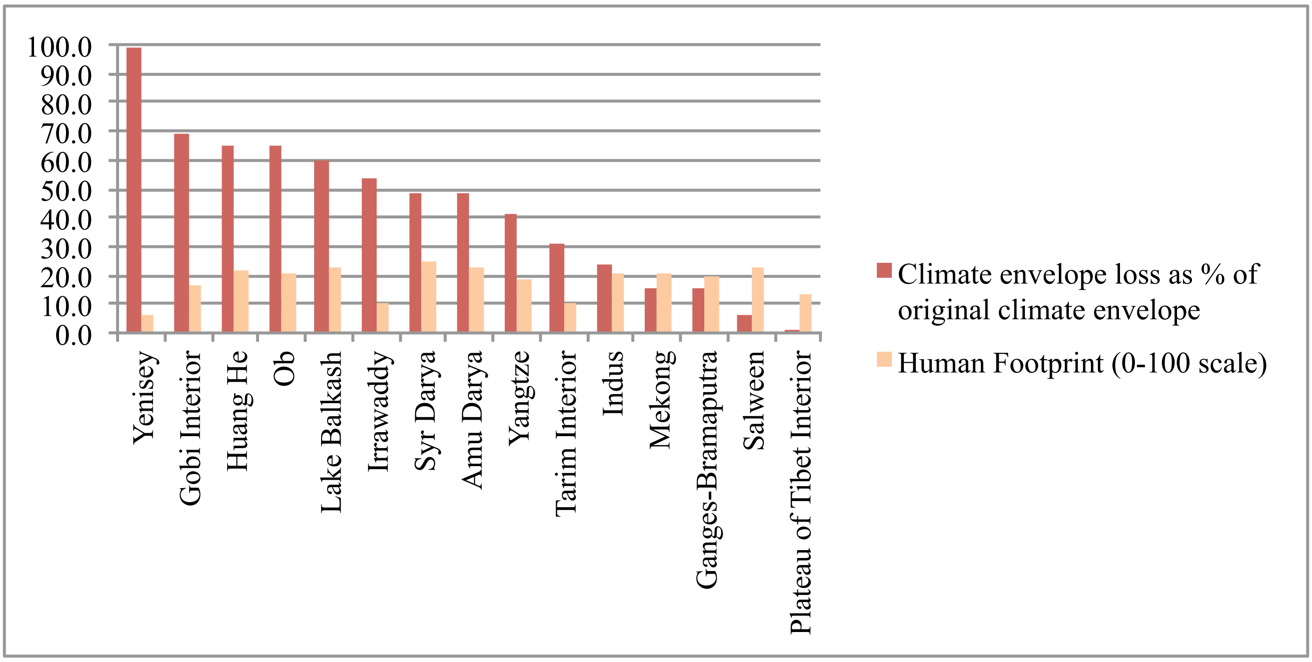


Figure 1. *Relative vulnerability of snow leopard habitat to climate envelope change and human footprint (WWF, 2014).*

As Xu and Grumbine (2014) indicate, given the relatively rapid rate and scale of climate-driven change in the Asian Highlands, the likelihood of regional ecosystem regime shifts or 'landscape traps' is a growing concern. It is estimated that around 30% of snow leopard habitat in the Himalaya may be lost due to a shifting treeline[2] and consequent shrinking of the alpine zone, mostly along the southern edge of the range and in river valleys (Forrest et al., 2012). According to Schickhoff et al. (2015) treeline shifts are of substantial ecological relevance due to possible implications for regional biodiversity and ecological integrity. A widespread upward encroachment of subalpine forests would displace regionally unique alpine tundra habitats and possibly cause the loss of alpine species. Therefore, the warmer and wetter conditions consistent with climate change predictions in this region may result in vegetation communities at higher altitudes, with forests ascending into alpine areas, the snow leopards' preferred habitat (Forrest et al., 2012; Shen et al., 2011). Similar to Forest et al. (2012), we assume that the impacts of climate change on snow leopards will be primarily through changes in habitat, rather than through direct physiological impacts of temperature and precipitation on snow leopards. There is also, however, the risk of increased competition from other predators, including the common leopard (*Panthera pardus*). As the treeline ascends into the alpine zone, this will increase habitat for the larger common leopard. Lovari et al. (2013a) suggest that the bigger, adaptable common

[2] The alpine treeline is conventionally taken to be the upper-most elevation where any individual tree having a height of 2 m or more can be found. Usually this is not a clear-cut line between forest and non-forest vegetation, but rather a transition zone from dominant trees to shrubs or grassland (Singh et al., 2012).

leopard, as the superior competitor, is likely to outcompete the smaller, specialised snow leopard, though they also suggest that the avoidance of interspecific aggression rather than exploitation of resources, could be the major factor allowing the coexistence of potentially competing large predators (Lovari et al., 2013b).

Within the study area, climate change is likely to impact on current snow leopard habitat. During 1936-2005, the average annual air temperature in Kazakhstan increased by 0.31°C every decade, and it is predicted that under a medium scenario, the change in average annual air temperature will be +4.6°C by 2085 (based on 1961 – 1990 base period, Yesserkepova, 2013). This level of change is likely to have profound impacts on biodiversity. Within ASNR, there is evidence that glaciers are melting at an ‘alarming rate’ and air pollution from nearby Almaty (and Talgar) is impacting on ecosystems (Farrington, 2005)

1.5. Study Area- Almaty State Nature Reserve

ASNR is one of the oldest protected areas in the Tian Shan range, initially established in 1931 with an area of 130 km^2. The site was designated a nature reserve in 1935 but de-protected in 1951 and re-established in 1961. Between 1935 and 1945, the nature reserve reached a maximum size (10,000 km^2) before being reduced in size and divided into several different protected areas after the Second World War. The reserve reached its present delineation in 1983 (UNEP 1991a). The reserve is an important site for biodiversity in Kazakhstan.[3]

The reserve abuts the heavily populated environs of Kazakhstan’s largest city, Almaty (population 1.2 million), and also the town of Talgar. The reserve can be reached by car at several places along its northern boundary, or by foot from a number of popular hiking trails beginning on the outskirts of Almaty and elsewhere. The main trail through the reserve leads up the 20 km long canyon of the middle-fork of the Talgar River to the Talgar glacier fields, the most extensive glacier fields in the Northern Tian Shan. The trail thus effectively cuts through large areas of prime snow leopard/prey species habitat. Saparbayev & Woodward (2008) identify tourism as a major threat to snow leopards in the reserve, and whilst this is clearly the case, it is entirely possible that climate change will become the most significant threat over the coming decades. According to Farrington (2005:97), the reserves’ glaciers are currently melting at an ‘alarming rate’ and there is evidence that air pollution from Almaty

[3] Plant life in the Almaty Nature Reserve is diverse, with 950 recorded species representative of steppe, wet meadow, forest, and alpine ecosystems, including 13 species of trees and 63 species of shrubs. Notable plant species include Schrenk’s spruce, willow, birch, wild apple, and wild geraniums (UNEP 1991a). Fauna in the reserve includes both woodland and alpine species such as snow leopard, Siberian ibex, elk, roe deer, grey marmot, and two species of pika. Birdlife in the reserve includes golden eagle, lammergeyer, Himalayan snowcock, and chukar.

is harming ecosystems. As far as we are aware, there has been no research conducted to model the implications of climate change related habitat loss on snow leopard populations in ASNR.

