IMPERIAL COLLEGE LONDON
Faculty of Natural Sciences

Centre for Environmental Policy

Conservation of migratory species in the face of new threats and limited data availability: Case study of saiga antelope in Uzbekistan

By

Emma Marsden

A report submitted in partial fulfilment of the requirements for the MSc.

12th September 2012

DECLARATION OF OWN WORK

I declare that this thesis

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

Signature:……………………………………………………………………………………

Name of student (*Please print*):……………………………………………………………

Name of supervisor:……………………………………………………………………………

Abstract

The saiga antelope, *Saiga tatarica*, is a critically endangered species but relatively little is known about the population that migrate south into the Ustyurt plateau of Uzbekistan during the winter months. This population is now facing both new conservation opportunities and new threats. Funding has been made available for saiga monitoring in the region and a protected area extension for the saiga has been proposed, whilst simultaneously a border fence built between Kazakhstan and Uzbekistan threatens to cut off the saiga migration route and cause animal deaths due to entanglement. Science is needed to support conservation decision-making on all areas of change and time is limited.

This study uses mapping and species distribution modelling using existing saiga sightings data to build up a scientific evidence base on the factors affecting saiga distributions in Uzbekistan. Sightings data are assessed to identify gaps and bias, and to make recommendations for future monitoring efforts. MaxEnt models are used to identify the factors affecting saiga distribution, areas important for saiga protection and possible impacts of the new border fence.

Results show that the saiga data for Uzbekistan are of poor quality and efforts are needed to reduce bias in monitoring. Models indicate that zones of the proposed new nature reserve overlap well with areas that are important for saiga all year round, as well as covering newly identified potentially permanent populations, and that saiga should be able to survive north of the border if their migration route is cut off. However, heavy snowfall during the migration period means that they are at a high risk of getting entangled in the fence. Mitigation measures are needed across the length of the fence, not just in the eastern section as previously believed.

Overall, better data are desperately required but cannot be collected in the time frame available for action to protect the saiga. Mitigation measures to reduce the impact of the fence need to be implemented before the saiga move south at the end of the year. This study provides recommendations for future action.

Acknowledgements

With thanks to my supervisors, E.J. Milner-Gulland and Elena Bykova, for their help and guidance throughout this project. Special thanks also to Joe Bull for all his help and for answering my thousands of questions.

I would like to thank Sarah Robinson and Tim Davies for their fantastic advice on using R, Igor Lysenko for his guidance on using ArcGIS and Anthony Dancer for his advice regarding MODIS data.

Contents

List of tables

List of plates

List of figures

Problem statement

Migratory species are very much under threat. In a global analysis of the status of ungulate migrations, Harris et al (2009) report that migrations for six out of 24 species were extinct or unknown and that the majority of migrants had declined in abundance. The decline of mass migrations is of considerable conservation concern, not least because they are an incredible, unique and often ancient phenomenon, but also because their decline has the potential to impact ecosystems across a huge spatial scale. One of the key requirements for the success of conservation programmes for migratory species is a good understanding of the problem (Martin et al, 2007), however the monitoring of these species is fraught with challenges (Singh & Milner-Gulland, 2011a), and therefore conservation decisions often have to be made in the face of limited data availability.

Due to their very nature, migratory species are often vulnerable to a wider range of more severe threats than their sedentary counterparts (Jarnemo, 2008). Key potential threats to both the species and its migration include poaching, habitat loss, barriers to migration and climate change (Harris et al, 2009). The saiga antelope (*Saiga tatarica*), an evolutionarily distinct keystone species inhabiting the Central Eurasian steppe, has suffered greatly at the hands of such threats. It underwent a dramatic population crash of 95% in under a decade following the breakup of the Soviet Union in 1991 (Milner-Gulland et al. 2001) and is listed as Critically Endangered on the IUCN Red List (Mallon, 2008). NGOs such as the Saiga Conservation Alliance advocate urgent action in order to conserve the saiga and its ancient migration pattern (SCA, n.d.), however in areas such as the Uzbek Ustyurt Plateau conservation decision-making is made difficult by a lack of knowledge and data availability on saiga in the region. This study aims to help inform saiga conservation decision-making in Uzbekistan in three key problem areas: species knowledge, protected area planning and the mitigation of impact of a new border fence.

(i) Species knowledge

Unlike countries such as Kazakhstan, which have long-running aerial saiga monitoring programmes in place, relatively little is known about saiga in Uzbekistan. The Ustyurt is a sparsely populated landscape, with poor roads and very harsh conditions for monitoring during the winter when the saiga migrate into the region (Olson, 2011). Political relations with neighbouring Kazakhstan are poor, the results of which include a ban on aerial monitoring in the Utsyurt border region and little collaboration on saiga conservation. Until recently there was also very little funding available for monitoring programmes (Offord, 2011). This has resulted in disparate and often low quality sources of data on the saiga, yet an understanding of saiga distribution and migration in Uzbekistan is essential for predicting how the species may respond to threats and for determining the best action to conserve it (Martin et al, 2007). Overall, this problem can be divided into two aspects where science is needed: firstly, the factors driving saiga distribution in Uzbekistan need to be investigated to strengthen the knowledge base upon which conservation actions are taken, and secondly, an analysis of the quality of existing data are needed to make recommendations for future monitoring programmes. Scientist and founding member of the Saiga Conservation Alliance, Elena Bykova, recently received a Whitely Conservation Award to fund saiga monitoring in Uzbekistan; identifying gaps and bias in existing data can help ensure that this funding is put to optimal use.

(ii) Protected area planning

Whilst a reserve currently exists in Uzbekistan, the Saigachy, it is not enforced and is effectively a "paper park". There are now plans to extend the Saigachy so that it ranges from the western border with Kazakhstan along the northern border until it meets the Aral Sea, covering a total area of 7,352 sq km (Esipov et al, 2009a). This project will be industry-funded, thus acting as a means for the destructive oil and gas companies working in the region to offset their environmental impact. Within the reserve there are plans to use a zoning system with three tiers of protection: (i) strict protection (i.e. no-go area), (ii) limited human activity, and (iii) mitigation measures in place. Science is needed to inform decision-making on where these zones should be placed to best conserve the species.

(iii) Fence impact mitigation

Saigas in Uzbekistan have long been affected by poaching and habitat loss, however this year a new threat has emerged. As part of agreements made during the formation of a customs union with Belarus and Russia, Kazakhstan is required to build fences along its borders (Milner-Gulland, 2012; Zuther, 2012). For the saiga this means that they may be barred from completing their migration into Uzbekistan. This has the potential to be hugely damaging to the saiga population as they may suffer from entanglement in the fence, harsher environmental conditions including reduced access to vegetation due to higher snowfall, as well as increased vulnerability to poaching. However, hunting inspectors in Kazakhstan have claimed that by planting dense bands of saxaul (*Haloxylon ammodendron*), a shrub, sufficient shelter, food and barriers to entanglement can be provided for the saiga (Makash & Husainov, 2011). As the fence is already almost completed along the northern border of Uzbekistan in the Ustyurt, urgent action is required to address concerns for the saiga. Science is need to inform decisions about such actions; questions such as how the fence is really likely to impact the saiga, and where and what mitigation measures should be put in place need to be answered.

Aims and objectives

Aim:

To improve the scientific evidence base for the conservation of saiga in Uzbekistan.

Objectives:

(i) To assess the status of knowledge of saiga in Uzbekistan and evaluate the success of monitoring in the Uzbek Ustyurt
(ii) To utilise species distribution models to investigate the factors affecting the distribution of saiga in the region
(iii) To assess using maps and models how well the proposed Saigachy nature reserve fits the distribution of the saiga
(iv) The investigate the possible impact of the new border fence between Uzbekistan and Kazakhstan

Research tasks:

Objective	Research tasks
(i) Status of saiga knowledge and monitoring in the Uzbek Ustyurt	- Analysis of reliability of saiga sightings data, identifying any gaps and sources of bias - Analysis of success of monitoring methods - Recommendations for future monitoring
(ii) Factors affecting the distribution of saiga in the region	- Use MaxEnt model jacknifes and permutation importance measurements to test which factors affect the distribution of the saiga at different times of year

(iii)	The design of the extended Saigachy nature reserve	- Use visual analysis of saiga sightings maps and model outputs to assess where might be good to protect at different times of year - Use ArcGIS to add model outputs from the different seasons together to assess where is important to focus protection efforts throughout the year
(iv)	The possible impact of the new border fence between Uzbekistan and Kazakhstan	- Project model for Uzbekistan north of the border to assess where saiga are crossing into Uzbekistan and whether they could survive if their migration was restricted by the fence

1. Background

1.1 Monitoring migratory species

1.1.1. Challenges

Monitoring is an essential part of conservation practice as it firstly helps to assess the magnitude of the problem and inform decision-making (Nichols & Williams, 2006), and secondly helps to evaluate the effectiveness of conservation action (Singh & Milner-Gulland, 2011a). However, conducting a successful monitoring programme can be incredibly challenging, especially in low capacity developing countries such as Uzbekistan. Challenges are presented by the species itself, the area it inhabits and the intricacies of the monitoring programme design.

One of the main difficulties in monitoring migratory species is the fact that they are migratory. Large areas need to be covered and different areas need to be monitored at different times of the year, with migration routes potentially crossing political boundaries. Another species-based challenge is detectability, for example saiga can be relatively rare, difficult to spot and count and are easily alarmed into running away (Offord, 2011). Detectability can lead to issues with sample sizes and can also be a significant cause of variation in the data. Time in the season (and thus age) and sex have been found to affect detectability of moose on the Norwegian island of Vega (Solberg et al, 2010) and different observers have been found to detect African ungulates at variable rates (Collier et al, 2011). Additionally, Young et al (2010) suspect that rainfall, and thus vegetation colour, contributed to inter-annual variation in Mongolian saiga detectability. Problems posed by the species themselves often require further resource input, e.g. more monitors and better equipment, in order to overcome them, however this is not always available.

There can be both environmental and anthropogenic challenges posed by the area to be monitored. In an analysis of monitoring methods for ungulates in Central Asia, Singh and Milner-Gulland (2011a) highlight the remoteness of ungulate habitat as an important challenge faced by monitoring programmes. This can be enhanced by harsh environmental conditions for monitoring – Uzbekistan suffers extreme cold and snow in the winter (Azimov et al, 2006) and very hot temperatures in the summer. Again, overcoming these challenges can require specialist equipment (Olson, 2011). Regulatory issues in the study region can also play a role, for instance the political relations between Kazakhstan and Uzbekistan have result in a ban on air travel across the Uzbek Ustyurt plateau, ruling out any aerial surveying.

Challenges in programme design include acquiring funding, ensuring expertise and avoiding bias. Successful monitoring can require substantial and sustained funding, however McNeely et al (2009) state that few Asian governments are putting much emphasis on environmental or conservation agendas and a lack of political will can limit the work of NGOs, as is the case in Uzbekistan. A lack of funding also serves to intensify other challenges, as noted above. In addition to problems with funding, low capacity developing countries can suffer from a lack of monitoring expertise and this can result in biased or error-prone monitoring programmes (Singh & Milner-Gulland, 2011a). A commonly-cited example of this is the bias that was found to exist in Kazakhstan's aerial monitoring programme for saiga (Norton-Griffiths & McConville, 2007). Avoiding bias in monitoring can be incredibly problematic. Detectability is one source of bias, as described above, however others include spatial bias in sampling effort (Boakes et al, 2010), e.g. towards roads, settlements or areas where the species is well-known to occur, temporal bias, e.g. towards time periods where the conditions for sampling are most favourable, and observer bias, e.g. with some observers over- or under-estimating counts (Offord, 2011).

1.1.2 Methods

Whilst monitoring methods should be chosen to best address the challenges described in section 1.1.1, those challenges also restrict which can be chosen. Singh and Milner-Gulland (2011a) categorise monitoring options for ungulates into four mediums: aerial, ground-vehicular, ground-walked and ground-other. A brief introduction will be given to each method:

(i) Aerial surveys

These are potentially very useful for monitoring ungulates such as saiga because they can cover very large areas. They have been used for saiga monitoring for many years in Kazakhstan, but unfortunately there have been issues with bias in the methodology (Norton-Griffiths & McConville, 2007). Experimental investigation has shown that factors such as plane height and survey strip width can significantly bias results (Pennycuick & Western, 1972). Aerial surveys are also difficult to carry out if there are challenges with funding and poor conditions.

(ii) Ground-vehicular surveys

These have been used to monitor saiga in Russia and Kazakhstan (Singh & Milner-Gulland, 2011a). Issues include limiting bias due to sampling only near roads, while a pilot study in Uzbekistan struggled with problems with fuel freezing and drivers reluctant to travel in poor conditions (Olson, 2011). The cars available to hire in Uzbekistan are often liable to breaking down, however the cost of purchasing two new Toyota Land Rovers for saiga monitoring was estimated to be $137,840 (Offord, 2011). Motorbikes are a possible alternative.

(iii) Ground-walk surveys

These have the advantage of being much cheaper but are impractical for saiga monitoring because it is impossible to cover large areas and conditions are harsh.

(iv) Ground- other surveys

Examples of these include camera traps and participatory monitoring. While camera traps are expensive and of little use with broadly distributed species, a successful participatory monitoring programme has been implemented in Uzbekistan. Participatory monitoring involves encouraging teams of locals to record saiga sightings as part of their day to day activites and advantages include the engagement of local communities (Danielsen et al, 2009), however the challenge of expertise became an issue in Uzbekistan and recommendations were made for improved monitor training (Bykova & Esipov, 2011).

One slightly different monitoring method is satellite radio collaring. This technique only monitors where the animals are travelling, rather than their abundance, but it helps to minimise the challenges of the migratory nature of the species, the harsh conditions and remoteness of their environment and some of the issues with bias in monitoring. Satellite collaring of saigas has been carried out in Kazakhstan, Uzbekistan and Mongolia (Zuther, 2010; Salemgareev et al, 2011; Ito et al, 2010; Buuveibaatar et al, 2012). While such monitoring is expensive, the projects have been carried out in Kazakhstan and Uzbekistan in collaboration with a number of academic institutions, e.g. Torotti University and the Uzbek and Kazak Institutes of Zoology, governmental bodies, e.g. the Kazak Committee on Forestry and Hunting, and NGOs, e.g. the Association for the Conservation of Biodiversity of Kazakhstan, the Royal Society for the Protection of Birds (RSPB) and the United Nations Environment Programme (UNEP) (Salemgareev et al, 2011). Unfortunately it appears that no monitoring programme is challenge free and satellite collaring has its own set, including technical difficulties with the collars not transmitting (Salemgareev et al, 2011) and difficulties with catching enough saiga to collar and in a manner that minimises stress to the animal (Ito et al, 2010; Zuther, 2010). These challenges result in smaller sample sizes and recently published collaring data for the Ustyurt population relied on only two collared saigas (Zuther, 2012).

1.2 Barriers to migration

Migrations are inherently risky, as evidenced in their effects on energy, predation risk and fecundity costs (Milner-Gulland et al, 2011), however it is the resulting increased risk of contact with humans that can cause the most severe threats to species and their migration patterns (Jarnemo, 2008). In a global analysis of the status of ungulate migrations, Harris et al (2009) report that migrations for six out of 24 species were “extinct or unknown” and that the majority of migrants had declined in abundance. The decline of mass migrations is of considerable conservation concern, not least because they are an incredible, unique and often ancient phenomenon, but also because their decline has the potential to impact ecosystems across a huge spatial scale. Removing barriers is identified one of the key methods of conserving migrations (Harris et al, 2009) and is of considerable interest in the case of the saiga antelope in Uzbekistan (Milner-Gulland, 2012). Fences will potentially the most pressing threat to the Uzbek saiga (Zuther, 2012), however they are also vulnerable to the effect of other barriers, e.g. railways, roads and human settlements.