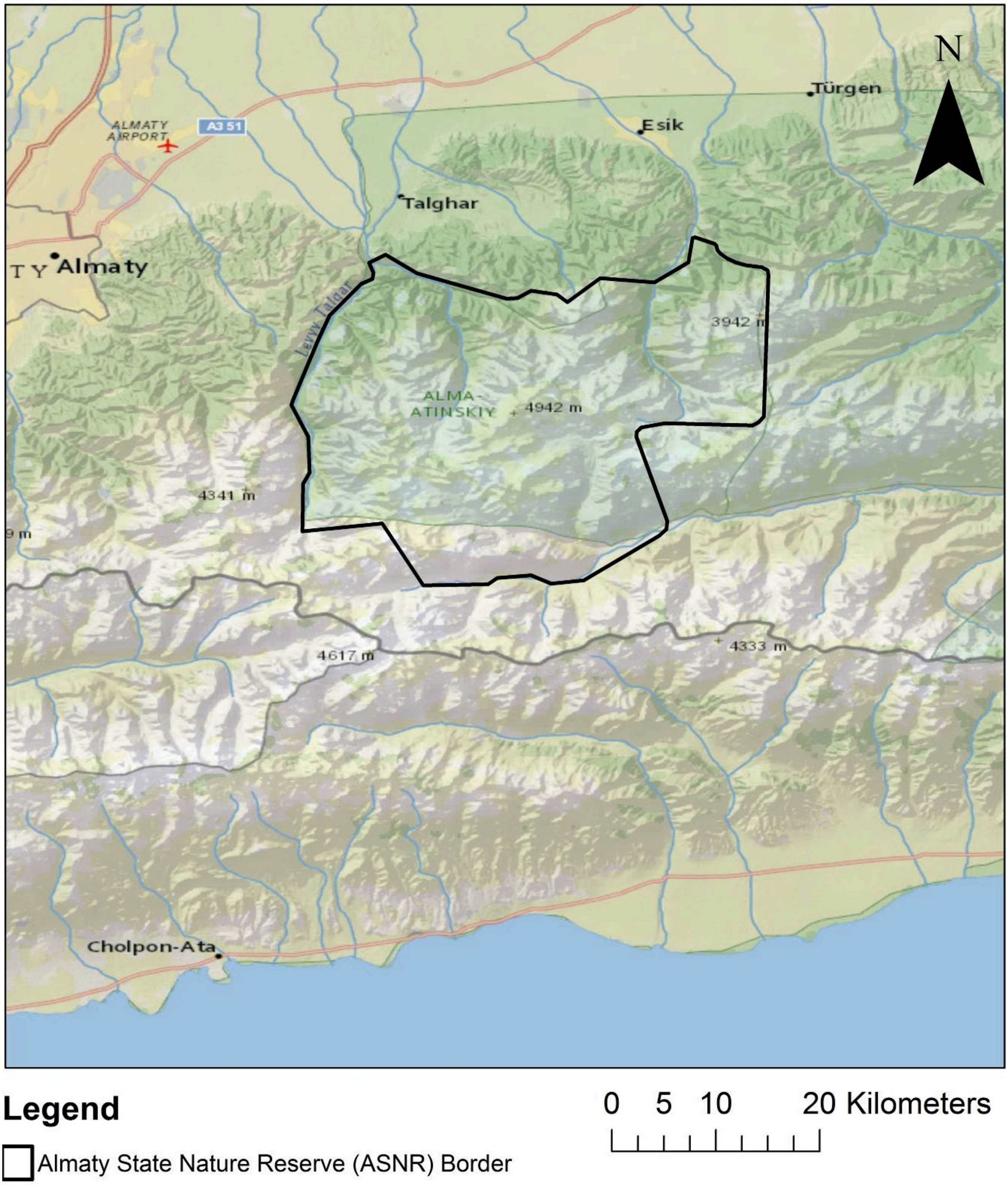


Figure 2: *Map of southern Kazakhstan and northern Kyrgyzstan showing the location of Almaty State Nature Reserve*

1.6. Research Aims

In order to address the snow leopard threats and information needs discussed above, and to meet the 2013/14 Snow Leopard Network funding call, the following research aims were developed:

Research Aims

- Estimate snow leopard population density and abundance (and ungulate prey species abundance)
- Produce models of snow leopard population change under different climate change scenarios using a fuzzy logic approach
- Build capacity within ASNR to continue monitoring work & to establish a citizen science programme
- Develop climate smart conservation plans for the reserve
- Develop best practice approach (tool kit) for snow leopard monitoring in ASNR which can also be applied in other regions

2. METHODOLOGY

2.1 Remote Camera Trapping and Population Estimation

2.1.1. Trapping Protocol

With the advent of digital photographic technology, the use of remote cameras has been growing as a methodological approach in wildlife biology as they are less intrusive, less costly and require fewer man-hours to effectively generate an abundance of data (Karanth and Nichols 1998) than direct observational techniques. As such they can be effectively applied to reduce sampling effort in remote and challenging landscapes (Sathyakumar et al. 2011). Remote cameras have typically been used to measure species abundance through population estimates and population density (Karanth and Nichols 1998, Baldwin and Bender 2012, Dougherty and Bowman 2012), but this methodological approach also holds potential for measuring habitat use and other behavioural patterns (Ohashi et al. 2012, Steenweg et al. 2012, Clapham et al. 2014).

In recent years, the number of studies using remote cameras has grown dramatically and the models being developed to analyse their data have increased in complexity and reliability (Burton et al. 2015). Traditional analyses have used mark-recapture (CMR) methods to estimate population size and density, but these may not work for low-density populations as it is difficult to obtain a sufficient sample size of capture-recapture events (Bater et al. 2011, Baldwin and Bender 2012).

Remote camera trapping approaches have proven successful for snow leopards (Jackson et al. 2005; 2006) and in this study we adapted the protocol of Jackson *et al.* (2005) using CMR in combination with an elevationally stratified saturation sampling approach to estimate snow leopard abundance supported by ungulate prey abundance surveys and standard sign survey techniques, based on the SLIMS approach developed by Jackson & Hunter (1996, see also McCarthy *et al.*, 2008). These data were triangulated with local/expect knowledge (interview-based) to produce a robust estimate of both snow leopard and ungulate prey populations in ASNR.

We used Bushnell Trophy Cam HD cameras for this project, and found that in general they coped well with the alpine conditions in ASNR. Some cameras were left in the field for 11 months and continued to operate on one set of lithium batteries in temperatures down to -22°C. A total of 40 camera traps were deployed in Almaty State Nature Reserve between August 2014 and May 2015. The location of the camera traps are given in Figure 6.

A trap night was defined as a 24-hour monitoring period by each camera, as in Ríos-Uzeda et al. (2007). Where images of an individual were separated by less than five minutes on a single camera or 10 minutes within a geographically contiguous camera group they were not considered independent events. Catch Per Unit Effort (CPUE) was calculated on this basis for snow leopards, competitors (brown bear *Ursus arctos,* Eurasian lynx *Lynx lynx,* grey wolf *Canis lupus,* and red fox *Vulpes vulpes*), and primary prey (Siberian ibex *Capra sibirica,* red deer *Cervus elaphus,* Eastern roe deer *Capreolus pygargus* and wild boar *Sus scrofa*)

2.1.2 Individual Identification

We tested a number of population estimation techniques with the captured photo data including: individual identification through local knowledge; expert knowledge; 3-D pattern recognition software (ExtractCompare; conservationresearch.co.uk 2013); and 2-D pattern recognition software (Wild-ID; Bolgeret al., 2011). For comparison and to identify the effect of photographic quality on individual identification we also used photographs of 4 captive individuals held at Lakeland Wildlife Oasis in Milnthorpe, UK.

For individual identification by experts we followed the methodology of Jackson et al. (2006). All photographs were classified according to the aspect of the animal (face, left and right flank, and tail). Photographic quality was subjectively scored on a scale from 0 (no useful information) to 5 (clear full-frame side-on image with good contrast) taking into account the lighting, contrast, angle of the animal to the camera and size of the animal in the frame.

All images showing the same aspect were compared blindly and scored as a ‘match’ (clearly the same individual), ‘no match’ (clearly a different individual) or ‘not identifiable’ if the images contained insufficient information to unequivocally confirm or refute a match. Matches were only accepted if they were independently confirmed by two experts. Figure 3 gives an example of a confirmed match. Images of all quality scores were matched this way, however, only individuals with images with minimum score of 3 for a given aspect were used to determine the minimum number of individuals detected.

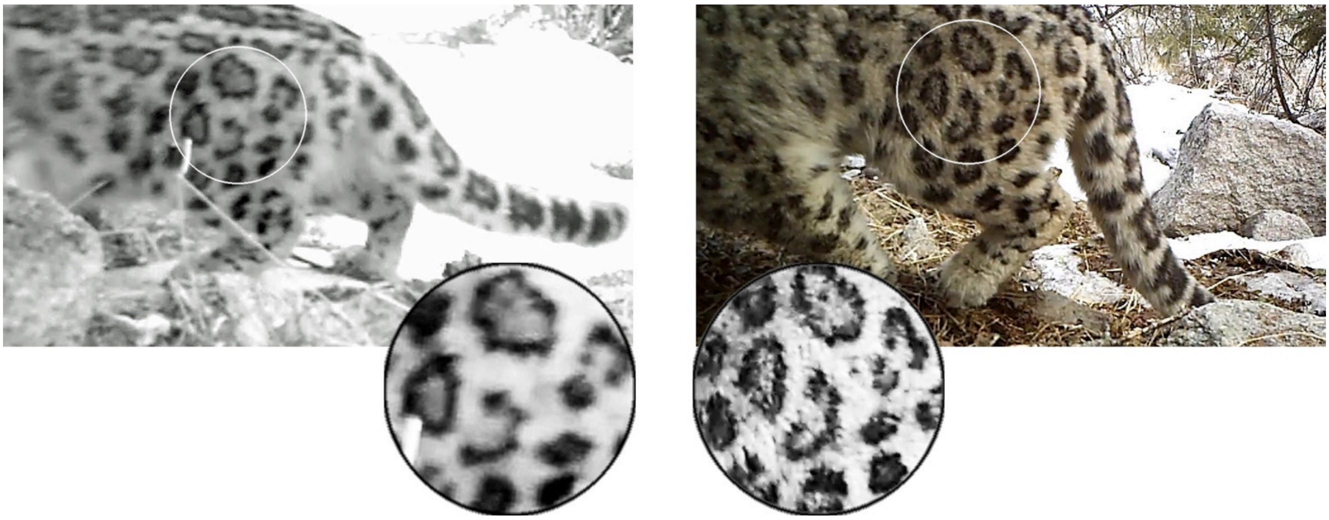


Figure 3: *Camera trap images of the same individual snow leopard. The left picture was taken at 08:12hrs local time on 28 Feb. 2015 using the camera's infrared flash, the right picture was captured by the same camera trap at 16:45hrs on 07 Mar. 2015 using natural light. Insets show the pelage patterns used for identification.*

2.1.3 Population estimation

While all independent capture events were considered in the calculation of CPUE, encounter histories for individuals used within population estimation were based one camera trap night as the minimum sampling interval. As such, any individual which was captured more than once (whether by the same camera or not) within a 24 hour period would register one encounter in the encounter history. Where this was the first encounter this would be considered the marking event with encounters in subsequent 24 hour periods being recaptures. Given that the extended sampling period necessary to generate sufficient snow leopard encounters and the continuity of habitat beyond the boundaries of the sampling area both present violations of the closed population assumptions of simple CMR models, we applied a Cormack-Jolly-Seber open population capture –recapture model (Cormack, 1964; Jolly, 1965; Seber, 1965).

Our sampling protocol conforms to the assumptions of an open population capture recapture model in that:

- "Marked" animals (i.e. those for which we have established a high confidence individual identification) are representative of the population (i.e. a random sample)
- Numbers of releases are known (all marked animals are released in a camera trapping protocol)
- Marking is accurate and persistent throughout the sampling period

- There is little delay between capture and release relative to the sampling period (there is no delay in a camera trapping protocol)
- The fates of marked individuals are independent (for example mothers with accompanying offspring would not be as separate individuals)
- All individuals have the same survival and recapture probability for each sampling interval

While Cormack-Jolly-Seber models are restricted to single year estimates, this is a robust approach and is well suited to the low capture probabilities typical of low density carnivore populations (Lebreton et al., 1992). Population estimation was conducted using Program MARK (White and Burnham, 1999).

By applying and integrating a range of techniques for snow leopard survey and census we have been able to generate a robust estimate of the snow leopard population and distribution within the portion of the reserve studied, whilst also providing an estimate for the entire reserve.

2.2 Fuzzy Modelling

Data were analysed following a normalization, fuzzification, fuzzy inference and defuzzification process. The evaluation of different alternatives becomes possible through the use of scenario driven data change and sensitivity analysis within the fuzzy model environment. In this manner we are able to show the potential for impact of different variables, which in this work includes climate change indicators such as temperature, precipitation, snow cover and canopy cover, on the ASNR snow leopard population.

Fuzzy logic allows the incorporation of both quantitative and qualitative data, and their aggregation into composite indicators, that expresses difficult to define terms such as sustainability (Kouloumpis et al., 2008). The use of fuzzy logic is particularly effective in the biology sciences where variability is enormous and it depends on a rich variety of environmental and endogenous factors. Much of the data and knowledge considered concerns system aspects that combine issues of complexity alongside epistemic and linguistic uncertainty (Adriaenssens et al., 2004). The combination of non-linear, uncertain, plural and partial nature of knowledge that is used to evaluate such systems aligns itself with the use of natural language, linguistic variables and values based on the fuzzy logic methodology (Zadeh, 1965). Fuzzy logic uses mathematical tools which handle ambiguous concepts and reasoning to give crisp number answers to problems populated with issues of uncertainty and partial knowledge (Cox et al., 1999). At its simplest, fuzzy logic is a generalisation of a standard logic proposition based on two truth values, false and true, to the degree of truth membership between zero and one. In this context fuzzy logic does not concern the likelihood of an outcome, but the degree to which the outcome itself occurred, in the sense that it cannot be described unambiguously (Zadeh, 1965). Phrasing the question changes from ‘what is the probability of sustainable use occurring?’ to ‘what degree of sustainable use is occurring?’ Examples of fuzzy logic approaches for the modelling of biodiversity as a System of Systems at various levels of organisation and for the adaptive management of wildlife for climate change have already been proposed in the literature (Phillis & Kouikoglou, 2012; Prato, 2011).

2.1.2 The Fuzzy Model - Fuzzy Snow Leopard Evaluation

Schematically the evaluation model is shown in Figure 4. The fuzzy snow leopard value of each location is produced as a composite measure of the described evaluative indicators. Thus, fuzzy snow leopard value is comprised of two primary components; current habitat status and pressure to habitat status. Each of these primary value components are further comprised of secondary components; current habitat status described by other species, topography, landscape, and disturbance, with pressure to habitat status described by vegetation, precipitation and temperature.

Each secondary component is assessed using a range of tertiary indicators, for example other species comprises two basic indicators that characterise the presence of other competitor species and prey species. These basic indicators are described and measured by a variety of units over a wide range of scales which requires a normalisation procedure before being entered in to the fuzzy model.

The fuzzy snow leopard model was run on ‘if-then’ rules to produce a composite estimate of the snow leopard environment across a variety of locations. The adjustment of key tertiary indicators in line with specific climate change scenarios provides data to inform and support discussion around the potential for population change in response to changes in the physical environment. In this manner we have been able to illustrate the potential change in population state if, for example, snow cover, temperature and vegetation cover are altered by climate change.

2.3 Field Team

The field teams for the 2014 and 2015 fieldwork seasons included staff from all the partner institutions, and were led by Dr Ian Convery and Dr Owen Nevin, with GIS and fuzzy logic support from Dr Claire Holt and Dr Darrell Smith (respectively).

2014 - Ian Convery (UoC), Owen Nevin (CQU), Azim Baibagysov (KazNU); David Harpley (volunteer field worker, from Cumbria Wildlife Trust), Altynbek Janyspayev (ASNR).

2015 - Ian Convery (UoC), Volker Deecke (UoC), Owen Nevin (CQU), Azim Baibagysov (KazNU); David Harpley (CWT), Altynbek Janyspayev (ASNR).

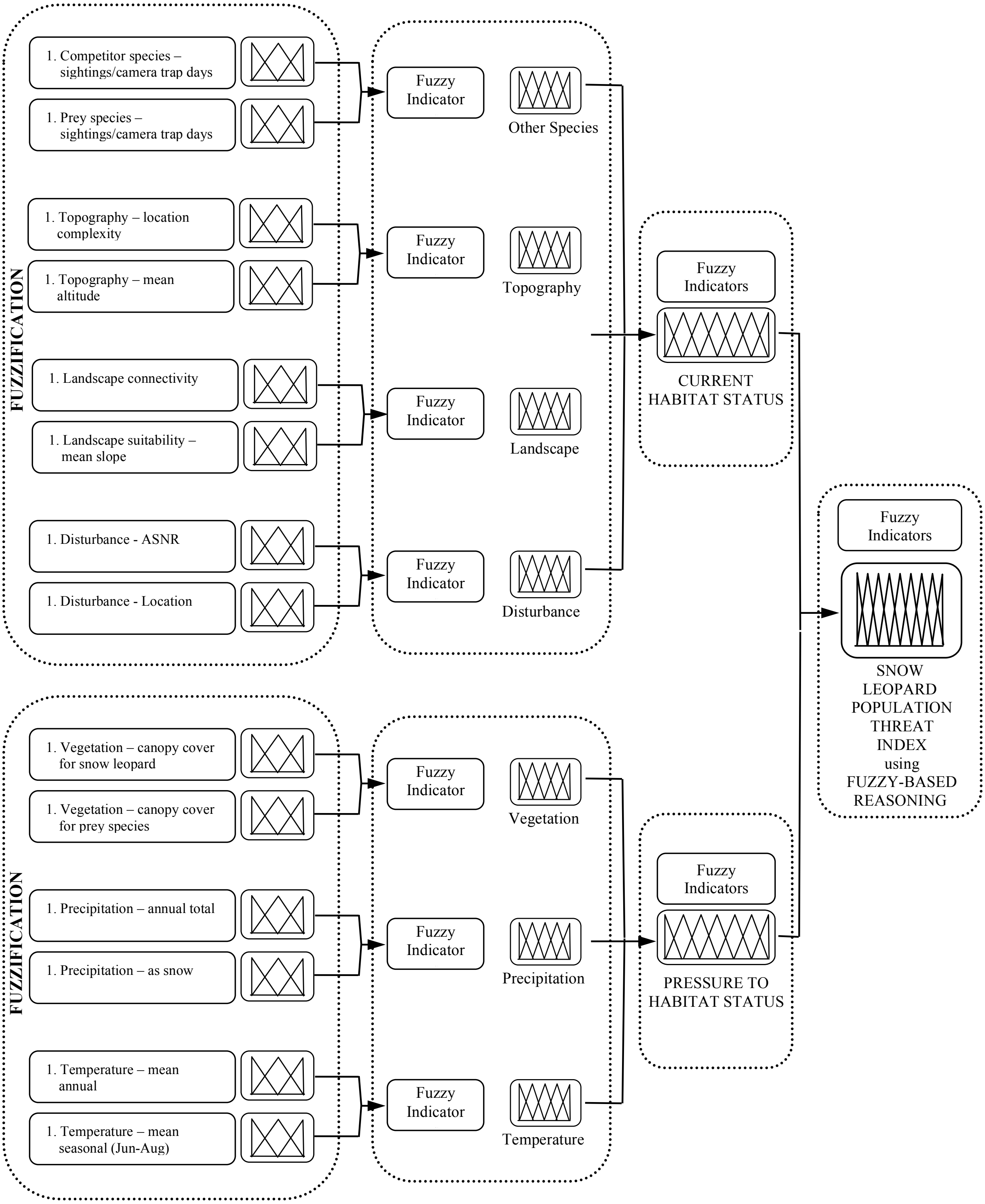


Figure 4: *Schematic of the hierarchical fuzzy model for snow leopard environmental evaluation across a range locations in ASNR.*

2.4 Overview of Research Timeline

Table 1: *Gantt chart giving the timeline of the research project*

	2014									2015							
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug
Desk research and detailed project planning	■	■															
Field work I: Establish camera network & research protocol					■												
Field work II: Collect cameras from field														■			
Ongoing data collection						■	■	■	■	■	■	■	■	■			
Data analysis						■	■	■	■	■	■	■	■	■	■	■	
Project workshop														■			
Submit project report																	■
Dissemination (ongoing)																	■