1.2.1 Fences

Fences may be erected to mark a variety of boundaries: political, individual land ownership, transport route boundaries, or even, very rarely, species boundaries, e.g. for wildebeest in the Serengeti. In the vast majority of cases, fences that impede migration routes can pose a considerable threat to the species and the migration itself. They can cause death, e.g. by starvation, dehydration and entanglement, can isolate sub-populations and can increase human-wildlife conflict (Gadd, 2012).

Specific examples of damaging effects of fences on migratory ungulates in the literature cover impacts such as starvation, increased predation and entanglement. A fenced protected area in Saudi Arabia is thought to be responsible for a huge die-off of Arabian oryx and sand gazelle, with 560 oryx and 2815 sand gazelle deaths between 1999 and 2008. Restricted migration caused starvation and increased vulnerability to drought (Islam et al, 2010). In Pilanesburg National Park, South Africa, blue wildebeest no longer migrate due to fences, but this has given their lion predators a huge advantage and the Pilanesburg population was found to be much more vulnerable to predation than migratory populations elsewhere (Tambling & Du Toit, 2005). An example of entanglement strikes much closer to home, with reports of Mongolian gazelle and getting caught and dying on barbed wire fences (CMS, 2011; Fig.1.1).

Figure 1.1 Mongolian gazelle caught in barbed wire fence on the Russian-Mongolian border (CMS, 2011).

The specific fence threat to the saiga in Uzbekistan is a border fence with Kazakhstan and the literature shows that border fences commonly impact migratory ungulates across the globe. Olson et al (2009) report that hundreds of Mongolian gazelles got caught in Russian-Mongolian border fences in May 2008, while Kaczensky et al (2011) argue that by if Mongolian border fences with China could be opened in certain areas, 70,000km^2 of Asiatic wild ass habitat could be connected. Border fences between the US and Mexico are also thought to be permanently separating subpopulations of bighorn sheep, which previously relied upon a degree of dispersal (Flesch et al, 2010). Evidence of negative impacts of border fences elsewhere can help build a case for impact mitigation on the Kazakhstan-Uzbekistan border.

Alongside the unfortunate real-life examples of damage, the modelling of the potential impacts of fences and other barriers is also progressing. Holdo et al (2011) used a habitat model with a simulated barrier to predict a mean drop in wildebeest population size of 35% in the Serengeti if barriers were built across the northern section of the park. Such modelling techniques make the case for mitigation more robust.

1.2.2 Other barriers

The threats of roads and railways are similar to those of fences. Mortality can occur as a result of blocking, aversion and collisions. Jordhoy (2008) reports evidence of an ancient wild reindeer migration in southern Norway that was driven extinct by increased road and railway traffic and also perhaps by reduced population sizes. Interestingly, Ito et al (2008) carried out a carcass census of Mongolian gazelles around an international railroad and found that the impact of the railway was stronger on one side than on the other. Elucidating the reasons for such a one-sided impact could yield important conclusions for mitigation action. Pipelines and power lines may also form barriers to migration for ungulates (Reimers et al, 2007).

Human settlements form a further type of barrier to migration; disturbances include roads, fences, noise and light (Kusta et al, 2011) and are often found to result in aversion. Vistnes and Nellemann (2007) discuss studies showing that "reindeer and caribou reduced the use of areas within 5km from infrastructure and human activity by 50-95%, depending on the type of disturbance". Similarly, while historically determined by environmental factors, there is now evidence that saiga calving site selection in Kazakhstan has become predominantly driven by distance from human settlements (Singh et al, 2010b). While aversion on its own may not necessarily halt the migration, when combined with other threats such as climate change, habitat loss and border fences, aversion could be particularly damaging and therefore needs to be taken into account. Human settlement can also result in resource competition for migratory species, e.g. through agriculture and livestock (Western et al, 2009).

1.2.3 Mitigation

Since the impact of fences on species migration is a key threat addressed in this study, mitigation measures to reduce fence impact will be focussed on. There are three different stages at which such mitigation measures can be implemented: they can be used to reduce the barrier effect of the fence, to protect animals restricted by the fence and to restore lost migrations. The ideal option for reducing the barrier effect would be to remove the fence (Olson, 2012), however, this is not always possible (e.g. Milner-Gulland, 2012) and wildlife-friendly fencing options might thus be more favourable. These include removing the bottom strand of wire to allow animals to pass beneath the fence (CMS, 2011; Milner-Gulland, 2012), removing the barbs from the wire (CMS, 2011) and using a flag to make the fence clearly visible to moving animals (Milner-Gulland, 2012).

Wildlife crossing structures are another means of reducing the barrier effect of fences, these may be underpasses or overpasses. There are a number of issues with using such structures; they are expensive, it can be difficult to know where best to place them and animals may be wary of them and reluctant to pass through (Olson, 2012). Getting the size of the passes right can be important for encouraging animals to use them, however Grilo et al (2010) report mixed findings on species underpass measurement preferences in Banff National Park. In an evaluation of the wildlife crossing effectiveness, Bissonette and Cramer (2008) identify some important conditions for success: (1) crossings should be adapted to the target species, e.g. pronghorn prefer open, natural-looking structures (saiga are likely to be similar), (2) crossings need to be easily visible and in the animals' straight line of sight if possible, and (3) crossings need to be well-maintained.

Protecting restricted animals can be essential for ensuring their survival if their migration is curtailed. For example, in Saudi Arabia in response to an ungulate die-off due to fences around a reserve, an emergency plan was implemented including providing food and water resources to replace those that the animals would have been migrating to find. As highlighted by Berger (2004), protection measures need to be location-specific.

The restoration of lost migrations is needed when there has been no migration for a period of time. Methods depend on where and how the migration was stopped. Fynn and Bonyongo (2011) suggest an interesting negotiation approach, whereby conservation areas of low functionality are identified and exchanged for land in important migration areas to create corridors.

Further, more general points about mitigation methods that are noted in the literature include the need for monitoring and maintenance of mitigation efforts (Olson, 2012). There is no point continuing with a technique that is not reducing fence impact, and poorly maintained structures, e.g. loose wire on fences, can harm animals. Opportunities for achieving further conservation success are also identified; Berger (2004) notes the scope for landscape-level thinking when planning mitigation, e.g. the creation of a network of corridors, while Flesch et al (2010) identify crossing structures as an opportunity for collecting data via remote surveillance technologies, e.g. sensors.

1.3 Species distribution models

Species distribution models (SDMs) can yield a range of information that can be of great importance for species conservation. They can identify optimal areas for protection, e.g. Singh et al (2010a) investigated how well current protected areas in Kazakhstan covered predicted future distribution of saiga with climate change, and also the factors affecting species distribution, e.g. Monterroso et al (2009) found that prey abundance and minimal human disturbance were the most important factors affecting the distribution of the European wildcat, *Felis silvestris*, in southern Portugal. Other applications of SDMs include the assessment of risks such as spread of exotic species and land cover change (Rodriguez et al, 2007). There are a wide range of SDMs (Guisan & Thuiller, 2005), however the most appropriate model often depends on the data available. For saiga in Uzbekistan there are no presence-absence data, records only exist for actual sightings and the date they were recorded. Therefore, a SDM based on presence-only data must be used, the most widely utilised of which is MaxEnt (http://www.cs.princeton.edu/~schapire /maxent/; Phillips et al, 2006).

1.3.2 MaxEnt

MaxEnt is a software application that provides a user-friendly interface for applying a maximum entropy modelling technique. Inputs to the model are species location data and a set of environmental variables provided in spatial grid format. Due to the lack of absence data, the model takes a set of background samples, i.e. random points throughout the study area with their associated environmental characteristics, along with the set of locations where the species are known to be present and estimates two probability density functions, as described by Elith et al (2011):

$f(z)$ = the probability density of environmental covariates across the landscape

$f_1(z)$ = the probability density of environmental covariates across locations where the species is present

MaxEnt chooses the type of density function, rather than the user choosing it, based on the data provided (Phillips, n.d.); it chooses the distribution of $f_1(z)$ to be that closest to $f(z)$. It then estimates a ratio of $f_1(z)/ f(z)$, which provides a "raw" measure of which factors are important in determining distribution, and this measure undergoes a logistic transformation to produce a more easily interpretable output that is a proxy for a probability of species presence in any particular cell (Elith et al, 2011). This is a maximum entropy approach because $f(z)$ is equivalent to the null model, or uniform distribution; if there is no information on occurrence, as is the case in $f(z)$, then no improvement can be made on a model assuming that the species distribution across the landscape is proportional to that of its environmental conditions (Elith et al, 2011). So, by selecting the distribution of $f_1(z)$ that is closest to that of $f(z)$ we are choosing the model that is closest to the uniform distribution and is hence of maximum entropy.

Put simply, the MaxEnt model compares the environment in which the species is known to occur with what the environment is like in general throughout the landscape. The factors identified as being important in determining species presence act as constraints in the maximum entropy model selection of species distribution (Phillips et al, 2006).

Advantages of MaxEnt are that it is quite easy to use but that more advanced settings, e.g. regularisation parameters, can be altered if required, it can produce a range of useful outputs, e.g. jacknifes of factor importance, and that it performs well against other modelling methods (Elith et al, 2006). Disadvantages include that the user interface makes it less clear to see how the models work and that it is sensitive to sampling bias and to changes in default settings such as the regularisation parameters, particularly if reprojecting the model onto another area (Phillips & Dudík, 2008).

1.3.3 Factors of interest in modelling saiga distribution

This study aims to investigate and model the factors affecting the distribution of saiga in Uzbekistan. When determining the factors affecting a species distribution, it is important to consider spatial and temporal resolution. Different factors are important at different scales for different species, for example, in red deer in the Swiss Alps it was found that habitat selection largely occurred at the landscape scale, with little selection at the local scale (Zweife-Schielly et al, 2009). In the case of saiga in Uzbekistan, we must consider the regional-scale factors, which are likely to be the drivers of migration, and also more local-scale factors, which still have the potential to yield important insights into saiga distribution.

Figure 1.2 Grazing saiga. Photo by Aline Kuhl.

Saigas are relatively small, growing to a height of around 70cm (EDGE, n.d.; Fig.1.2). They form migratory herds of up to a thousand animals and feed on a diet of grasses and legumes. Saiga habitat is characteristically open, dry and flat – either steppe grassland or semi-arid desert, and mortality varies with environmental stresses (Bekenov et al, 1998). Four key factors affecting saiga distribution are snowfall, vegetation, human settlements and barriers to movement, and a further two, surface water availability and slope, could also be important. Each of these will be discussed briefly in turn.

(i) Snowfall

There is a fairly strong consensus that saiga migration is driven by snowfall in the winter, the ultimate cause being the resulting limited access to food (e.g. Singh et al, 2010a; Esipov et al, 2009b; Bekenov et al, 1998; Chilton, 2011). However, there is some discrepancy about the level of snowfall necessary to trigger migration. Esipov et al (2009b) report that snow cover greater than 5cm triggers saiga movement, whereas Bekenov et al (1998) state that the saiga actually stay in areas of the desert where snow is 5-10cm deep; the Large Herbivore Network (n.d.) cites 20cm as the limiting snow depth for saiga, yet Bekenov et al (1998) cite examples of saiga obtaining food at 25-30cm, although they do note that this was only under exceptional circumstances. Overall, perhaps further research is needed in order to determine the more precise aspects of migration drivers, but it is clear that snowfall is an important factor influencing saiga distribution on the regional scale.

Temperature is a related factor which may also be a driver of migration in saiga, though it is likely to correlate with snowfall.

(ii) Vegetation

A study of saiga distribution across the range of all four saiga populations found that migration was driven by vegetation productivity, which was itself determined by precipitation (Singh et al, 2010a), and normalised difference vegetation index (NDVI) has also been noted to be useful in predicting future saiga distributions (Pettorelli et al, 2011). However, while the saiga are in Uzbekistan much of the landscape is covered by snow, therefore one might expect vegetation to be a less important factor affecting distribution. Certainly, previous studies of saiga distribution in Kazakhstan have found NDVI to be an important factor during spring rather than winter (Chilton, 2011; Singh et al, 2010a). Yet it may still be important to consider vegetation, firstly because there is evidence that some saiga remain in Uzbekistan during Spring (see data), and secondly because different types of vegetation may provide food and shelter even during the period of snow cover, or at least are being argued to do so. The shrub species saxaul (*Haloxylon ammodendron*) is credited by Makash and Husainov (2011) as being the solution to saving saiga in the face of building a border fence between Kazakhstan and Uzbekistan. They argue that planting thick bands of saxaul would provide shelter from the wind, food for the saiga and a barrier to stop the saiga getting entangled in the fence. However, once again there is considerable debate on this matter; as discussed by Lushchekina et al (1999), there is evidence of saiga avoiding saxaul, something that is arguably even more likely to happen if it is planted in dense thickets. Overall, vegetation should be considered as a factor influencing saiga distribution because it is known to be a good predictor of saiga distribution in the spring but its likely relevance Uzbekistan in the winter is as yet unclear. Investigating the importance of vegetation in the winter can help to bring further scientific credibility to the arguments surrounding saxaul as a conservation technique.

(iii) Human settlements

Human settlements are thought to be avoided by saiga. They produce noise and light, and the saiga are more vulnerable to poaching. Singh et al (2010b) found that, while historically determined by environmental factors, saiga calving site selection in Kazakhstan has now become predominantly driven by distance from human settlements. When considering human settlements, it is important to note that their impact on saiga distribution may be masked/skewed by any bias in data collection – it is likely that, particularly in the case of participatory monitoring, more extensive monitoring has been undertaken within a reasonable distance of settlements.

(iv) Barriers

Potential barriers to saiga movement in the Uzbekistan Ustyurt include anthropogenic impacts such as fences, railways and roads, as well as natural features such as the Aral Sea (Fig.1.3). The impact of such barriers might be that the saiga avoid them and change the direction of their movement. Alternatively, it is possible that there might be a clustering of saiga as they attempt to cross the barrier. The outcome may depend on the nature of the barrier itself and perhaps on how long it has been there, e.g. saiga may have changed route to avoid a railway that has been there for many years, as well as the genetic basis for migration in saiga, i.e. how much of the migration pattern is genetically determined and thus unlikely to shift (Bolger, 2008). As with the impact of human settlements, we must be wary of monitoring bias when considering features such as roads (Chilton, 2011).

Figure 1.3 Map of the Uzbekistan Ustyurt (Offord, 2011). Red lines demarcate the country border, solid grey lines indicate roads and black and grey striped lines indicate railway lines. Red dots show the locations of settlements

(v) Water

Singh et al (2010a) found that saiga migration in Kazakhstan is driven by productivity and precipitation and Singh and Milner-Gulland (2011b) report distance from water as a determinant of spring saiga distribution in Kazakhstan. Water availability may be an important factor to include in this study because it may determine why saiga leave Uzbekistan again once the snow melts in March. Esipov et al (2009b) speculate that the aridification of the Ustyurt could be the reason why the saiga no longer remain in large groups in Uzbekistan all year round.

(vi) Gradient

Saiga prefer open, flat habitat (Bekenov et al, 1998). While the Ustyurt plateau provides a vast area of this habitat, at the eastern edge of the plateau there is a steep drop down towards the Aral Sea, known as the “chink”. It would be interesting to test whether this has any impact on saiga distribution.