3 RESULTS

3.1 Camera Trapping and Population Estimation

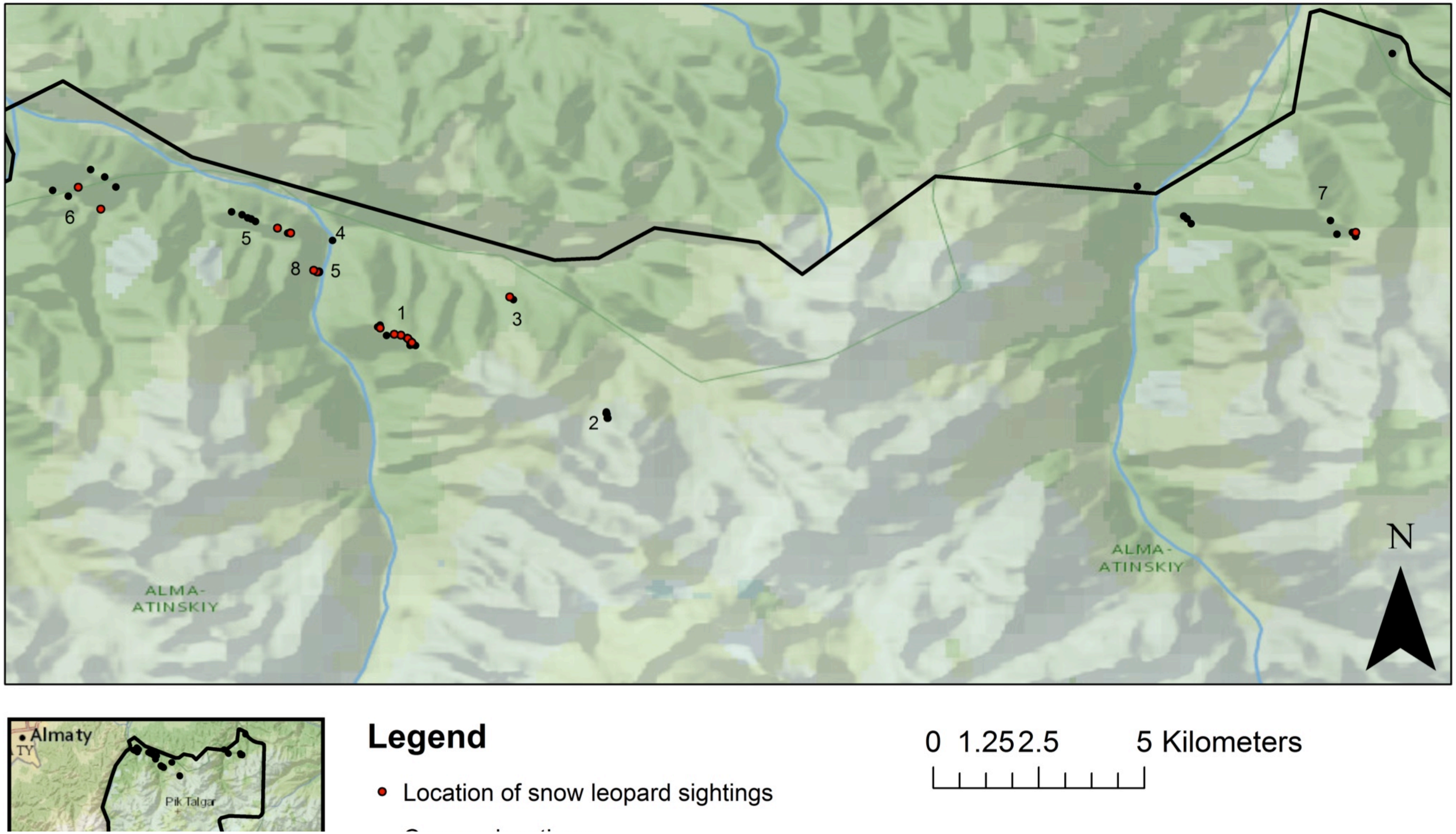
3.1.1. Trapping effort

The 40 camera traps were deployed for a total of 5152 traps nights and yielded 50 i events of snow leopards (with between 1 and 10 images per event), 275 capture eve (Siberian ibex: 55, red deer: 121, roe deer: 89, wild boar: 10), 68 capture events (Himalayan snow cock, *Tetraogallus himalayensis*: 41, Tolai hare, *Lepus tolai*: 1' *chukar*: 10) and 68 capture events of competitors (Eurasian lynx: 13, grey wolf: 5, fox: 10). Figure 6 shows that snow leopards were detected in all parts of the s exception of Trails 2 (Right Talgar Mountain Range), and 4 (Middle Talgar Gorge) the trails with least trapping effort (with 3 and 1 cameras respectively), this perc well be the result of sampling bias. The snow leopard capture rate in this study wa capture events per 100 trap nights.

3.1.2 Individual Identification and Movement Patterns

Analysis of 272 images taken of the four captive individuals held at Lakeland Wil that both image recognition programmes only performed reliably with images of a q higher. Trained experts could consistently identify the same individual in images higher. Because vast majority of the images obtained in the field received a quality we ended up using visual matching to determine the minimum number of indiv population size.

The majority of images showed the left flank (22) followed by tails and faces flanks (12). The 50 detections of snow leopards yielded at total of 39 matches wit giving by far the most reliable results. These matches are shown in Figure 6.


6
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ALMA-
ATINSKIY
Almaty
Pik Talgar
Legend
Location of snow leopard sightings
0 1.25 2.5 5 Kilometers

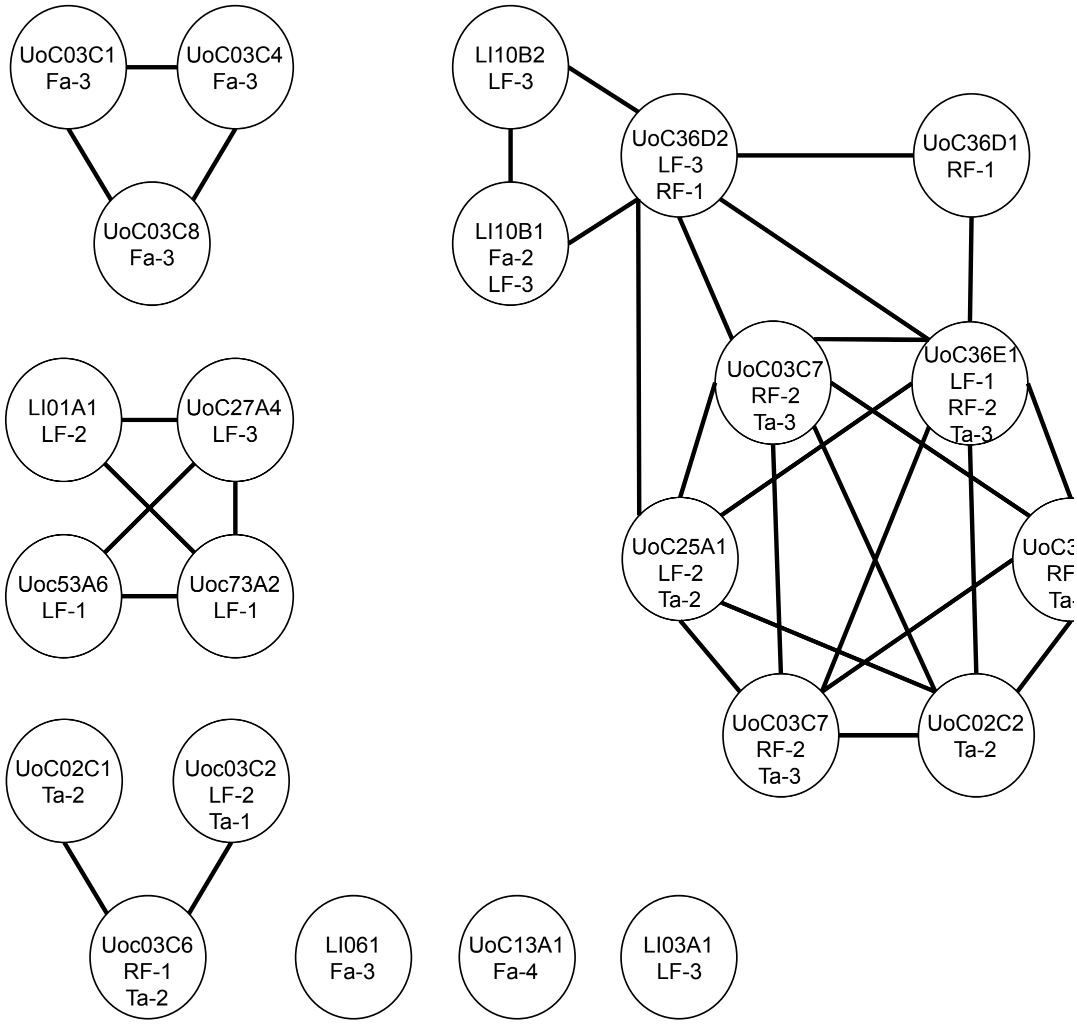

Figure 6: *Diagram showing the results of the photographic identification (leopards. Each circle in the diagram represents a unique capture event of a sno events are identified by the camera deployment (e.g., UoC03C) followed by a seq each time a snow leopard was captured by this camera (e.g., UoC03C1, UoC03C name is the aspect (Face, Right Flank, Left Flank, Tail) and the picture qual information, 5 = clear full-frame image with good contrast).*

The results show that a large number (10) of capture events represent a single other individuals were only captured once or a few times. The largest number of was given by the analysis of left flanks and gives a minimum population siz Analysis of the movement patterns of the individual captured 10 times demonstrate much of the study area having been detected in all clusters except for Trails 2, 4 and