2 Methodology

2.3 Data collection

While this project involved no fieldwork, data had to be collected from a number of sources and a key part of this work is to recognise the reliability of such secondary sources.

2.1.1 Saiga sightings

Saiga recordings in Uzbekistan have been accumulated into a database by Elena Bykova of the Institute of Zoology in Uzbekistan. They span a time period from December 2005 to the present and sightings from this are still being collected from monitors, processed and added to the database. This database makes up the bulk of the saiga data used in the models, supplemented by a few chance sightings recorded by scientists working in the Ustyurt this summer.

Three types of data collection are covered by the database:

1. "General monitoring" – recordings made by travelling along roads, usually without a scientific monitoring programme. These data are most problematic as it is likely to be heavily biased. For example, there were 47 sightings recorded in December 2005, however mapping shows that they nearly all follow a single line along the road next to the railway. Such a bias could significantly skew the models and so this data was excluded.
2. Participatory monitoring – involving local communities in saiga monitoring is one of the action points agreed by signatories of the Memorandum of Understanding on the Conservation, Restoration and Sustainable Use of the Saiga Antelope (CMS, 2010). To achieve this in Uzbekistan, a network of "Saiga Friends" has been created and local people have received benefits such as salaries for their contribution to monitoring (SCA, n.d.).
3. Transect distance sampling – in 2012 a pilot distance sampling monitoring programme was run to assess the potential for employing this technique on an extended timescale for monitoring in Uzbekistan (Offord, 2011). Such a

programme would be funded by a Whitley Conservation Grant awarded to Elena Bykova. In distance sampling, the observer travels along transects and stops as soon as a saiga is observed, reducing error due to scaring the saiga into running. The distance and angle of observation to the saiga are recorded so that the perpendicular distance from the transect to the saiga can be calculated and these distances can then be used to produce models of saiga distribution. The pilot programme used local scientists on motorbikes to travel the transects. Unfortunately, not enough recordings were made this year for such a model to be produced, however the saiga location data are still useful for MaxEnt modelling. This data collection type should be the most reliable as a set programme was designed to reduce bias, e.g. transects rather than roads, regularly timed monitoring.

Not all the data in the database was used, some sightings, e.g. those in Kazakhstan, were deemed to be in areas that had only been monitored rarely and not very thoroughly, therefore including that area would lead to a less reliable model. Saigas migrate north in the summer and there were not enough sightings to run a model for July, August and September, so any data for this period was excluded. As described above, sightings from December 2005 were also excluded due to their heavy bias.

A total of 186 sightings were used in the final models. Table1 summarises the breakdown of the sightings data by data collection type (Table 2.1):

Table 2.1 Number of saiga sightings recorded by each data collection type, as used in the models.

Data collection type	Number of sightings
General monitoring	12
Participatory monitoring	147
Transect distance sampling	24
Chance sightings	3

2.1.2 Factors

Six factors were chosen to be included in the models based on a literature review of factors affecting the distribution of saiga (Table 2.2). These are discussed in greater detail in background section 1.3.3. While it was noted that, since saiga move in groups and not at very high speeds, there is likely to be spatial autocorrelation in the model, the decision was made not to incorporate latitude and longitude in the model to try to account for this. This was because the environmental factors are likely to show strong correlation with latitude and longitude therefore incorporating them would remove nearly all the variation resulting in an uninformative model.

Table 2.2 Factors to be included in the model, with reasoning and source information

Factor	Why included	Source	Details
Snow coverage	Snowfall is thought to be a driver of saiga migration because it limits access to vegetation (e.g. Esipov et al, 2009; Bekenov et al, 1998; Chilton, 2011).	MODIS/Terra Snow Cover Monthly L3 Global (MOD10CM) data set (Hall et al, 2006; http://nsidc.org/data/docs/daac /modis_v5/mod10cm_modis_terra_snow _monthly_global_0.05deg_cmg.gd.html)	0.05 Degree resolution Used snow coverage and quality assessment (QA)layers Coverage is a monthly average calculated from daily datasets as a percentage per pixel
Night time land surface temperature (LST)	Temperature has the potential to act as an environmental trigger for migration, both south ahead of snow and north to better vegetation in the summer.	MODIS/Terra Land Surface Temperature and Emissivity Monthly L3 Global (MOD11C3) data set (LP DAAC, n.d.a; https://lpdaac.usgs.gov/products/ modis_products_table/mod11c3)	0.05 Degree resolution Used nighttime lands surface temperature and LSTE quality control layers Monthly average calculated from daily datasets

Normalised difference vegetation index (NDVI)	Vegetation is known to be of use in predicting saiga distribution (Singh et al, 2011a; Pettorelli et al, 2011). NDVI is a commonly used and well-documented vegetation index (Solano et al, 2010).	MODIS/Terra Vegetation Indices Monthly L3 Global (MOD13A3) data set (LP DAAC, n.d.b, https://lpdaac.usgs.gov /products/modis_products_table /mod13a3)	1km resolution (downloaded as sinusoidal projection) Version 5 Used NDVI and NDVI pixel reliability layer Monthly average calculated from 16-day datasets
Distance to nearest settlement	Saiga are thought to avoid human settlements (e.g. Singh et al 2010b)	Coordinates of four key settlements in the study area were extracted from Google Earth (Google Inc, 2012)	Four settlements are Jaslyk, Karalpakstan, Bostan and Kubla-Usturt
Distance to nearest road	Roads in the Uzbek Ustyurt can be very wide (up to 1km, Joseph Bull, pers comm.) and could potentially form a barrier to saiga movement.	DIVA-GIS Uzbekistan roads shapefile (DIVA-GIS, n.d.; http://www.diva-gis.org/datadown)	Cross checked road locations with scientist who had recently travelled in the area
Distance to railway	There is evidence of railways acting as a barrier to other ungluates (e.g. Ito et al, 2008)	DIVA-GIS Uzbekistan railroads shapefile (DIVA-GIS, n.d.; http://www.diva-gis.org/datadown)	

Uzbekistan border information was also used to determine the area of the study site. This was downloaded from DIVA-GIS's free online data source (DIVA-GIS, n.d.; http://www.diva-gis.org/datadown).

2.2 Data processing

2.2.1 Study sites

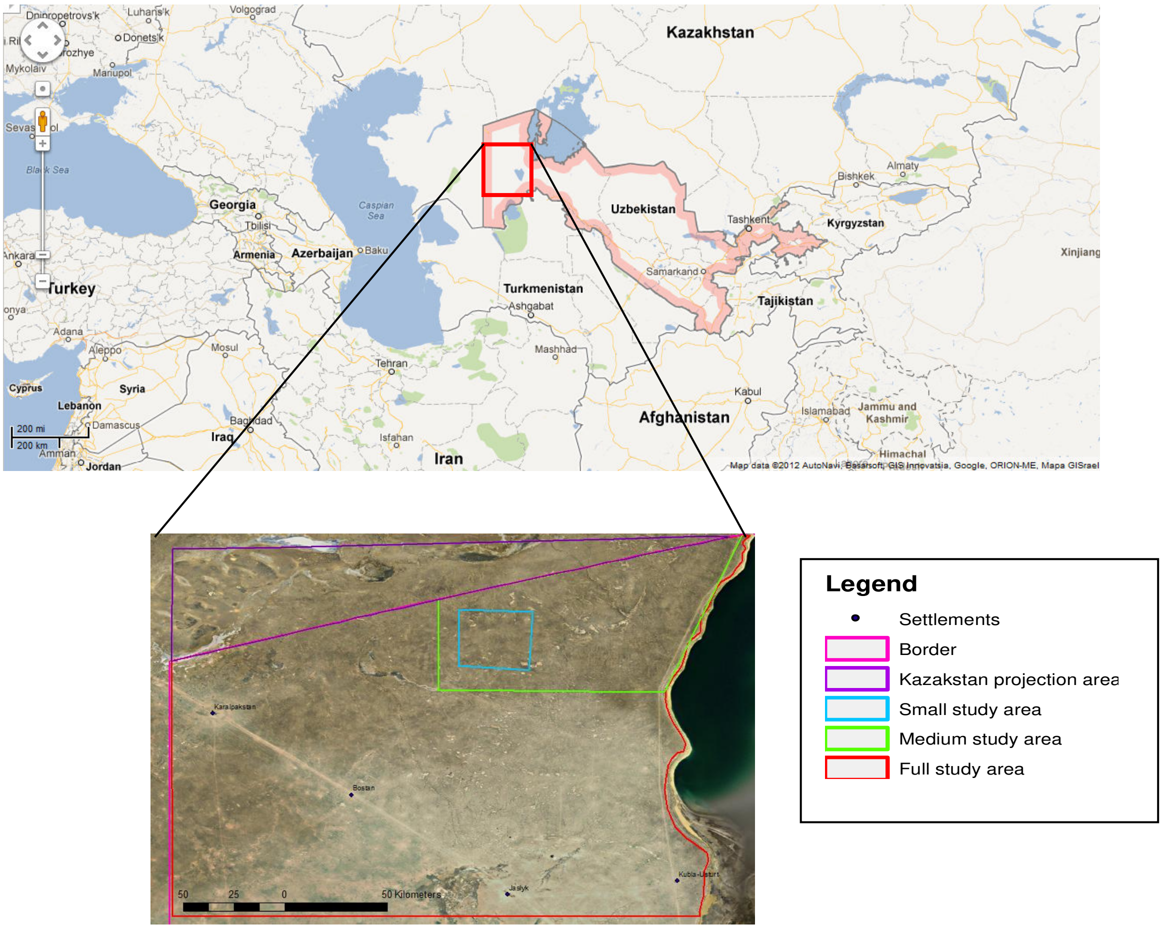


Figure 2.1 Map of Central Asia (Google Maps, 2012) with red box indictating the location of the study area (shown in lower map) in the Uzbek Ustyurt plateau. In lower map, lines indicate study areas; red outlines the full study site, green the medium study site and blue the small study site. The pink lines show the Uzbek-Kazak border and the purple outlines the area of Kazakhstan into which the model was projected. Coordinates for the south-west corner of the study sites are: full (43.934,52.543), medium (44.512, 54.018) and small (45.112, 54.594).

Multiple study site sizes were chosen in order to investigate whether the factors affecting saiga distribution differ at different scales, as has been found in other ungulates (e.g. Zweife-Schielly et al, 2009;Fig.2.1). The full study site is 39590.0km^2 and was chosen to encompass the existing saiga recordings and settlements without becoming too large, as study areas larger than the range of the species can result in a decreased reliability of models (Phillips, n.d.). The medium study site is 7689.0km^2 and was chosen to represent a more regional scale covering the top corner of the full site, which was thought to be an important area for saiga migration into Uzbekistan (E.J. Milner-Gulland, pers.comm.). The small site is 994.1km^2 and was chosen because there was a higher density of saiga sightings in the region. In studying the small site it was predicted that more local effects of vegetation and other factors might be picked up on.

Investigating the effect of the fence was carried out by projecting the model into Kazakstan. The purple outline in Figure 2.1 indicates the projection area. This area was chosen to be not too large in order to minimise extrapolation of the model to environmental values not encountered in the reference area for the projection. In hindsight, it would have been better to project the model into a rectangular area running parallel to the border.

2.2.2 Time periods

Models were run for three different time periods in the saiga migration: from October to December (Period 1), from January to March (Period 2) and from April to June (Period 3). The data was aggregated into groups of three months in order to increase saiga sighting sample sizes without averaging out important changes in environmental factors. The periods were set by the snow melt in March, so that the final three months which have no snow were separated.

2.2.3 Factor data processing template

MaxEnt requires all environmental layers to have identical geographic extents, therefore a template was designed and all layers were manipulated to match it (Table 2.3).

Table 2.3 Specifications of attributes of environmental layer template, with details about why they were chosen.

Attribute	Specifications	Why
Coordinate system	World Geographic System 1984 (WGS84)	Most widely used system
Cell size	0.011726945	Highest resolution of the environmental datasets (NDVI)
Pixel corner points	Mean of Jan, Feb and March 2006 temperature datasets	Made a template to resample all others to, which factor was chosen has very little importance
Extent	Cut all to the same three study area shapefiles	As described above

2.2.4 Snow data

The snow cover datasets were downloaded as hdf files from the Land Processes Distributed Active Archive Centre's (LP DAAC) Data Pool (https://lpdaac.usgs.gov /get_data/data_pool), when selecting modules to download the option to only select those with minimum cloud cover (<10%) was checked. The MRT tool (LP DAAC, n.d.c.; https://lpdaac.usgs.gov/tools/modis_reprojection_tool_swath) was used to reproject the data to WGS84, change the pixel size and save the output as a geotiff file.

The QA layer was used to create binary quality masks to 'clean' the poor quality pixels from the snow data. Table 2.4 shows the data values in the QA layer. All good quality pixels (i.e. those with a value of 0) were set to contain the value 1, whilst all those with lower quality were set to contain NA. The mask was then applied by multiplying its pixel values with those of the snow layer, so that all good quality pixels remained the same while all poorer quality pixels contained NA and were excluded.

Table 2.4 Values of the Snow Cover MOD10CM quality assessment (QA) layer (Hall et al, 2006).

Pixel value	Quality
0	Good quality
1	Other quality
252	Antarctica mask
254	Water mask
255	Fill

The Raster package in R (Hijmans & van Etten, 2012; R Core Team, 2012) was used to find the mean snow cover percentage per cell for each season (via the raster stacking and calc functions), to resample to fit the pixel template and to cut the data to the different study area polygons. The final output was saved in a .asc file format for MaxEnt.

2.2.5 Temperature data

The temperature data was downloaded via the ftp site (ftp://e4ftl01.cr.usgs.gov/ MOLT/ MOD11C3.005/). The MRT tool was used to reproject data, change the pixel size and save as a geotiff file.

Quality masks were again made, although by a slightly longer process. Land surface temperature (LST) quality data are interpreted in bit-format, so all the (decimal) values contained in the downloaded quality layer were identified using ArcGIS and rewritten in binary form. Table 2.5 shows the quality information contained in the quality control layer.

Table 2.5 Quality information contained in the MOD11C3 Quality Control layer, from LP DAAC (n.d.a).

Bit No.	Name	Explanation
00-01	Mandatory QA flag	00 = LST produced, good quality, not necessary to examine detailed QA 01 = LST produced, unreliable or unquantifiable quality, recommend examination of more detailed QA 10 = LST not produced due to cloud effects 11 = LST not produced primarily due to reasons other than clouds
02-03	Data quality flag	00 = Good quality data 01 = Other quality data 10 = LST affected by clouds &/or sub-grid clouds, &/or oceans 11 = LST not screened
04-05	Emissivity error flag	00 = Average emissivity error <= 0.01 01 = Average emissivity error <= 0.02 10 = Average emissivity error <= 0.04 11 = Average emissivity error > 0.04
06-07	LST error flag	00 = Average LST error <= 1 K 01 = Average LST error <= 2 K 10 = Average LST error <= 3 K 11 = Average LST error > 3 K

Rules for accepting or rejecting a pixel based on its quality layer values were as follows:

Step 1: Mandatory QA flag

- If mandatory QA flag = 00, accept
- If mandatory QA flag = 01, check data quality flag
- If mandatory QA flag = 10 or 11, reject

Step 2: Data quality flag (if necessary following step 1)

- If data quality flag = 00, accept
- If data quality flag = 01, check LST error flag
- If data quality flag = 10 or 11, reject

Step 3: LST error flag (if necessary following step 2)

- If LST error flag = 00, accept
- If LST error flag = other, reject

The rules were designed to be conservative, whilst also avoiding removing too much of the data. To create the masks, accepted values were reset to a value of 1 and rejected values were reset as NA. These masks were then applied via multiplication with the temperature data in the same way as for the snow data.

The Raster package in R was then used to find the mean values for each time period, to resample to fit the pixel template and to cut the data to the study area polygons. The completed files were saved in a .asc format for MaxEnt.

2.2.6 NDVI data

The NDVI data was downloaded and reprojected via the MODIS package in R (Mattiuzzi et al, 2012). No data were available for November 2006 or January 2010. The MODIS package does not process the pixel reliability layer, so the MRT tool was used to reproject this data and save it as a geotiff. The Create Mosaic Dataset tool in ArcGIS 10.0 (ESRI, 2011) was then used to mosaic the two tiles making up the full pixel reliability dataset area (mosaic method = closest to centre, operator = max so that the -1 fill values are replaced by the correct reliability values from the adjacent tile).

Table 2.6 Quality information contained within the MOD13A3 pixel reliability layer with explanation, from LP DAAC (n.d.b)

Pixel value	Summary QA	Explanation
-1	Fill/No data	Not processed
0	Good data	Use with confidence
1	Marginal data	Useful but look at other QA information
2	Snow/ice	Target covered by snow/ice
3	Cloudy	Target not visible, covered in cloud

Quality masks were created from the pixel reliability data in the same manner as for the snow and temperature quality data. Table 2.6 shows the interpretation of pixel reliability values. It was decided that both ‘good’ and ‘marginal’ data should be accepted, as test runs with only good data indicated that large quantities of data had been removed from the model.

The Raster package was again used for averaging, resampling and cutting.

Interpreting NDVI data must be done with caution. Different plants have different reflectance values, however in general higher positive values indicate more extensive, healthy vegetation, whereas values closer to zero or negative values indicate poor or no vegetation (Justice et al, 1985).

2.2.7 Distances data

Distances to points and lines were calculated using the Euclidean Distance tool in the Spatial Analyst toolbox of ArcGIS 9.3 (ESRI, 2009). This data was then imported in R for resampling and cutting using the Raster package.

2.3 MaxEnt

MaxEnt version 3.3.3 was used to run the models (Phillips et al, 2006; http://www.cs.princeton.edu/~schapire/maxent/). Cross-validation of models was performed based on 10 replicates and the maximum number of iterations was set to the default value of 500, as preliminary runs showed that this was more than enough to allow model convergence. The regularisation parameters were left at their default values despite the fact that, as discussed in section 1.3.2, it is known that models are sensitive to these parameters. This decision was made because it was felt that the bias in the data inputted into the model was such that it was likely to have a much bigger impact on model reliability and so parameter tweaking would be a worthwhile activity only once better quality data can be inputted to the models.

2.4 Preliminary tests: Model exploration

A sensitivity analysis was run to investigate whether the particular combination of variables and assumptions used was skewing the model outcomes and to look for combinations that improve model training area under curve measurements (AUC), a proxy that was used to represent model reliability. Elith et al (2006) argue that a minimum model AUC of 0.75 is needed to ensure that sufficient trust can be placed in the models and so this was chosen as the target value, however it was recognised that biased sightings data might make this difficult to achieve. In addition to AUC, visual inspection of model output was also used in the sensitivity analysis as the distribution maps produced by MaxEnt also indicated errors and what might be influencing output and correlation tests were run to look for co-varying factors. Six model exploration tests were run (Table 2.7) and the results can be viewed in the Appendix A.

Table 2.7 Table indicating the six model exploration tests that were run and why

Test	Why run
Removing roads	Test runs of the model showed that probability of saiga presence was much higher around roads and this was predicted to be caused by biased saiga data collection
Removing railways	Maps of the study area show that three of the four settlements are located on the railway line, indicating the potential for co-variance
Including distance to border	It was noted in preliminary testing that distance to settlement was more important in Periods 1 and 3, when the saiga are on the move, suggesting that it could perhaps be migration driving the importance of the factor rather than the settlements themselves. This would be better explained by the distance to the Uzbek border.
Changing time periods (snow and non-snow)	It was thought that splitting the data into two snow (December to March) and non-snow (April to June) periods might be more biologically realistic, as well as boosting the number of saiga sightings by extending Period 2 to include an extra month.
Changing time periods (separating years)	It was also thought that the models might be less reliable because the environmental data was averaged across a period of seven years, during which time it may have undergone some shifts. A test using sightings from two months modelled with environmental data from those two months was compared with a test using the same sightings modelled with environmental data averaged across all years for the two months.
Using only transect data	As discussed in section 2.1.1, some saiga data were collected via a more reliable method than others. Tests were run to establish whether the models could be improved by only

	using data collected via distance sampling transects, thereby hopefully reducing bias due to roads. One model was run using only April and May 2012 (i.e. transect data) and another using non-transect data for period 3.

2.5 <u>Final models</u>

The final MaxEnt models contained snow cover, temperature, NDVI and distance to settlement as factors. Factor importance was assessed using the jacknifes and permutation importance tables produced by MaxEnt. The models were run for the three study site sizes and for study periods 1, 2 and 3. To complete the third research objective, informing on protected area planning, the full site MaxEnt outputs for the models described above were imported into ArcGIS and the values for the three study periods added together. The pixels were then coloured according to how high the total value was and therefore how suitable and important each 1km pixel area is for saiga in the October to June period.

Models containing only snow, temperature and NDVI data as factors were projected into Kazakhstan, as distance to settlement information was not known for the Kazak region. The original models to be projected using the MaxEnt projection function were run on the full study site; this was because by covering a larger area there was less chance of the model encountering environmental values in Kazakhstan that had not been found in Uzbekistan and therefore a decreased risk of error due to extrapolation.

3. Results

3.1 Knowledge of saiga in Uzbekistan

3.1.1 Basic description of data

As reported in the methodology, there were 186 saiga sightings in the full study area between 2006 and 2012, although it should be noted that there are more sightings from this year still pending collection in Uzbekistan. In the medium site, there were 99 sightings and in the small site, 36. The sightings are relatively well distributed throughout the whole study area (Fig.3.1), with a greater density around the small study site region.

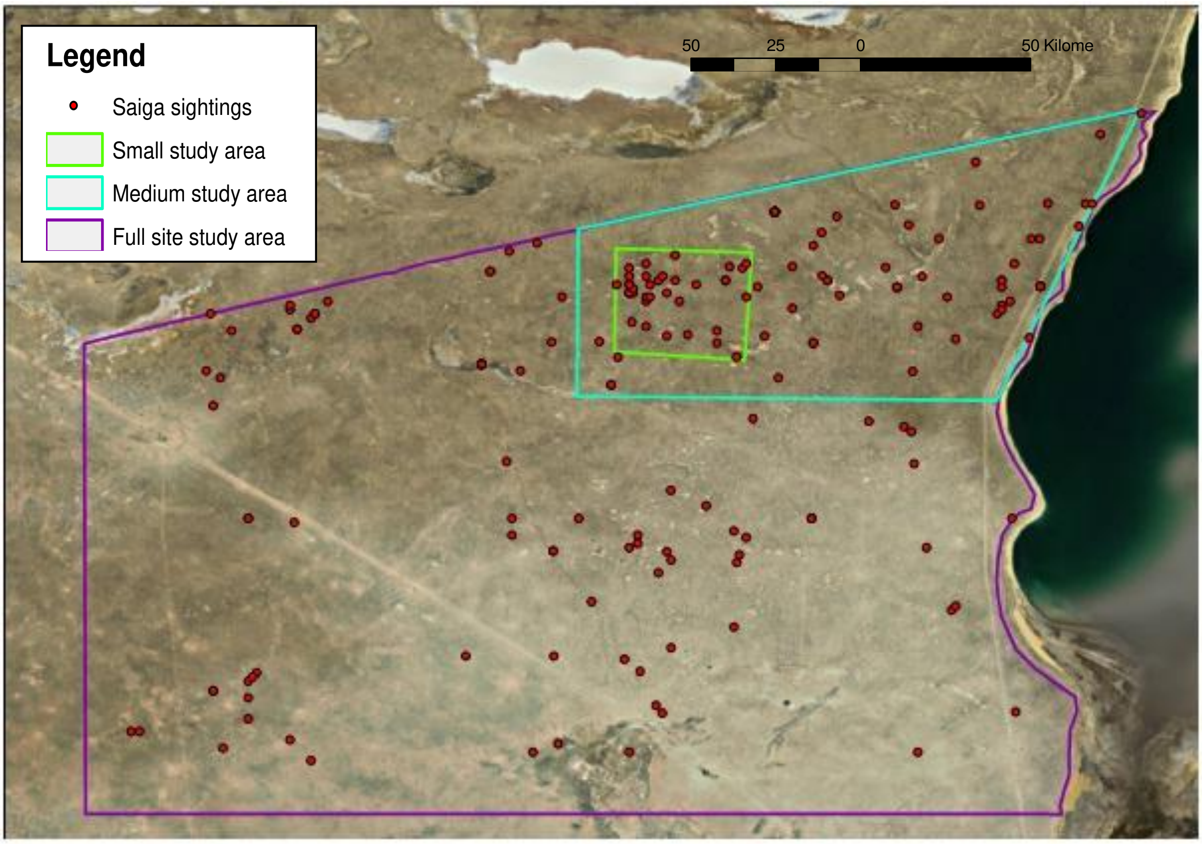


Figure 3.1 Map to show the locations of saiga sightings from 2006 to 2012 on the Uzbekistan Ustyurt with the three study sites – small, medium and full.

Tables 3.1 and 3.2 show a breakdown of the sightings data used in the models by month and by year. It is interesting that the number of sightings increases from March into summer when the snow is either melting or has melted; this is likely to be due to the fact that conditions become much easier for monitoring. Also of note is the lack of sightings for 2011, but there may in fact be more data from the participatory monitoring programme for this period that has yet to be processed (Elena Bykova, pers.comm.).

Table 3.1 Number of saiga sightings recorded in each month, as used in the models.

Month	Number of sightings	Years recordings taken
October	10	2006, 2007, 2009, 2010
November	10	2006, 2007, 2009, 2010
December	17	2006, 2007, 2009, 2010
January	18	2007, 2008, 2010
February	15	2007, 2008, 2009, 2010, 2011
March	26	2007, 2008, 2009, 2010, 2011
April	29	2007, 2008, 2009, 2010, 2011, 2012
May	37	2007, 2008, 2009, 2010, 2011, 2012
June	24	2007, 2008, 2009, 2010, 2011, 2012

Table 3.2 Number of saiga sightings recorded in each year, as used in the models.

Year	Number of sightings
2006	11
2007	28
2008	42
2009	29
2010	37
2011	12
2012	27

The outputs of the processed environmental variables are also informative (Fig,3.2). Snow cover is greatest in period 2, with the majority of areas averaging around 60% cover, before melting to none in period 3, whilst period 1 shows intermediate cover. There appears to be some latitudinal gradient in period 2, with lower snow cover in the south east corner of the site. The night time temperatures of periods 1 and 2 are relatively similar, with an increase in period 3. The north east corner consistently shows lower temperatures in all three periods, potentially due to an effect of its proximity to the Aral Sea or perhaps has a result of its overall more continental location.

It seems that period 2 has the most extensive and most uniform vegetation cover, despite the presence of snow, with less in periods 1 and 3. This could be because the extensive snow cover in period 2 results in all the vegetation being either covered or of a similar poor quality. The masks used to remove poor quality pixels also removed data obscured by snow and ice, therefore it is also possible that the average NDVI values for Period 2 are skewed more towards those of March, as these values were not removed from the calculations by the masks. There is a clear latitudinal gradient in NDVI, which could be due to drier conditions further south. The diagonal line seen through the NDVI values is where a railway, wide road and pipeline run through the plateau.

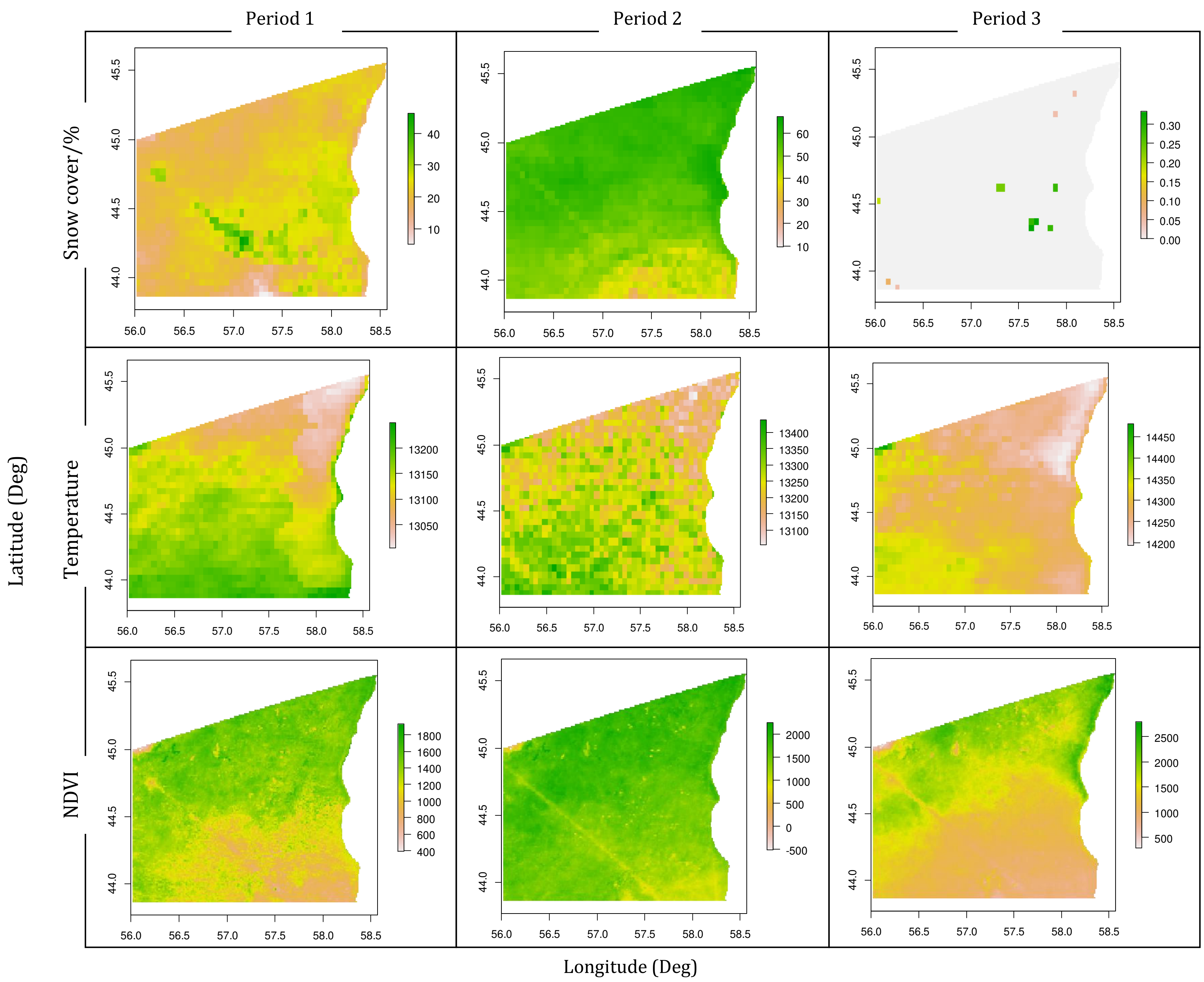


Figure 3.2 Maps to show the distribution of snow cover, temperature and NDVI across the study area in the three study periods. Colours refer to the distribution over the area in a single period, therefore when comparing across periods, careful consideration should be taken of any change in the scaling.