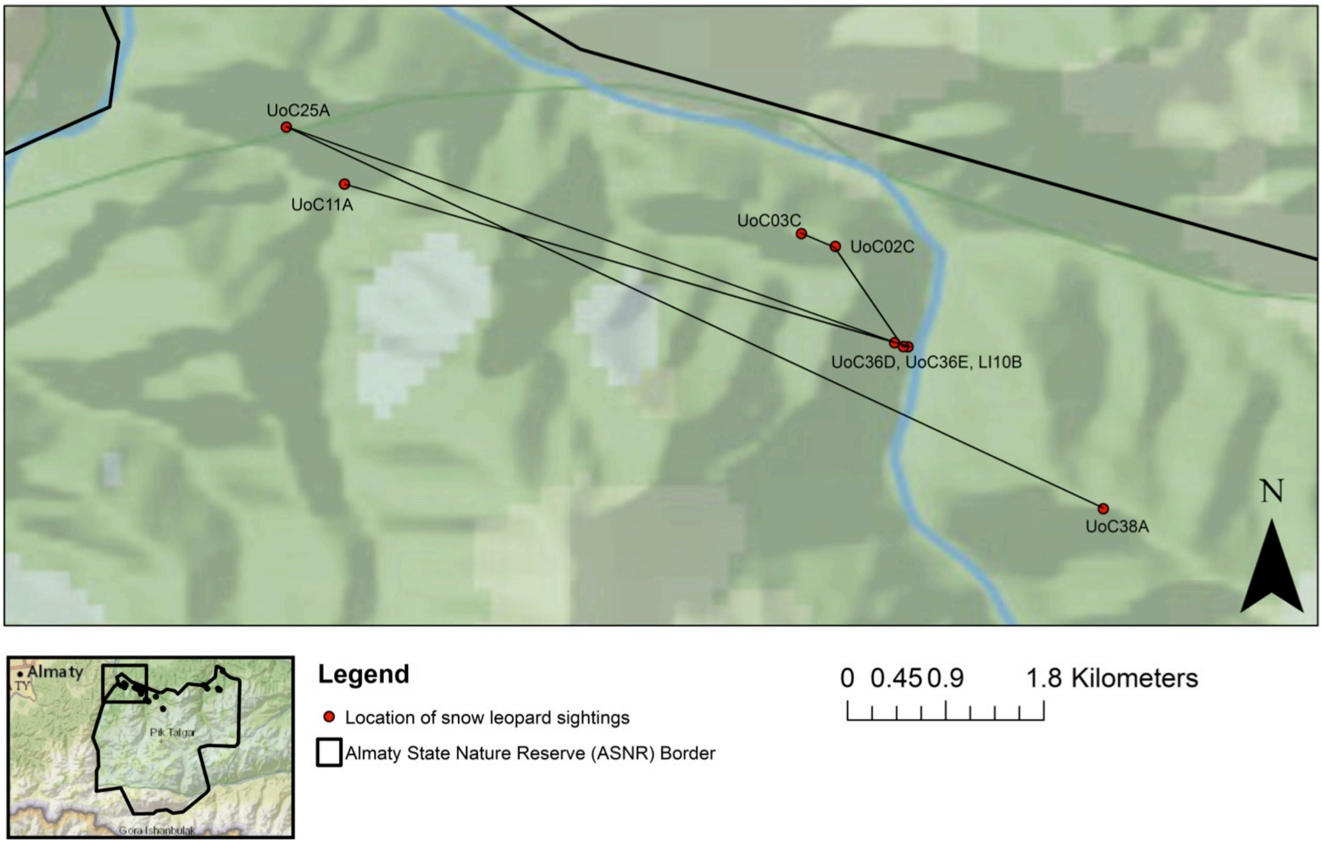

Figure 7: *Map of the northern part of Almaty State Nature Reserve showing the movement patterns of an individual snow leopard captured 10 times during the course of the study.*

3.1.3 Snow Leopard Population

Based on minimum identified recapture event profiles and acknowledging that the extended capture period and continuity of habitat present violations of the closed population assumptions, the Cormack-Jolly-Seber population estimate for snow leopards is 11 individuals within the core study area (250km^2) with a standard error of 1.5126 individuals and a 95% confidence interval of 11 to 18. Our population estimate for the whole reserve is 39.6 individuals, with a standard error of 5.44536 individuals and a 95% confidence interval of 39 to 64.[4]

3.1.3 Prey abundance

Prey abundance varied greatly with elevation across the study area (Figure 8) with the peak in availability occurring in the alpine zone just above treeline. The composition of prey also varied with elevation with Siberian ibex dominating at higher elevations and Eastern roe deer dominating at lower

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[4] This is an extrapolation based on a reserve area of 900km2 (park area of 700km2, plus 200km2 of 'buffer habitat' adjacent to the reserve boundaries.

elevations; red deer occurred throughout the elevations sampled but were absent from steep rocky escarpments.

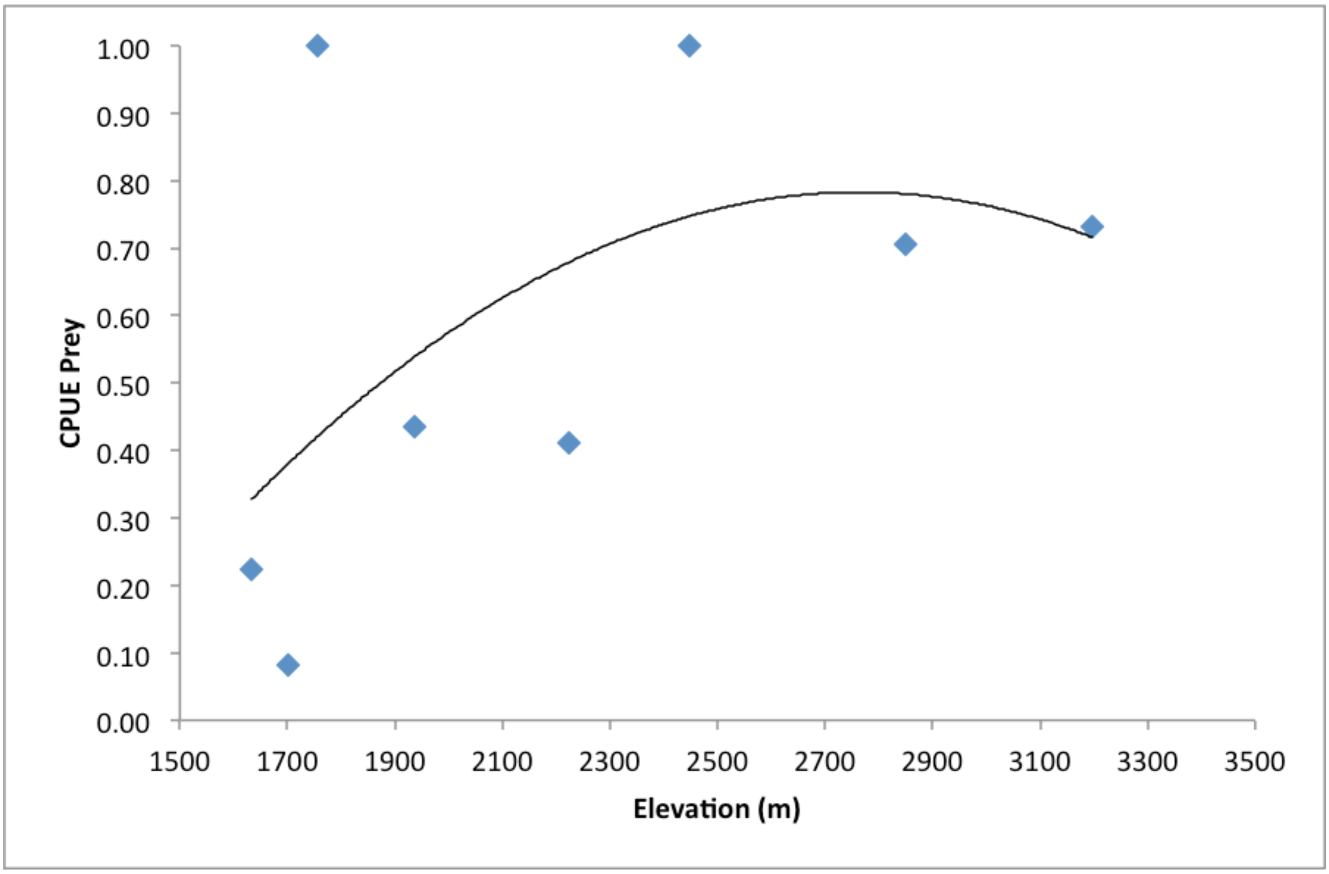

Figure 8: *Abundance of primary prey of snow leopards at different altitudes in Almaty State Nature Reserve based on catch per unit effort (independent capture events per trap night) .*

3.2 Fuzzy Logic Snow Leopard - Climate Change Model

Mean values for each camera cluster describe the tertiary indicators used as inputs to the fuzzy snow leopard model. These input data are further described by the fuzzy composite output (Table 2). The relationship between the fuzzy snow leopard model output and snow leopard sightings per camera trap days provides the current environmental model basis against which climate change scenarios can be assessed (Figure 9).