3.1.2 Data quality

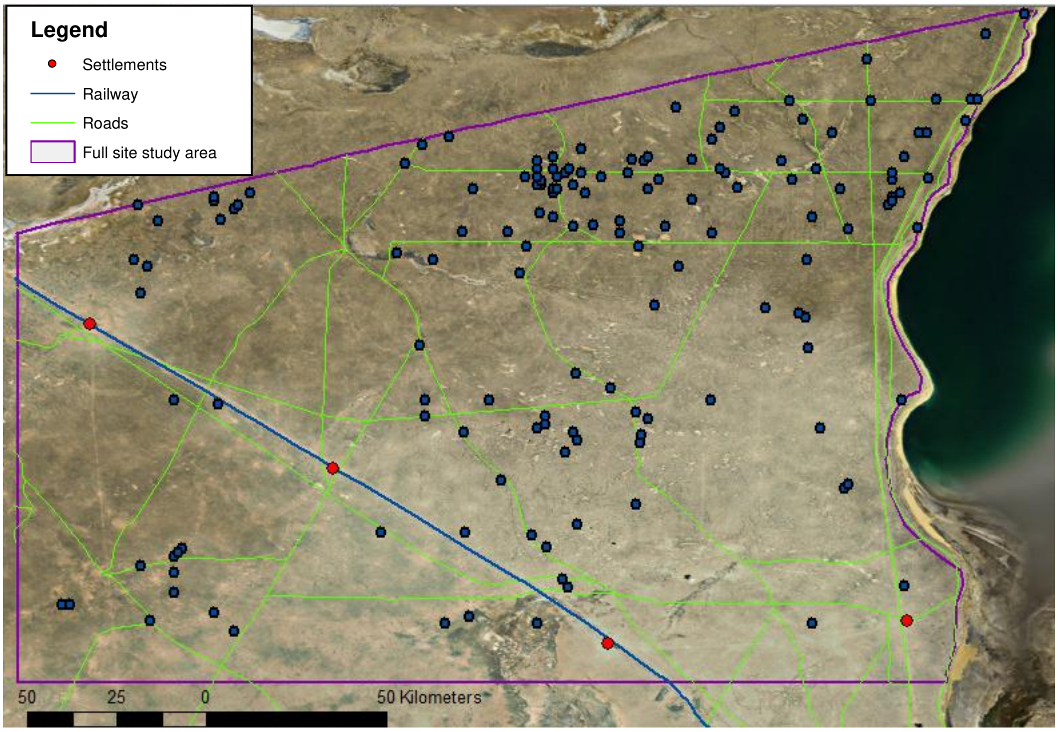


Figure 3.3 Map showing the locations of saiga sightings (dark blue circles) with features of the landscape: roads (green lines), railways (blue line) and settlements (red circles).

Roads and settlements were identified as possible sources of bias in the monitoring data and were firstly investigated through visual analysis (Fig.3.3) and by analysing the data by collection type (Figs.3.3-3.6; Table 3.3). Across all sightings, the distance to the nearest road is significantly less than the average across the whole region (Wilcoxon signed rank test; V=4542, p<0.001;Fig.3.4a), and dividing the data by collection type shows that this holds for all three monitoring methods (Table 3.3). However, there is a significant relationship between data collection type and distance to roads (Kruskal Wallis test; χ^2=15.187, df=2, p<0.001) and boxplots indicate that the sightings made by general monitoring were on average closest to roads, next closest were transect sightings and furthest away of the three types were participatory monitoring sightings (Fig.3.5a). This is contrary to what was expected, as the transect monitoring programme should have, in theory, removed bias towards roads. Plotting the transect data sightings (Fig.3.6.) suggests that transect lines overlap with some roads and also perhaps that the scientists are not strictly adhering to the transect lines while monitoring.

Distance to roads showed marginally significant variation with study period (Kruskal-Wallace test; χ^2= 5.1071, df = 2, p-value = 0.0778, Fig.3.7a.); this of relevance to the discussion of bias because roads in the Ustyurt plateau are particularly treacherous in the snow and are sometimes best avoided altogether (Joe Bull, pers.comm.). The fact that in Period 2 sightings tend to be further away from roads indicates that monitors may be avoiding them and therefore reducing bias slightly.

Distance between saiga sightings and the nearest settlement is significantly greater than the average distance across the whole study area (signed rank test; V=17319, p<0.001; Fig.3.4b), as would have been predicted given existing knowledge of saiga distribution. The fact that this holds across all collection types (Table 3.3) indicates that general and participatory monitoring data do not result in a severe bias towards settlements, as might have been expected. However, there is again a significant relationship between data collection type and distance to settlement (Kruskal Wallis test; χ^2=14.788, df=2, p<0.001). As expected, given that the monitoring was done in the summer months, the transect data collection shows the least evidence of clustering around settlements, with general monitoring data being collected closer to settlements (Fig.3.5b). Dividing the data by study period showed a significant relationship between distance to settlement and study period (Kruskal-Wallace test; χ^2 = 20.0658, df = 2, p-value < 0.001; Fig.3.7b), however it is unclear whether this is due to the movement of the saiga or bias in monitoring towards settlements in the harsh conditions of period 2. Overall, without data on monitoring effort, it is difficult to draw reliable conclusions about bias in monitoring towards settlements – it is possible, for instance, that the general monitoring effort was distributed evenly and that participatory monitoring was biased towards areas further away, although this seems unlikely.

Year of study was identified as an additional potential source of bias as it shows a significant relationship with study period (Kruskal-Wallace test; χ^2 = 30.9594, df =

2, p-value <0.001; Fig.3.7c). Uneven monitoring effort in different periods throughout the years of study could result in bias if the saigas are varying their distribution between years.

Table 3.3 Outputs from single- sample Wilcoxon signed rank tests investigating whether the average distance from saiga sightings collected by three different monitoring methods (general, participatory and transect) to the nearest roads and settlements were significantly different from the average across the region. The null hypothesis was that the sightings were not located at a distance significantly different from the study region average. The alternative hypothesis for the distance to the nearest road was that the saiga sightings were located at a distance significantly less than the study region average (0.0594Deg). The alternative hypothesis for the distance to the nearest settlement was that the saiga sightings were located at a distance significantly greater than the study region average (0.0547Deg). Chance sightings were included in the general monitoring category.

		Data collection type		
	Alternative hypothesis	**General**	**Participatory**	**Transect**
Distance to nearest road	Distance is *less* than region average	V=1, p<0.001	V=3205, p<0.001	V=78, p=0.0189
Distance to nearest settlement	Distance is *greater* than region average	V=120, p<0.001	V=10878, p<0.001	V=300, p<0.001

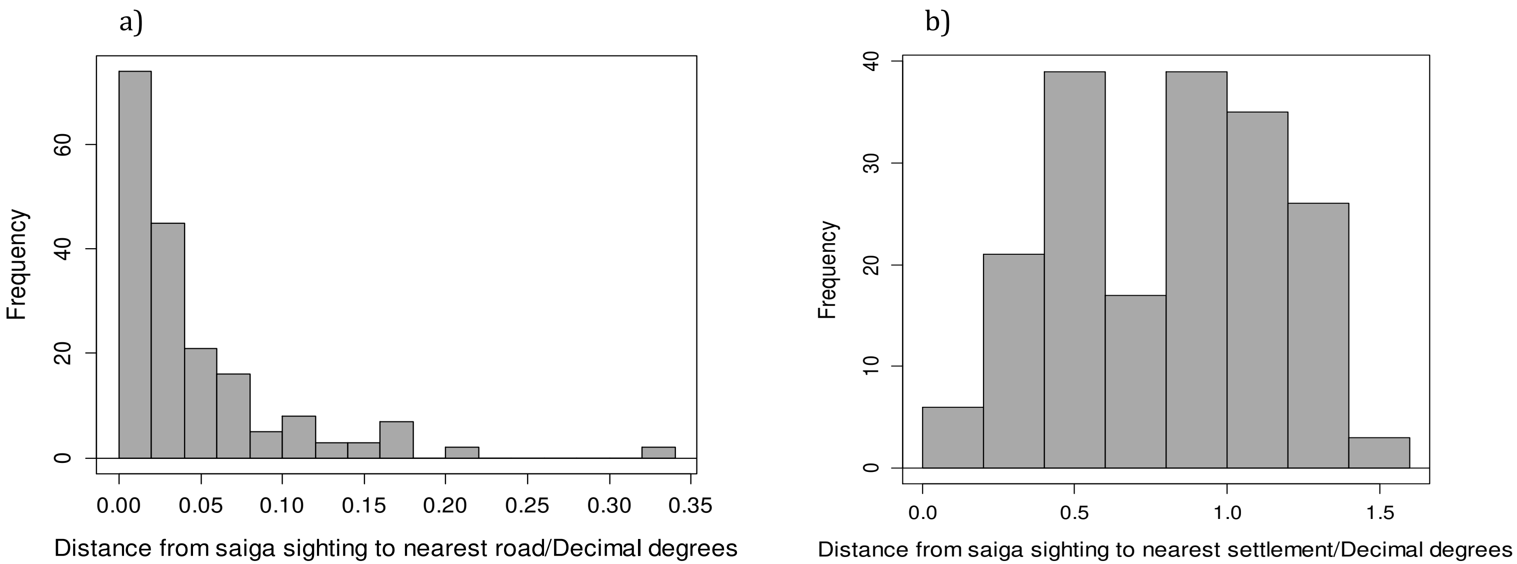


Figure 3.4 Frequency histograms showing the distance from saiga sightings to a) the nearest road (region average = 0.0594Deg, and b) the nearest settlement (region average = 0.0547Deg).

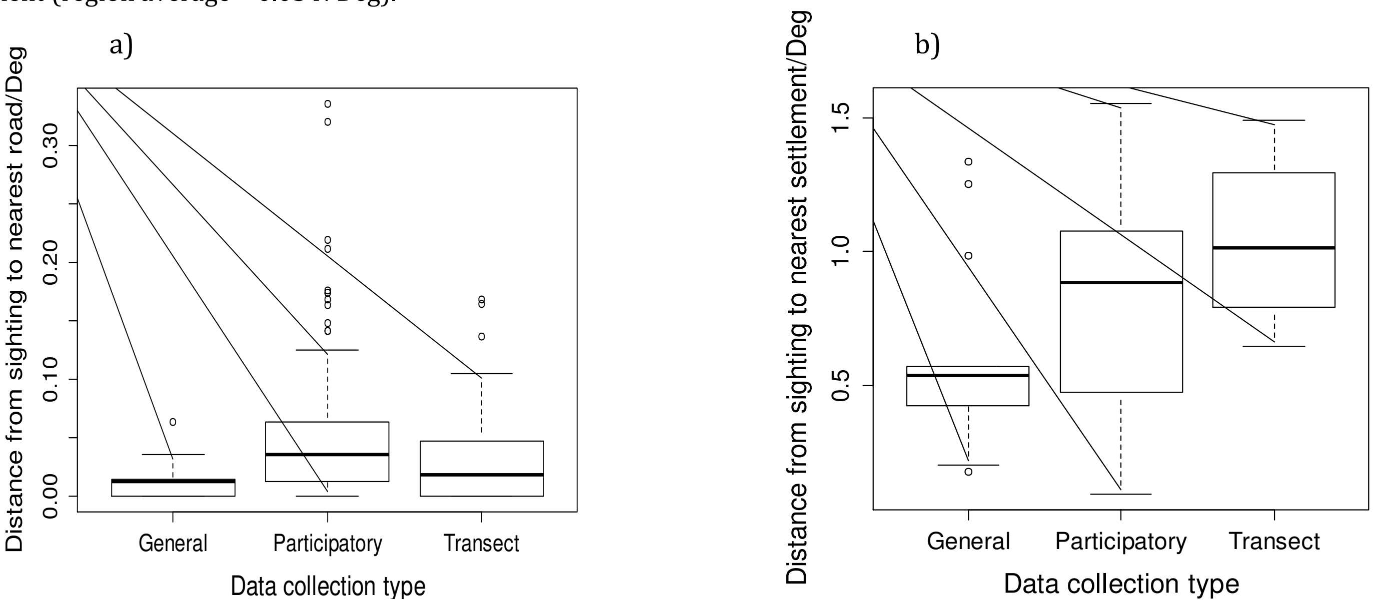
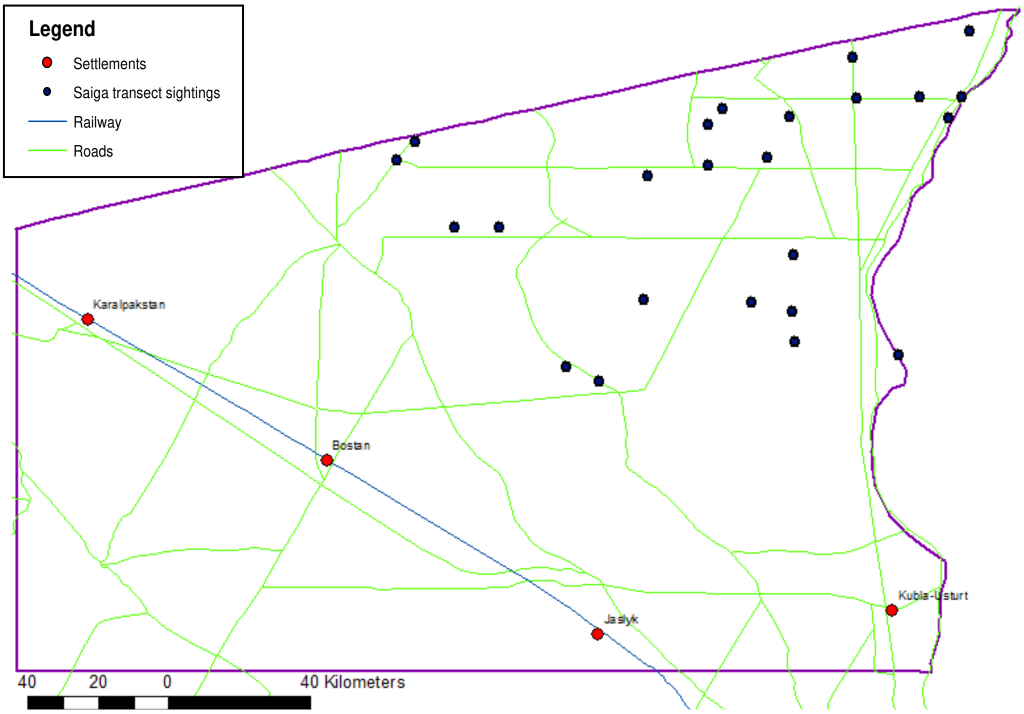


Figure 3.5 Boxplots to show data collection type with a) distance from saiga sighting to nearest road ($p<0.001$) and b) distance from saiga sighting to nearest settlement ($p<0.001$). The chance sightings were included in the general monitoring category.

a)



b)

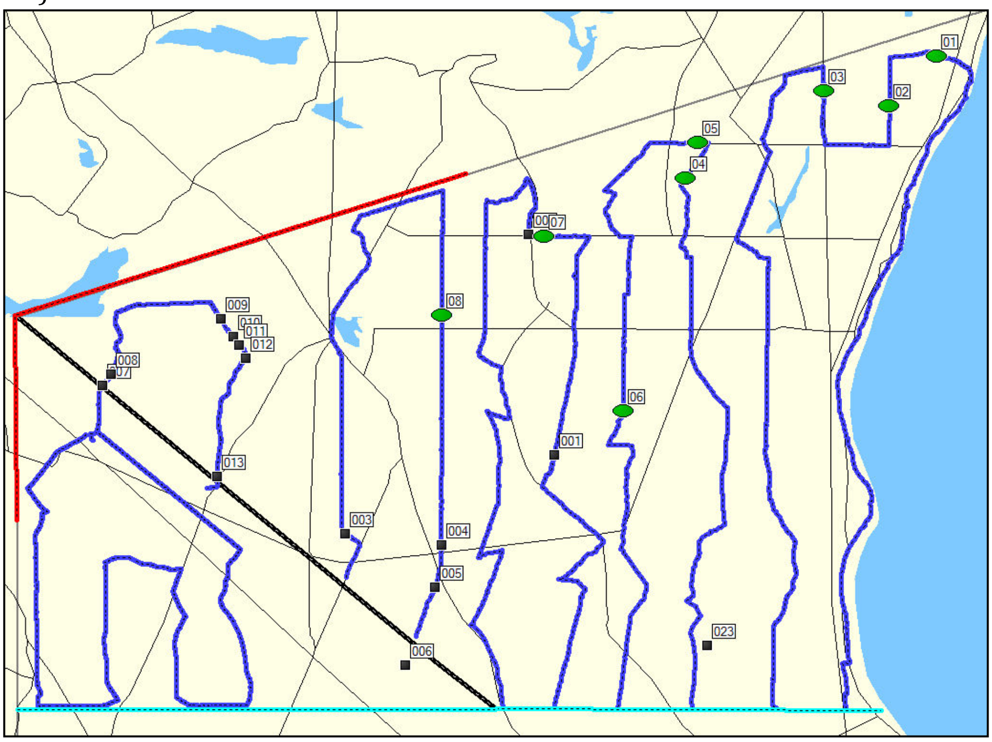


Figure 3.6 Map A shows the locations of saiga sightings (dark blue circles) collected by transect monitoring and the locations of roads (green lines); Map B shows the locations of the transects (dark blue lines) and roads (grey lines), from Elena Bykova (unpublished).

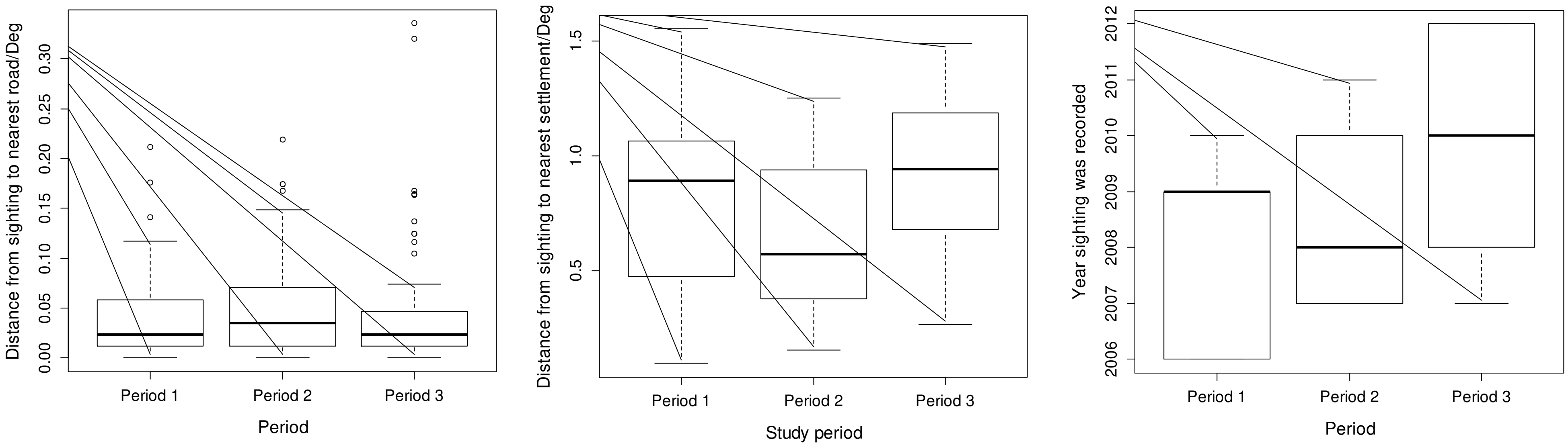


Figure 3.7 Boxplots showing distances from saiga sightings a) to the nearest road, b) to the nearest settlement and c) in each year of monitoring, in each of the three study periods. Period 1 is October to December, Period 2 is January to March and Period 3 is April to June.

Additional bias in the models could be the result of co-variance, both with factors included and not included in the model (Table 3.4). The distance of sightings to the nearest settlement shows significant correlation with latitude and with longitude. This indicates that there may be spatial autocorrelation in the data, as expected. Temperature, snow, NDVI and distance to settlement all show a significant degree of correlation with one another and this is likely to be because they all follow similar gradients along latitudinal and longitudinal axes.

Table 3.4 Correlation matrix of p-values from Spearman's rank correlation tests between variables. Values for environmental variables are an average across the study period (i.e. October to June) and correspond to the locations where saigas were sighted. Df =185. N.S. indicates p-values that were not significant.

	Distance to road	Distance to settlement	Latitude	Longitude	NDVI	Snow	Temperature	Year
Distance to road	-	0.0121	0.0276	n.s.	0.0759	n.s.	n.s.	n.s.
Distance to settlement	0.0121	-	<0.001	<0.001	<0.001	<0.001	<0.001	n.s.
Latitude	0.0276	<0.001	-	<0.001	<0.001	<0.001	<0.001	n.s.
Longitude	n.s.	<0.001	<0.001	-	0.0069	<0.001	<0.001	n.s.
NDVI	0.0759	<0.001	<0.001	0.0069	-	<0.001	<0.001	n.s.
Snow	n.s.	<0.001	<0.001	<0.001	<0.001	-	<0.001	n.s.
Temperature	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001	-	n.s.
Year	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-

3.1.3 Migration

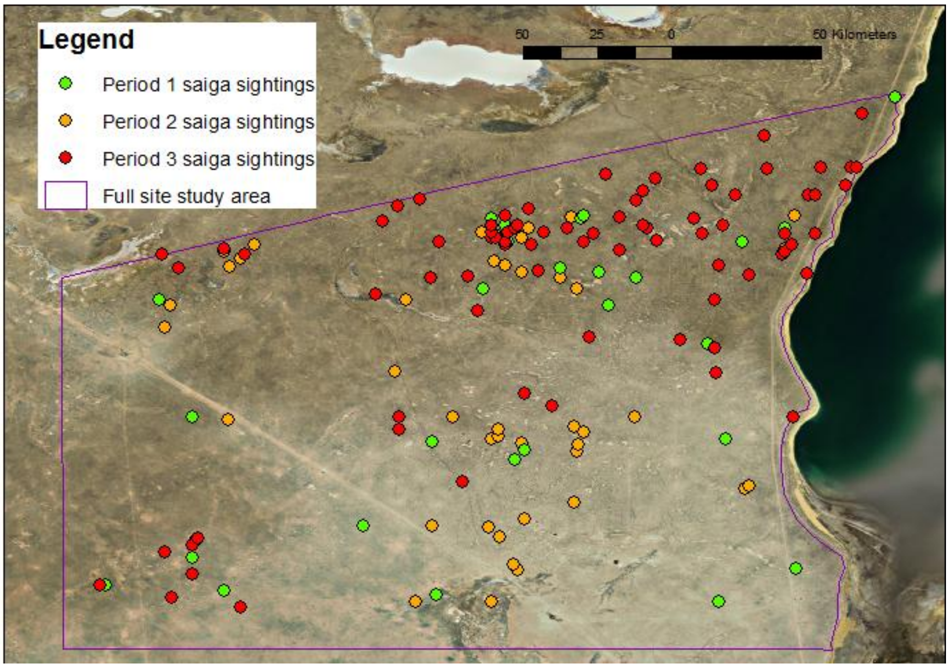


Figure 3.8 Map of the full study site area (outlined in purple), with saiga sightings shown for the three study periods: period 1 (Oct-Dec, green), period 2 (Jan-Mar, orange) and period 3 (Apr-Jun, red).

There is an indication but not clear evidence that the saiga are migrating into and out of Uzbekistan between October and June (Fig.3.8). Period 1 sightings are fewer in number (n=...) and more sparsely distributed.. The period 2 sightings tend to be more southerly and more widespread, indicating that this is the period where saiga are most settled in Uzbekistan, while period 3 sightings show a distinctly northerly distribution, suggesting a possible return-migration. These observations are confirmed by the MaxEnt model outputs (Fig.3.9) and by a Kruskal-Wallis test showing that distance to border is significantly correlated with study period (χ^2 = 17.11, df = 2, p-value < 0.001); Fig.3.10). However, the fact that saiga are found in Uzbekistan through to June (Table 3.1) is contrary to the historical belief that they return to Uzbekistan in March and therefore may be indicative of a permanent population in the north of the study region. The cluster of sightings in Periods 1 and 3 in the south-west corner of the site suggests there may be a permanent, sedentary population here as well, particularly as saiga are relatively unlikely to frequently cross the railway line, with its associated main road and gas pipeline.

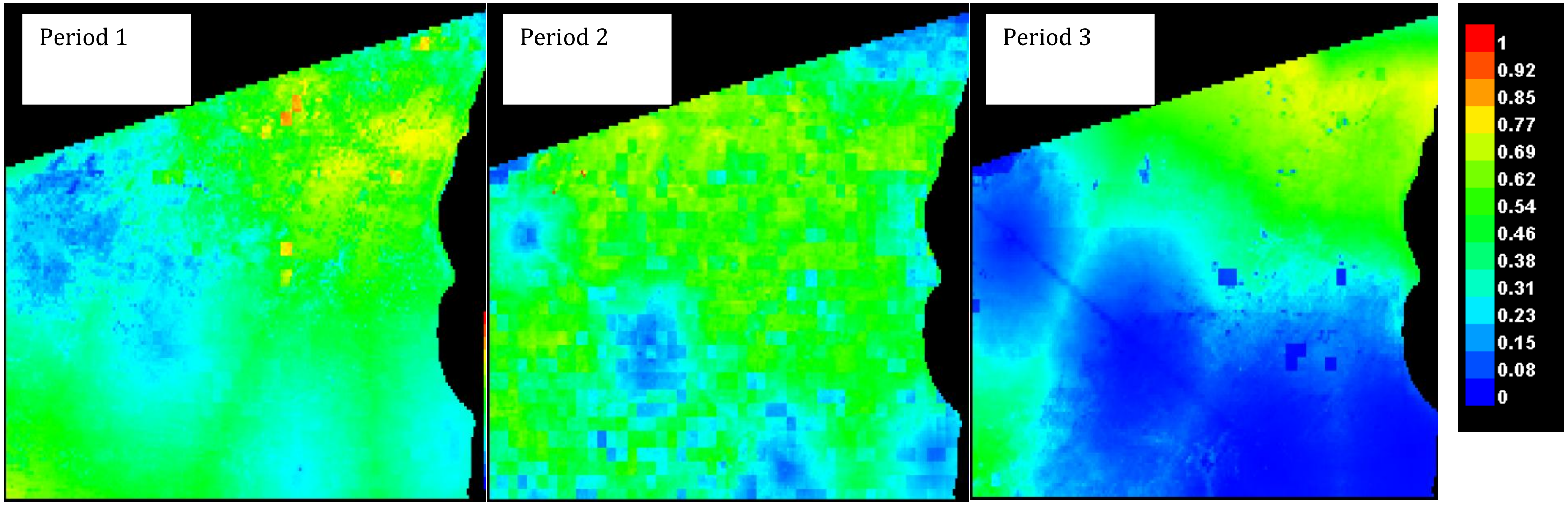


Figure 3.9 MaxEnt model outputs for the full study area for study periods 1 (AUC=0.663), 2 (AUC=0.628) and 3 (AUC=0.797). Factors included in the model were snow cover, temperature, NDVI and distance to nearest settlement, and model outputs are an average of 10 replicates. Pixel values of 1 (red) indicate a high probability of saiga presence and values of 0 indicate a low probability of presence (blue).

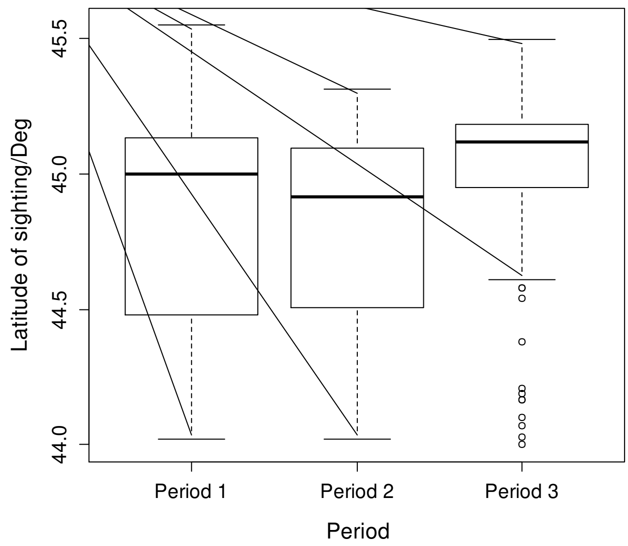


Figure 3.10 Boxplot showing latitude of saiga sightings in each of the three study periods (χ^2 = 17.11, df = 2, p-value < 0.001). Period 1 is October to December, Period 2 is January to March and Period 3 is April to

3.1.4 Factors affecting saiga distribution

The training AUC values for the MaxEnt models with the four factors are not as high as were hoped for (Table 3.5). While only Period 1 in the small site and Period 3 in the full site are of impressively high reliability, the other models are not too unreliable considering the bias in the data supporting them. Only, Period 2 in the small site and period 3 in the medium site should be disregarded completely. A Spearman's rank test shows that there is no relationship between model and the number of saiga sightings informing the model (r_s=0.167, df=8, p=0.678; Fig.3.11), suggesting that a lack of data are a key factor affecting model reliability.

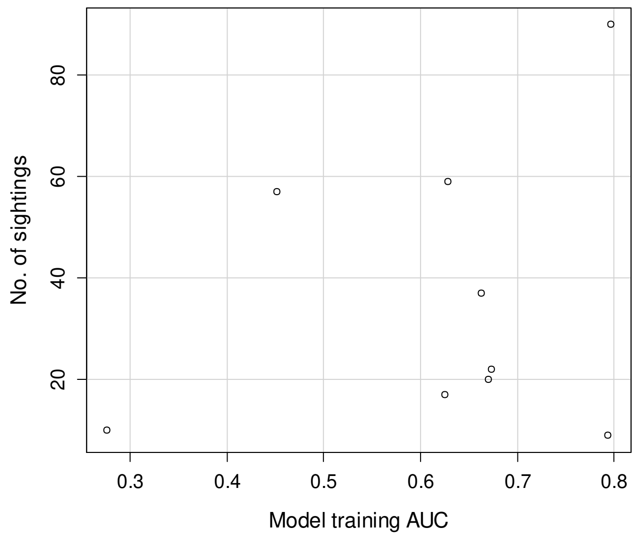


Figure 3.11 Scatterplot showing relationship between the training AUC of the nine models run - three study site areas for each of the three study periods (r_s=0.167, df=8, p=0.678).