Table 2: *Mean values for each location provide the tertiary level basic indicator input for the fuzzy snow leopard environmental index model.*

CURRENT HABITAT STATUS

	Mean values from study sites							
Tertiary level indicator	Trail 1	Trail 2	Trail 3	Trail 4	Trail 5	Trail 6	Trail 7	Trail 8
Competitor species-sightings/camera trap days	0.01	0.00	0.03	0.09	0.02	0.01	0.00	0.07
Prey species-sightings/camera trap days	0.02	0.01	0.28	0.04	0.04	0.10	0.07	0.07
Topography-complexity	57.07	38.29	14.70	0.00	59.62	210.89	549.48	17.15
Topograhy-altitude	2849.00	3196.86	2225.00	1634.00	1937.73	1700.63	2447.00	1755.00
Lanscape Connectivity (scale 1-5)	3.86	3.86	3.25	3.00	2.62	2.54	3.75	2.75
Suitability of habitat - slope	28.89	20.00	18.13	22.50	13.75	26.67	28.89	22.50
Disturbance 1 (m)	3818.54	6680.27	4501.01	1218.82	1386.51	1136.23	3697.64	1737.37
Disturbance 2 (scale 1-5)	1.81	1.67	2.67	3.00	2.36	3.04	2.33	2.92

PRESSURE TO HABITAT STATUS

	Mean values from study sites							
Tertiary level indicator	Trail 1	Trail 2	Trail 3	Trail 4	Trail 5	Trail 6	Trail 7	Trail 8
Vegetation-canopy cover snow leopard	6.05	0.00	43.75	100.00	51.36	28.75	3.50	40.00
Vegetation-canopy cover prey species	6.05	0.00	43.75	100.00	51.36	28.75	3.50	40.00
Precipitation-annual	900.12	900.12	900.12	900.12	900.12	900.12	900.12	900.12
Precipitation-as snow	141.05	162.51	0.00	0.00	0.00	0.00	81.25	0.00
Temp-annual	0.16	-3.31	6.40	12.31	9.28	11.65	4.18	11.10
Temp-seasonal	8.73	5.25	14.97	20.88	17.84	20.21	12.75	19.67

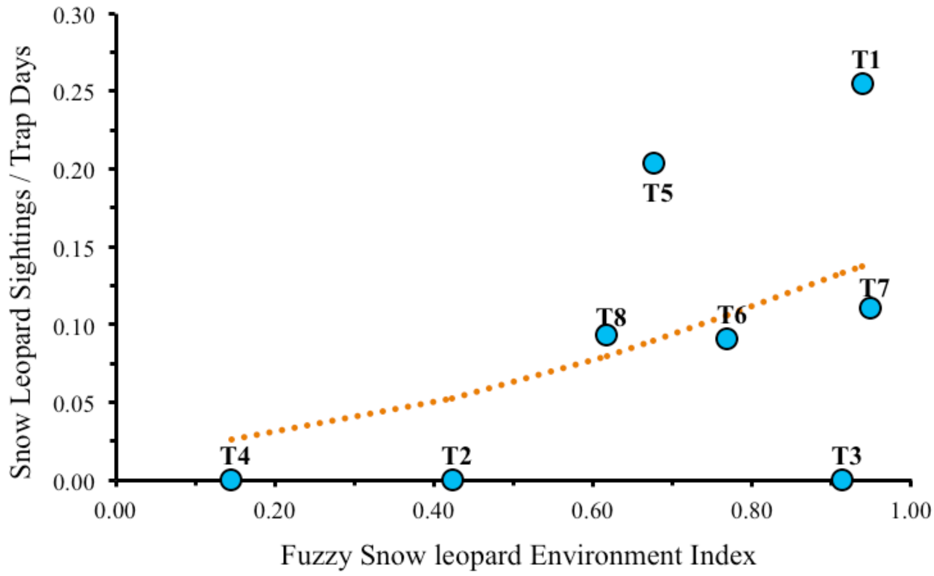

Figure 9: *Fuzzy snow leopard environment index plotted against mean snow le each trail; the dashed line describes the modelled current snow leopard / environm*

Three climate change scenarios are considered that follow IPCC project temperature change, as used by Forrest et al. (2012) in their assessment of sn vulnerability to treeline shift in the Himalaya; scenario B1 +1.8^{0}C, scenario A1B A2 +3.4^{0}C. The climate model assumes a rise in temperature is associated with con in temperature and canopy cover alongside associated reductions in precipit connectivity. These consequential changes are modeled using an adiabatic lapse altitude and a rising of treeline by 100m / 1^{0}C. Climate change adjusted terti variables result in a change to the fuzzy model output. These climate scenario adj characterise the potential for climate driven change to snow leopard habitat suit Change in habitat suitability across the observed trail areas is suggested by all th scenario fuzzy model outputs; change in fuzzy snow leopard environment index va an increase of 117% to a decrease in index value of 38% (Table 3). When presente to the current environment status quo these data broadly describe a pattern that re response across an altitudinal gradient (Figure 11).

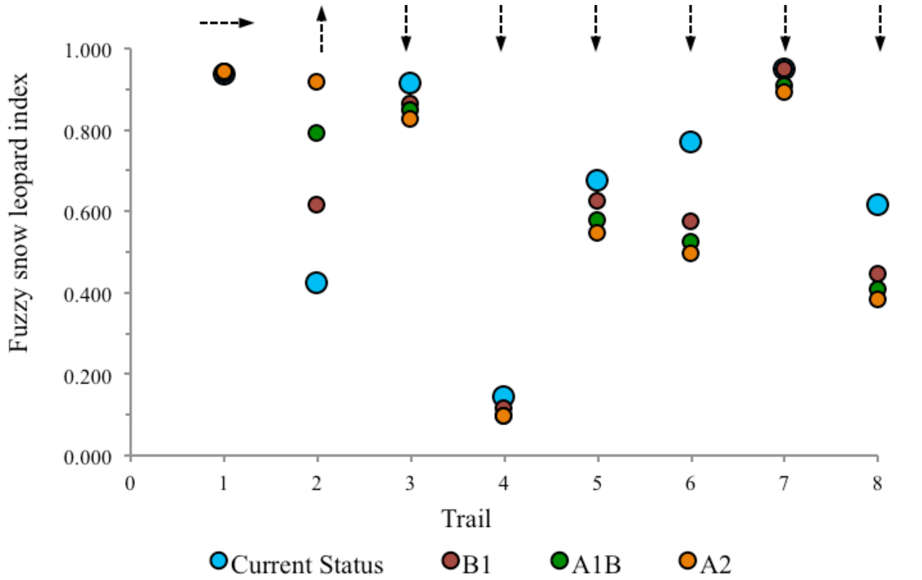

Figure 10: *Change in fuzzy snow leopard environment index associated with the three climate change scenarios for each trail; arrows describe the direction of change in habitat suitability with projected increasing global temperature, as defined by the index value.*

Table 3: *Percentage change in fuzzy snow leopard environment index across the three climate change scenarios; B1, A1B and A2.*

			Climate scenario related change		
Trail	**Altitude (m)**	**Current Status**	**B1**	**A1B**	**A2**
2	3197	0.423	+0.6%	+0.0%	+0.6%
1	2849	0.938	+45.8%	+86.9%	+116.9%
7	2447	0.949	-5.5%	-7.2%	-9.4%
3	2225	0.914	-19.7%	-31.7%	-31.9%
5	1938	0.676	-7.3%	-14.4%	-19.1%
8	1755	0.617	-25.4%	-31.7%	-35.6%
6	1701	0.769	+0.0%	-4.1%	-5.9%
4	1634	0.145	-27.5%	-33.8%	-37.6%

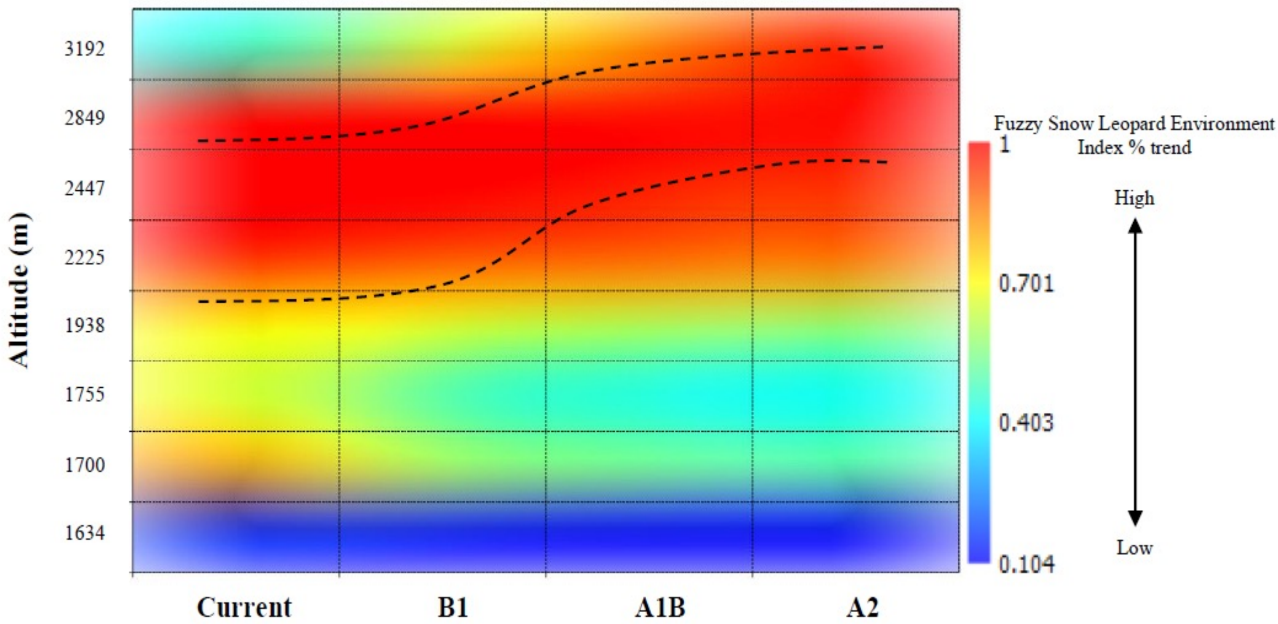

Figure 11: *Matrix plot of modelled snow leopard environmental index; constriction of red banding illustrates the pressure due to increased temperature on high value snow leopard habitat.*

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4 DISCUSSION AND CONCLUSIONS

4.1 General Discussion

The first photograph of a wild snow leopard was not published until 1980, and with live-capture rates as low as 3/1,000 trap-nights, conventional capture–recapture methods are logistically difficult (McCarthy et al., 2008:1826). Camera trapping is therefore an important tool in snow leopard conservation, and has been used increasingly over the last decade or so. Capture rates in this study were 0.97 independent capture events per 100 trap nights therefore falling at the higher end of the range of 0.1-1.1 independent capture events per 100 trap nights reported by McCarthy et al. (2008).

The analysis of our camera trap photographs showed that camera trapping and visual identification is a robust and powerful tool to estimate snow leopard abundance and analyse movement patterns. Analysis of the pelage patterns showed that it was possible to consistently identify individuals. With more strategic placement of cameras in future deployments or switch to active systems triggered by a light barrier, it may be possible to increase photographic quality and standardise the aspect of the photographs taken.

The camera traps covered an area of roughly 25x10km. In this area we detected a minimum number of 4 individuals (based on unique left flanks). The Cormack-Jolly-Seber population estimate was 11 individuals with 95% confidence intervals between 11 and 18 individuals. This suggests a population density between 4.4 and 7.2 individuals per 100km^2. These densities are comparable to those reported for Hemis National Park, Ladakh, India by (Jackson et al. 2006), in spite of methodological differences (e.g., differences in camera distribution, (Wegge, et al. 2004). If we extrapolate this density to the entire park, Almaty State Nature Reserve may be home to between 39 and 64 snow leopards, which represents between 0.6 and 1.6% of the global population (4,080-6,590 individuals, McCarthy & Chapron, 2003)

The analysis of movement patterns of snow leopards suggests that in Almaty State Nature Reserve, individuals frequently move between patches of high-altitude alpine habitat and lower ridges and slopes that are often densely wooded. Some camera deployments with the highest capture rates of snow leopards (e.g., UoC03C) were inside large patches of dense forest. As Jackson (1996) indicates, snow leopard habitat is usually within the alpine and subalpine zone, and may include elevations of 900m to around 5,500m but most commonly between 3,000 and 4,500m. However, in Pakistan, Russia and parts of India they are reported to migrate to lower elevations during winter, following prey (Roberts 1977; Dang 1967). In one of the earliest papers on snow leopard ecology, Hemmer (1973) reports that: seasonal migration from higher to lower elevations may depend on climatic conditions and the movements of ungulate herds, and during winter, it may descend to the lower zones. Populations of wild sheep that form the primary prey of snow leopards in other parts of their range (e.g., Lyngdoh et al., 2014), were not detected by our camera traps. Siberian ibex, another common prey species (e.g., Shehzad et al., 2012; Lyngdoh et al., 2014), were detected frequently, but are known to overwinter in exposed alpine habitat and not venture into the forest (Fox, et al. 1992). Our results therefore suggest that snow leopards in Almaty State Nature Reserve may be switching prey in the winter to feed on forest-dwelling ungulates such as red deer and roe deer.

Wolf and Ale (2009) identified that snow leopard activity was reduced around areas of human presence, especially trails, and as such, humans may be a substantial determinant of where snow leopards are active. The movement patterns documented by our study suggest that snow leopards frequently crossed valley bottoms when moving between alpine mountain ridges or from ridges to forested areas. This will bring them closer to areas of human activity and habitation and make them susceptible to anthropogenic disturbance, potential poaching and increase the likelihood of livestock depredation.

The fuzzy snow leopard model describes a general pattern of decreasing habitat suitability in response to global climate change, when compared to our fuzzy assessment of the current environmental status. The fuzzy snow leopard environment index not only describes change in habitat status, in relation to the three climate scenarios, but also highlights how the pattern of change will exert a disproportionate influence across the altitudinal gradient that comprises the snow leopard habitat. Similarly to Forrest et al. (2012), our results suggest that climate change could lead to some reduction in snow leopard habitat suitability in ASNR whilst some habitat will remain in suitable quality, but also importantly some areas will have the potential to become suitable for snow leopards to move in to. The model of current habitat status suggests the more suitable snow leopard environment can be found at altitudes between 2000 – 3000 m. Areas above and below this band are calculated as being of reducing levels of suitability, with lower altitudes below approximately 1600 m characterised as having lowest suitability. In this respect the model outputs are not dissimilar to the findings of previous studies where snow leopards have been found across a similar range of altitudes (Dang 1967; Hemmer, 1976; Roberts 1977; Jackson, 1996).

In regard to the potential for climate driven change to snow leopard habitat, the model suggests an overall reduction in area of suitable habitat. As temperature rises, described by the three climate change scenarios, habitat a lower elevations appears to be become unsuitable at a faster rate than habitat in higher elevations becomes available for snow leopards to move into. In this respect our model describes a pinching effect whereby the overall availability of suitable snow leopard habitat will be reduced in response to increasing temperature. Broadly speaking, our figures for change in habitat suitability accord with those of Forrest et al. (2012) who describe a 30% reduction in snow leopard habitat due to treeline shift in the Himalaya. Whilst our model indicates a loss of up to 38%, on trails with a suggested decrease in the fuzzy snow leopard index, interestingly we also identify the potential for increasing habitat at elevations over 3000 m of up to 117%. These potential additions to snow leopard habitat are not seen until we introduce the highest rise in temperature of $+3.4^0$C that comes with climate change scenario A2. However, the upper altitude limit of snow leopards and their prey will be determined by their physiological tolerance for oxygen deprivation. While high passes above 5500 m could act as dispersal corridors, it is unlikely that snow leopards will be able to live and hunt at these altitudes without the benefits of long-term physiological adaptations (Forrest et al., 2012).

In reaching these conclusions certain caveats apply, not least of which is the observed data used to construct the fuzzy model are limited in number and altitudinal range. Also in the use of temperature change as a hypothetical driver we have made assumptions about the nature of environmental change. We have built the model on rising temperature moving the treeline higher, with increasing canopy cover and a consequential decrease in snow cover and connectivity. We rely on global assumptions about weather patterns with respect to elevation, and give more influence to temperature than precipitation, other than temperature related changes to precipitation as snow. Following Forrest et al. (2012) we accept, but do not model, that natural factors such as topography, substrate, rate of soil formation, and wind can influence treeline movement where temperature and precipitation are otherwise suitable.

In our model primary variables are proposed and described using fuzzy numbers in order to produce an estimate of the observed snow leopard environment quality. In this manner the overall quality of the snow leopard environment is characterised as a composite function of the condition of these primary variables, a condition that can decrease or increase in quality. Changing conditions described by differing climate change scenarios result in consequent changes to habitat quality which in turn will influence snow leopard persistence. Our use of fuzzy logic presents the integration of fuzzy concepts as an extension of more traditional methods of ecological knowledge acquisition and data analyses. Compared to conventional methods, the fuzzy approach allows for the description of ecological components and structures as fuzzy sets with no clearly drawn boundaries, providing a better reflection of the continuous character of nature. In situations where knowledge is partial, uncertainty is high and definitions are ambiguous and in conflict, adoption of a fuzzy logic based approach has the potential to provide a vital additional tool to support and inform the environmental decision making process (Prato, 2011).

The model raises the prospect of increased snow leopard activity at lower elevations, and/or increased completion from other predators at higher elevations. Forrest et al. (2012) state that snow leopards will have limited capacity to adapt physiologically and ecologically to warming conditions, and if forests do move upslope, they will likely be colonized by other species, including common leopards (*Panthera pardus*), wild dogs (*Cuon alpinus*), and in Bhutan, tigers (*Panthera tigris*). Snow leopards will then have to contend with resource competition from these species, which are better adapted to forest habitats. In ASNR, there is increased potential for competition with wolves (*Canis lupus*). We identified habitat overlap at lower elevations, and similar to McCarthy et al (2008), we suspect that as environmental conditions change this could niche overlap and create higher competition for food resources. Recent research by Jumabay-Uulu, et al. (2014) has also identified that this niche overlap might lead to competition for food when the diversity of profitable, large prey is low (see also Suryawanshi1 et al. 2012). This is likely to be more intense in winter, when snow leopards in Almaty State Nature Reserve appear to be switching from ibex that are largely unavailable to other carnivores to forest ungulates that are frequently preyed upon by wolves and Eurasian lynx.

It is less clear how snow leopards might interact with bears, and there is very little evidence from the literature, other than a report of a snow leopard killing and eating a 2 year old bear (Schaposchnikov (1956), cited in Hemmer, (1972)).

4.2. Have we met the Research Aims?

1. Estimate snow leopard population density and abundance (and ungulate prey species abundance)

The project has provided the first scientific assessment of snow leopard numbers within ASNR. Our population estimate for snow leopards is 11 individuals within the core study area (250km^2) with a standard error of 1.5126 individuals and a 95% confidence interval of 11 to 18. Our population estimate for the whole reserve is 39.6 individuals, with a standard error of 5.44536 individuals and a 95% confidence interval of 39 to 64.