Table 3.5 shows the permutation importance of the four factors in the model, jacknifes of training gain can be found in the Appendix C. Overall, NDVI and distance to settlement have the most influence on the models, however each model has a slightly different pattern of variable importance. For the full site, distance to settlement is the most important factor in period 1. This may be a consequence of the saiga migration pattern – the majority of saigas have yet to travel as far south as the settlements, suggesting that it is not the settlements themselves causing the saiga to avoid them.

In period 2, all four factors contribute to the full site model. This is perhaps because the saiga are at their most widespread throughout the region and because the environmental conditions are harshest. It is unsurprising that snow is very important as this is the study period with the heaviest snow and the saiga are migrating to avoid it. However, the jacknife (......) shows that the snow factor contains the least information that isn't already contained in other factors. If, as theory suggests, the saiga are migrating to avoid snow in order to access vegetation, this would explain why NDVI is also very important in the model and NDVI, along with temperature, would be likely to explain the lack of unique information contained in the snow factor. This argument is supported by the fact that NDVI is strongly correlated with both snow and temperature (Table 3.4).

In period 3 in the full site, distance to settlement is very important, which could be an effect of the return migration north of the saiga, particularly as latitude is strongly correlated with study period and the average latitude increases in Period 3 (Fig.3.10). Period 2 has sightings near and between settlements , indicating that the saiga are not too afraid to approach settlements at all, be it still at a considerable distance, lending confidence to the migration explanation. However, the influence of bias should also be considered; monitoring in Period 2 is potentially more localised around settlements due to harsh monitoring conditions (Fig.3.7b). The opportunity to monitor further afield in Periods 1 and 3 could mean a decreased focus on areas near settlements, leading to bias in the opposite direction. NDVI also has some importance in Period 3, and although not seen in the permutation importance, the jacknife of training gain shows that temperature explains a lot of the distribution if it is the only variable included, but that it contains little information that is not already contained in other variables. This could be explained in two ways, firstly the pattern of temperature does correlate with distance to settlement (Table 3.4), and secondly the dieback in NDVI driving the saiga north could be caused by rising temperatures. Both of these explanations seem plausible and the true cause could be a combination of the two.

MaxEnt model outputs for the medium and small sites can be found in Appendix B. The medium site is not too dissimilar from the full site in the importance of factors in the model. The key difference is the importance of distance to settlement rather than NDVI in Period 2. In this case, it seems that the sightings within the study area are clustered closer to the settlements and could again suggest bias in sampling. An alternative explanation is that the location where the saiga are crossing the border into Uzbekistan is towards the western side of the medium study area, and therefore closer to the settlements, with fewer migrating across in the north of the region.

The small site shows a more different pattern of factor importance. NDVI is much more important on a local scale, as anticipated, although this is slightly less so in Period 2 when snow also becomes important. This importance of snow on such a small scale suggests that even small changes in snow fall/cover could act as a trigger for migration. Similarly, it is interesting that temperature can influence distribution on such a small scale in Period 3, although the jacknife again suggests that temperature could be driving NDVI dieback, which then influences the saiga.

Table 3.5 Permutation importance of factors in MaxEnt model of saiga distribution across the three study sites for the three study periods, with their associated model training AUC values. Factors included in the model were snow cover, temperature, NDVI and distance to nearest settlement, and model outputs are an average of 10 replicates. Factors highlighted in blue are those with a permutation importance of great than 50%, factors highlighted in green are those with a permutation importance of greater than 20%.

		Permutation importance (%)				**Model training AUC**
		Distance to settlement	Snow	Temperature	NDVI	
Full site	Period 1	75.3	2.7	5.4	16.6	0.663
	Period 2	16.9	28.7	20	34.3	0.628
	Period 3	78.9	2.2	1.9	17	0.797
Medium site	Period 1	45.2	2.7	5.4	46.7	0.670
	Period 2	67.6	2.3	9	21.1	0.673
	Period 3	57.7	0.5	10	31.8	0.452
Small site	Period 1	0	18	0	82	0.794
	Period 2	10	31.6	0	28.4	0.276
	Period 3	16.6	0	17.7	65.7	0.625

3.2 Protected area planning

While the factors in the model may not be exclusively picking up on the effects that they are expected to, e.g. distance to settlement, they are still modelling where the saiga have been observed in the different study periods. When the cumulative outputs of the MaxEnt models for the three study periods are mapped, there is a clear band across the north-east of the study site that is important for saigas all year round (Fig.3.12a). This broadly corresponds to zones III and IV of the planned Saigachiy reserve (Figure 3.12b), indicating that these may be the optimal zones for enforcing strict protection of saiga.

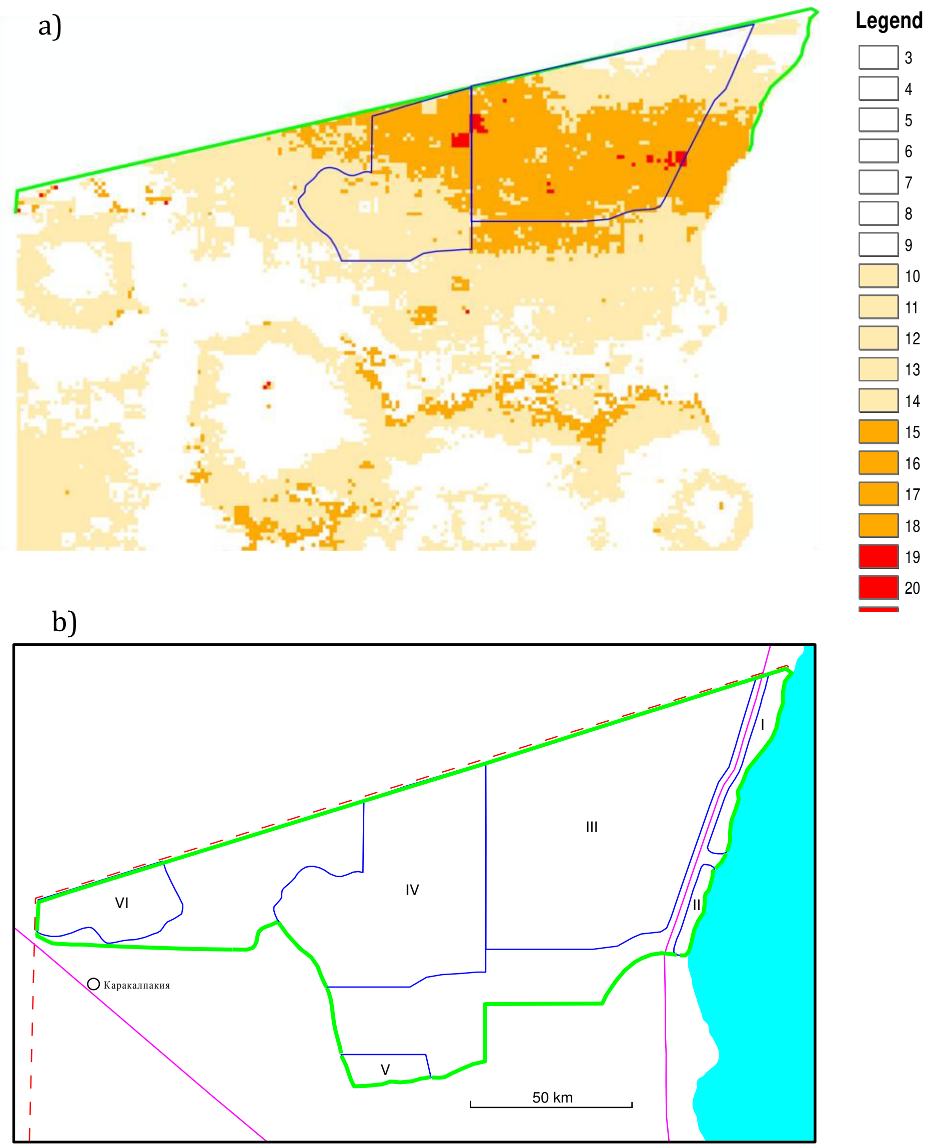


Figure 3.12 Map A shows the cumulative output of the MaxEnt models of the full study area for the three study periods. Higher numbers and darker colours represent areas of greater importance for saiga, blue lines outline the rough locations of the planned relevant zones in the Saigachiy reserve. Map B shows the planned Saigachiy reserve, (Esipov et al, 2009a). Blue lines outline different areas of the reserve: I- Duana, II – Zhideili, III – Almambet, IV – Churuk, V – Beleuly, VI – Zharynkuduk, the green line outlines the buffer zone and the pink line represents the railway.

3.3 Fence impact

Projections north of the border were modelled based on environmental factors (snow, temperature and NDVI) only (Fig.3.13). Using only environmental data are necessary because the lack of information on human variables in Kazakhstan means that having to use distances to only Uzbek settlements would be very unrealistic, however the overall reliability of these models is lower. An AUC of 0.525 for Period 1 is too low to be reliable, and although the values for Period 2 and Period 3 were higher (AUC=0.619 and 0.773 respectively), the Period 3 output still shows an unlikely ring of high probability saiga habitat in the south-east corner. That said, poor model reliability is an unavoidable downside of poor data availability and it is still interesting to interpret the results whilst keeping reliability in mind.

Figures 3.8 and 3.10 gave some evidence that the saiga are migrating south of the border, an activity that will be stopped by the erection of the border fence. The majority of the highest probability saiga potential niche area does appear to shift below the border in the snow period, but that the environment just above the border looks to remain semi-favourable for the saiga as well (Fig.3.13b). This outcome is promising in that is suggests that the saiga still have at least some potential to survive if their southern migration route is cut off, however one might predict that during a harsh winter the population could suffer badly. There is also a high likelihood of saigas trying to cross the border and getting tangled in the fence unless they can see and avoid it.

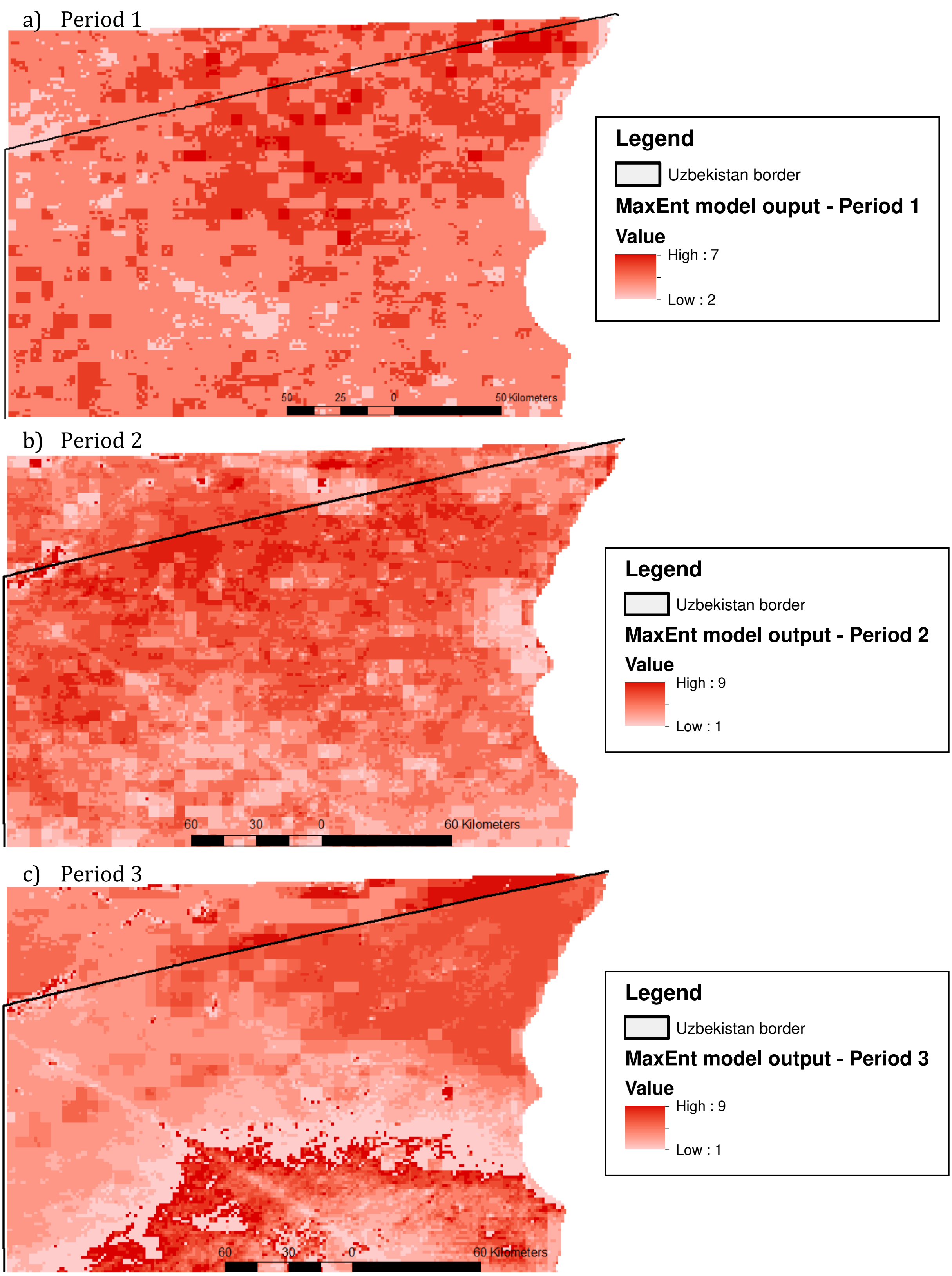


Figure 3.13 MaxEnt model outputs for the full study area for study periods 1 (AUC=0.525), 2 (AUC=0.619) and 3 (AUC=0.773), with projections of the model into a region of Kazakhstan. Factors included in the model were snow cover, temperature and NDVI, and model outputs are an average of 10 replicates. Pixel values of 9 (dark red) indicate a high probability of saiga presence and values of 1 indicate a low probability of presence (light red). The black line shows the country border.

4 Discussion

4.1 Knowledge of saiga in Uzbekistan

4.1.1 Data

4.1.1.1 *Reliability and sources of bias*

There were a total of 186 sightings the full study site across the 7 years of monitoring, plus a few extra outside of Periods 1, 2 and 3, however is this enough for a good model? Phillips et al (2006) in their literature explaining MaxEnt cite the example of *Bradypus variegatus,* for which they have 128 samples, a number they describe as “reasonable”. While the saiga model with the fewest samples at the full site (Period 1) only had 37 samples, Phillips et al’s model covers a region from Mexico to Argentina at a resolution of 0.5 degrees, producing 648,658 pixels. The Ustyurt study area only has 31974 pixels, therefore the ratio of study area (in pixels) to samples is lower even for the Period 1 model than the *Bradypus* “reasonable” model. However, the *Bradypus* model produces a high test AUC, unlike the saiga models. One reason for this difference could be that sloths are, unsurprisingly, not migratory, therefore the model does not have to contend with responses to changing environmental conditions. More importantly, the analyses of data quality suggest that although the number of samples may be reasonable, the quality and coverage of these are not. Quality of data may also be more important when working at higher resolutions as with the saiga models – factors such as sampling bias towards roads would not be an issue at lower resolutions.

There are the key sources of bias in the data:

(i) Conditions

Environmental conditions can be very poor for monitoring in winter, for example in the 2011/2012 transect sampling pilot it was too cold in the winter months so no data was collected until April. The difference in number of sightings between winter and spring makes it difficult to establish the true migration pattern; there is some evidence that the saiga are moving north-east in spring/summer but the Period 1 data are very sparse, making it difficult to decipher where the saiga have travelled from to get there. Ideally, there would be a consistent sampling effort repeated regularly throughout the year in order to attach more certainty to the conclusions made.