2. Produce models of snow leopard population change under different climate change scenarios using a fuzzy logic approach

The fuzzy logic modelling employed in this study, with training provided to KazNU staff, will model population trends and change in snow leopard distributions enabling climate smart adaptation of snow leopard conservation plans within and beyond the reserve. The use of fuzzy logic based models to support management decisions provides an additional tool which enables the bringing together of multiple information streams. The composite fuzzy outputs can be utilised to demonstrate both the potential consequence of outside influence and the possible effects of mitigation strategies.

3. Build capacity within ASNR to continue monitoring work & to establish a citizen science programme

The project provided camera traps and training to reserve staff to support existing snow leopard monitoring activities. ASNR is now able to establish a permanent network of trailcams to monitor both snow leopard and prey species population numbers (as an aside, one of the camera traps also identified 2 poachers inside the reserve and the images were used by police to secure a conviction). In May 2015 we held a final project workshop at ASNR headquarters, chaired by Professor Nurtazin from KazNU. There were over 30 attendees, including representatives from KazNU, ASNR, UoC, local government and Almaty Natural History Museum (Appendix I). The main focus of this event was to discuss the research findings and to identify future research directions. There was agreement that the project had been a success, and that ASNR/KazNU were now able to continue the snow leopard monitoring work established by the project. There was also agreement to continue the partnership and to seek further research funding, primarily to expand the research into other areas of the reserve. Whilst a citizen science programme was not established as part of the 'phase I' activities, there is potential to do this in the future, and to also include an educational component linked to schools in nearby Talgar. ASNR staff and KazNU graduate students were given field-based training in CMR techniques, including management and maintenance of camera traps.

4. Develop climate smart conservation plans for the reserve

The results of this study will inform ASNR snow leopard conservation planning (this will also form the basis for further research bids by the team).

5. Develop best practice approach (tool kit) for snow leopard monitoring in ASNR, which can also be applied in other regions

Our (novel) approach has worked well in the study area. The next phase of activity is to replicate this throughout ASNR, the results of which will inform a Kazakhstan-specific snow leopard tool kit,. We will work closely with other Kazakh snow leopard researchers in developing a best practice approach.

4.3 Academic Outputs

The project team is in the process of producing three peer review publications:

- Paper 1 – ***review paper*** focusing on climate change and snow leopards in case study of ASNR. Anticipated journal: Animal Conservation (Impact factor (IF) 2.69); The Journal of Wildlife Management (IF 1.64).

- Paper 2 – ***methodology paper*** focusing on the use of fuzzy logic in large carnivore/habitat change research. Anticipated journal: Conservation Biology (IF 4.33); Oryx (IF 1.82).

- Paper 3 - ***Using habitat suitability modelling to assess snow leopard habitat in Kazakhstan.*** This study will use expert opinion on habitat usage, land cover data and recently collected camera trap data on snow leopard locations within a species distribution model to highlight suitable habitat. Anticipated journal: Ecological modelling

In addition there have already been a number of newspaper and magazine articles publicizing the research, in both English and Russian (Appendix I).

4.4. Limitations of the study

A number of issues occurred during the project, which affected research activities. Most significantly, a moraine lake failure above the right Talgar river in May 2014 led to a major mud flow event which destroyed bridges and some roads/trails within ASNR. This event limited access within the reserve, and meant that research staff were unable to use horses to assist with fieldwork logistics (effectively preventing access to the relatively remote interior of the reserve). Research was limited to the southern boundary of the reserve. Though a project protocol was established, some of the cameras were reset to video by ASNR staff. This made identification more difficult. For various reasons some cameras were also under-deployed, limiting data collection.

4.5. Further Research

The capacity developed by the project will ensure that the project will continue long after the Snow Leopard Conservation Grant funding has ceased. The project properly equipped and trained what is effectively a well-educated and motivated team in ASNR/KazNU to model population trends and change in snow leopard distributions within the context of climate change, enabling climate smart adaptation of snow leopard conservation plans within and beyond the reserve. The team plans to bid for further funding to expand the research into other areas of the reserve as well as elsewhere in Kazakhstan. We firmly believe that this project, and in particular our novel use of fuzzy logical modelling, will become a model of good practice for snow leopard conservation in Kazakhstan and elsewhere.

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Appendix I

Setting up camera traps, Trail 1. August 2014.

Snow Leopard event Trail 2, with town of Talgar in background

Snow Leopard event, Trail 1.

ТУРИЗМ

ПОРТФОЛИО для БАРСА

Автор: Ольга ИСМАГИЛОВА
Фото предоставлено Алтынбеком ДЖАНЫСПАЕВЫМ

Начиная с августа этого года Алматинский заповедник совместно с КазНУ имени Аль-Фараби и Кембрийским университетом (Великобритания) участвует в проекте по изучению снежного барса. Алтынбек Джаныспаев работает в заповеднике орнитологом вот уже более 35 лет, и все эти годы он наблюдал не только за птицами, но и за барсами. Я думаю, что чаще, чем он, снежного барса в дикой природе не видел больше ни один человек на Земле. Так что его участие в этом проекте было предопределено.

Алтынбек, расскажите подробно о проекте, как он работает?

– Учёные Кембрийского университета летом расставили фотоловушки в наиболее перспективных местах: 16 штук по высокогорной части гребня водораздельного хребта между Правым и Средним Талгаром и 7 штук в верховьях Правого Талгара. 5 фотоловушек по своему усмотрению они установили в ельнике долины Правого Талгара, но туда, как и следовало ожидать, попадаются не барсы, а маралы, косули, медведи, волки, рыси и другие животные – куницы, белки, тетерева. Недавно я осмотрел фотоловушки в Правом Талгаре, и 7 штук пришлось снять, потому что они были установлены в неправильном месте: день и ночь снимали большей частью траву, колыхающуюся от ветра, ведь прибор реагирует на всё, что движется. Хотя в них горные козлы попались, и много птиц – улары, клушицы, альпийские галки,

68 Жетер Странствий | Казахстан | ноябрь-декабрь 2014

Russian language article publicising the research

Snow Leopard event, Trail 4

Project Workshop, May 2015

Appendix II – Financial Report

Fuzzy Logic modeling of Snow Leopard Populations - Financial Report
14th August 2015

	Budget GBP	Budget USD	Final Spend GBP	Final Spend USD
Exchange Rate applied *	£ 1.00	$ 1.59	£ 1.00	$ 1.69

PAYROLL COSTS

				BUDGET		FINAL SPEND	
				GBP	USD	GBP	USD
Name	Days	Salary	Overheads	Total	Total	Total	Total
UoC Project lead	15	£ 4,519	£ 3,547	£ 8,066	$ 12,825	£ 8,066	$ 13,637
UoC GIS expert	2	£ 603	£ 355	£ 958	$ 1,523	£ 958	$ 1,620
UoC large carnivore expert	7	£ 1,767	£ 355	£ 2,122	$ 3,374	£ 2,122	$ 3,588
UoC Fuzzy logic expert	5	£ 969	£ 887	£ 1,856	$ 2,951	£ 1,856	$ 3,138
Intern/placement	6 months	£ -	£ -				
Prof. Owen Nevin	20			£ 9,400	$ 14,946	£ 9,400	$ 15,893

NON PAY COSTS

		Budget GBP	Budget USD	Final Spend GBP	Final Spend USD
Travel & Subsistence					
	x4 return flights UK to Kazakstan	£ 2,400	$ 3,816	£ 2,452	$ 4,146
	Train fares to airports	£ 200	$ 318	£ 65	$ 110
	x1 return flight Australia to Kazakstan	£ 1,300	$ 2,067	£ 367	$ 620
	Subsistence - majority covered by the Reserve, small contingency	£ 350	$ 557	£ 439	$ 742
Equipment					
	x22 Bushnell Trophy ID cameras	£ 4,400	$ 6,996	£ 2,832	$ 4,788
	x1 hand held GPS	£ 200	$ 318	£ 159	$ 269
Kazakstan costs					
	Field technician cost in Kazakstan	£ 320	$ 509	£ 891	$ 1,506
	Workshop event for dissemination of findings	£ 300	$ 477	£ 417	$ 705
	Almaty State Nature Reserve - additional fieldwork assistance	£ -	$ -	£ 1,188	$ 2,009
Loan of 20 camera traps and other equipment to the project		£ 2,500	$ 3,975	£ 2,500	$ 4,227
Kazakh National University staff time, desk space, vehicles, lab facilities		£ 1,250	$ 1,988	£ 1,250	$ 2,113
Almaty National Nature Reserve staff time, maintenance of camera traps, accommodation, field support		£ 2,500	$ 3,975	£ 2,500	$ 4,227
	TOTAL PROJECT	**£ 38,122**	**$ 60,614**	**£ 37,462**	**$ 63,337**

	Budget GBP	Budget USD	Final Spend GBP	Final Spend USD
University of Cumbria contribution - pay	£ 13,002	$ 20,673	£ 13,002	$ 21,983
University of Cumbria contribution - non pay	£ 2,536	$ 4,032	£ 2,438	$ 4,121
Central Queensland University - pay	£ 9,400	$ 14,946	£ 9,400	$ 15,893
Kazakh National University	£ 1,250	$ 1,988	£ 1,250	$ 2,113
Almaty National Nature Reserve	£ 2,500	$ 3,975	£ 2,500	$ 4,227