(ii) Distance to settlements

There was a significant correlation between distance to settlement and data collection type, with the transect data being collected furthest away of the three types (although it was all collected in Period 3). The bias adds uncertainty; areas close to settlements have fewer sightings overall but are also potentially more heavily sampled. If a similar effort was employed throughout the study area, a much clearer picture of the saiga distribution would emerge. For example, in Periods 1 and 2, it seems that saiga are not migrating into Uzbekistan at the north-east corner as was previously thought, however this could be an artefact of the lack of sampling this far from settlements in poor conditions.

(iii) Distance to roads

Distance to roads is the clearest source of bias and can be seen by eye on a map of sightings. Even the transects follow the roads in some sections. This can lead to unreliable results due to a heavy sampling effort skew towards a small proportion of the total range and possibly a skew towards the environmental conditions surrounding the roads. Such skew could be important for factors such as NDVI, which was found to show a weakly significant correlation with distance to roads.

(iv) Spatial autocorrelation

Spatial autocorrelation was expected in the model because saigas form groups and do not move at very fast speeds, therefore if a saiga is sighted in one cell it is more likely to be sighted in a neighbouring cell, resulting in bias. As discussed in the methodology, including latitude and longitude as factors in the model would account for some of the spatial autocorrelation, however this would also be likely to remove nearly all of the variation in the model since latitude and longitude correlate with the other factors. It is hoped that once a greater quantity of better quality data has been collected, more complex models accounting for spatial autocorrelation may be a possibility in the future.

4.1.1.2 *Monitoring techniques*

Monitoring saiga on the Uzbek Ustyurt is particularly challenging; with difficult environmental and political conditions, a ban on air travel and, until recently, limited funding (Offord, 2011), it is not surprising that we see bias in the data. Of the three techniques that have been used, the “general” monitoring yielded the poorest quality data. However, it is also the cheapest and most straightforward, so it is easy to see why it was used, particularly in the early years of the study period. It provided a quick means of getting an idea of saiga numbers and locations. In terms of improving the models though, this biased data are less useful and general monitoring is no longer the most desirable technique.

The participatory monitoring programme is impressive in its success, not least in its high volumes of sightings (n=147). In terms of distance to settlement, while the interquartile range doesn’t reach as far away as the transect data, it is still very broad and not restricted to short distances from settlements as might have been predicted. The participatory data also shows the least bias towards roads of the three techniques. In their analysis of potential methods for monitoring ungulates in Central Asia, Singh and Milner-Gulland (2011a) list the fact that participatory data may not always be reliable as a possible disadvantage of the method and it is encouraging that this does not seem to be an issue in this case study. That said, an evaluation of the 2009-2010 participatory programme reported that more observer training was needed (Bykova & Esipov, 2011) and one should be wary when comparing potentially unreliable methods only to other potentially unreliable methods, the one that seems most reliable may still be very unreliable.

As highlighted by Danielsen et al (2009; pp.32), another potential success of participatory monitoring is that it "can empower local communities to better manage their resources". Such empowerment could make a real difference in Uzbekistan, where illegal hunting continues. A close relationship with the local population has been reported to have developed through the participatory programme (Bykova & Esipov, 2011). This, alongside other community involvement work carried out by the SCA, e.g. school "Saiga Days" (Bykova, Arylov & Klimanova, 2011) and saiga film screenings (Bykova, 2012), will hopefully aid progress and support for more successful conservation of the saiga and may particularly important for the implementation and success of the extended Saigachy reserve.

While the third technique, transect sampling, did yield important sightings data (24 sightings in two months), it also has space for improvement. There are two key issues with the method: the association with roads and the lack of data for the winter periods. The original methodology for the pilot programme, designed by E.J. Milner-Gulland and Elena Bykova, stated that each transect should be 50km long in the north-south orientation and be kept as straight as possible. However, maps of the data received do not show this pattern; roads have been followed leading to diagonal swerves and, in some areas, perpendicular juts in the transect routes. Obviously, the data collected in this way is still very useful, however following the roads does somewhat defeat the point of a scientific transect survey and results in bias issues as discussed above. In general, driving off-road in Uzbekistan can often not be too dissimilar from driving on-road (Joe Bull, pers.comm.), therefore it should hopefully be feasible to put a stronger emphasis on keeping to straight lines in future monitor training.

The second issue, the lack of monitoring in winter, is more concerning. Some transects were run, though only absences were recorded, in October, then none until April. The average temperature on the Ustyurt is reported at around -8°C in January (Azimov et al, 2006) and can reach much lower. These conditions can be very dangerous where roads are poor and vehicles are liable to breaking down. Weather-appropriate equipment and motivation are a necessity to achieve monitoring success (Olson, 2011). This evidence suggests that while motorbike surveys may be the most cost-effective means of implementing the transect programme (Offord, 2011), given the cold conditions, they are perhaps not a realistic enough form of transport, certainly not enough to persuade monitors to head out into the field. Additionally, further discussions may be needed about ensuring monitor safety in the field – two drivers (unrelated to the monitoring programme) died on the plateau as a result of freezing conditions this winter (Elena Bykova, pers.comm.).

Improving conditions may help improve motivation for the monitors, however there were also issues with the groups chosen to do the monitoring. One group were found to have poor professional skill, motivation and discipline, whereas others such as two groups made up of workers from a local gas station seemed much more reliable (Elena Bykova, pers.comm.). Gaining such insight is the main purpose of a pilot study and will be very useful when planning next year's monitoring programme.

4.1.1.3 *Recommendations*

To summarise the conclusions from the evaluation of different monitoring data, the general monitoring yielded poor quality data and should be abandoned in favour of more scientific approaches, the participatory programme has been very successful and looks promising for the future, and the transect pilot has highlighted some areas for methodological improvements. Overall, four key recommendations for future monitoring stand out:

1. *Improved scale and regularity*

   Filling in gaps in coverage, e.g. the potential north-east corner gap, and repeating monitoring efforts in a regular fashion will, with time, improve the reliability of the data and increase the confidence we can place in the conclusions drawn.

2. *Learning from the transect pilot*

Transects are an incredibly positive and promising step forward, however to success the problems of lack of monitoring in winter and bias towards roads must be overcome.

3. *Records of where has been monitored*

If GIS coordinates are taken all the way along the routes taken while monitoring and included in a database, these can be used to create a map of sampling bias which MaxEnt can take into account when modelling species distribution, this improving model reliability.

4. *Push for more collaring data*

While some collaring efforts have been made, the more data that can be made available and analysed, the better. Though less informative for distributional analyses, this will be of particular importance in investigating how saiga react to the fence.

4.1.2 Migration

Results show clear evidence of shifts in saiga distribution throughout the season, particularly towards the north-east in Period 3, but a lot of uncertainty remains about the migration. Questions must be answered about the Period 1 distribution, the potential sedentary population south of the railway and whether the population are actually leaving Uzbekistan.

The Period 1 population is the most evenly distributed throughout the study area, giving little indication as to the migratory behaviour of the saiga in these months. One might have expected that the saiga were only just entering Uzbekistan at this time, therefore would be clustered near the border, yet in fact some of the most southerly sightings were recorded in this period. More data would help to unravel this issue.

The cluster of sightings in the south-west corner in Periods 1 and 3 suggests that there may be a permanent population there. Although a few sightings very close to the railway give evidence that the saiga apparently can and do cross it, evidence from ungulates elsewhere, e.g. Mongolia (Ito et al, 2008) show that such crossings can be a barrier to migration. The cluster is also located notably further south than the railway. Studying the environmental variable maps suggests that a permanent population may well survive there, as the harsher environmental conditions, e.g. temperature and NDVI in Period 1, tend to centre on the south-east corner, descending along a latitudinal gradient further west. Additionally, the south-west corner is identified as favourable saiga habitat by the Period 2 model despite the fact that no sightings have actually been made in these months. This accumulation of evidence is enough to identify this area as of interest for further investigation. Focussing monitoring efforts south as well as north of settlements could help confirm these provisional conclusions and may also provide evidence for the justification of conservation efforts here.

The third area of migration uncertainty based on the data are whether and when the saiga are actually leaving Uzbekistan. The saiga are staying into June in the north-east corner and while there are few sightings in what would be Period 4, there is also a lower sampling effort and little collaboration between Uzbekistan and Kazakhstan on saiga to confirm movements. Additionally, uneven sampling efforts between winter and summer mean that it is impossible to grasp the relative numbers of saiga sightings in different regions in the different study periods. More collaring data or collaboration with scientists in Kazakhstan is needed to confirm that the saigas are actually leaving. Two collared individuals crossed the border into Uzbekistan this year (Zuther, 2012), but this is obviously a limited sample size and does not rule out the possibility of there being a permanent population. There was historically a large permanent population in Uzbekistan (Esipov et al, 2009b), but in more recent years saiga have moved in and out of the country (Bekenov et al, 1998), and there is extensive evidence that species migrations can alter or stop.

Bekenov et al (1998) map how saiga migrations altered with the harshness of the winter, Leon (2009) reports that the migration of the pre-Caspian saiga population appears to have ceased and Harris et al (2009) discuss examples of migrations ceasing at small population sizes. A permanent population would have important implications for saiga conservation; Uzbekistan would be required to recognise the saiga as a national animal and year-round protection would be needed.

4.1.3 Factors affecting saiga distribution

At the full site scale, in Period 1 distance to settlement had the greatest model training gain, in Period 2 all four factors had an effect though snow and NDVI had the greatest influence, and in Period 3 distance to settlement and NDVI were the most important predictors of saiga distribution. Unfortunately, the distance to settlement factor appears to be picking up the effect of the saiga moving north and south, rather than the effect of the settlements themselves. Periods 1 and 2 roughly correspond to the winter season used in other studies of drivers of saiga distribution, while Period 3 corresponds to the non-snow Spring season, allowing comparisons to be made.

The results of this study correspond fairly well to those of Chilton (2011), who used MaxEnt models to show that cumulative precipitation (effectively snow) was the most important driver of saiga winter distribution in West Kazakhstan, and that NDVI was the most important in summer. However, MaxEnt models run by Elliott (2011) based on data on saiga in the pre-Caspian population found that distance to the protected area and distance to water were the most important drivers in both seasons. Comparisons such as these can be problematic as the study areas covered can be very different, e.g. the Uzbek Ustyurt is much more arid and lacks an enforced protected area, and also the study periods differ, Elliott and Chilton's models were based on data from one year and are therefore susceptible to the influences of any climatic anomalies in that year (Elliott, 2011).

A more interesting comparison to be made is that with Singh et al's (2010a) study of saiga migration in four populations across Kazakhstan. Whilst logistic regression models were used rather than MaxEnt, 40 years of saiga sightings were utilised, rather than just one. The study found that saiga migration was driven by vegetation productivity, which was itself determined by precipitation. Additionally, the Kazak Ustyurt population was found to have a weaker association with precipitation, thought to be because the landscape is more desert and semi-desert. The distance to settlement factor and its associated problems aside, the results of the Uzbekistan study corroborate these conclusions to a reasonable extent. As discussed in the results section, a combined interpretation of factor permutation importance and jacknives, suggests that in Period 2 saiga are likely to be migrating to avoid snow (a proxy for precipitation) in order to access vegetation. In Period 3, NDVI is an important determinant of distribution but looks more likely to be driven by temperature, which would explain the weaker association with precipitation in the Ustyurt found by Singh et al. The fact that the overall general pattern suggested by both studies suggest is similar allows more confidence to be placed in the Uzbek model outputs, despite poor data quality and model AUC. However, as will be discussed below, much more work needs to be done before we can be truly confident.

The fact that NDVI increases in importance at the small site scale is an interesting and also potentially useful finding. Conservation decision-making often takes place at larger scales, e.g. the determination of the Saigachy reserve location, however local scale knowledge can help fine tune such decisions to ensure success. For instance, if there is a band of particularly high quality, saiga-favoured vegetation just outside the border of the reserve, this may increase the likelihood of saiga straying outside the reserve and provide a good target area for poachers. Whereas simply setting the boundary slightly further out could mitigate the problem for that area. Protected area planning will be discussed in more detail in section 4.2.

4.1.3.1 *Reliability and future work*

As discussed, the reliability of the models is poor, most do not reach the threshold AUC of 0.75 set by Elith et al (2006) and therefore limited confidence can be placed in the conclusions. While recommendations have been made to improve the saiga data, there are also areas of improvement concerning the factors in the models:

(i) Distance to settlement

The problem of the distance to settlement factor picking up the effect of overall saiga migration could be mitigated by using ArcGIS to only measure distance to settlement up to a maximum distance away (e.g. 50km), the rest of the region would then be masked out.

(ii) Improvement of Kazakhstan projections

By collecting information on roads and settlements in Kazakhstan, this data could be used to make the model projections into this area more realistic. The projections would also be more informative if they were done in a rectangular band positioned in parallel to the border, rather than the current triangular projection area.

(iii) Other factors for investigation

The model AUC scores could also be lower because other factors that explain the distribution are missing from the model. Factors for future investigation include: (1) a more specific measure of cumulative snowfall, as was found to be the best predictor in Chilton's (2011) West Kazakhstan study, (2) distance to the Saigachy protected area, once it has been introduced, (3) distance from drilling sites – Gazprom International's website states that it had drilled four exploratory wells in the Ustyurt by 2011 (Gazprom Int, n.d.), such infrastructure and activity could scare off saiga, and (4) distance to freshwater, a reliable data source could not be found for this study, however further investigation could prove fruitful.

4.1.3.2 *How might saiga distribution change in the future?*

Consideration of climate change is now an essential part of species conservation and other changes in the landscape of the Ustyurt mean that it is important to set the results of this study in the context of a dynamic and changing environment. Bull et al (2012, unpub) list four key ongoing changes in the Uzbek Ustyurt landscape. These are: (1) the reduction in area of the Aral Sea and the redeposition of the dust exposed onto the Ustyurt by the wind, (2) a reduction in grazing by livestock, causing plant community structure change, (3) industrial and infrastructural development, and (4) predicted increase in temperature with climate change. Bellard et al (2012, pp365) state that species may respond to changes in their environment by shifting their niche along three axes: "time (e.g. phenology), space (e.g. range) and self (e.g. physiology)". While the results of this study do not give detailed information about how exactly the saiga may shift their niche in response to the above changes, particularly in the case of the self axis, it is certainly arguable that there is a cause for concern.

The investigation of drivers of distribution highlighted vegetation as having a key influence on saiga. With rising temperatures, a spatial shift of the migration pattern northwards might be predicted, to coincide with a similar shift in vegetation. This effect may be enhanced or perhaps preceded by the effect of further industrial development, which the saiga may try to avoid. Since NDVI was so important in the models, the effect of shifting vegetation type as a result of a reduction in grazing pressure should be investigated to establish whether it poses a threat to the saiga. Overall, there is a good indication from even the general outputs produced by models in this study that the saiga and their migration are likely to be affected by changes occurring in the Ustyurt landscape, therefore this is an area that would benefit from further study. Models predicting shifts in saiga habitat suitability have been run for Kazakhstan (Singh & Milner-Gulland, 2011b) and similar models would help inform conservation planning in Uzbekistan.

4.2 Protected area planning

4.2.1 Where to protect?

The results of this study provide the sources of evidence that may be of use in protected area (PA) planning in the Uzbek Ustyurt. As discussed above, the location of a potentially permanent population and an indication of local scale factors likely to be important when setting PA boundaries were found, however the most important evidence is the location of a band in the north east of the region that is important for saiga all year round and would benefit from strict protection. There are still issues with reliability, for example, further study of the top north-east corner in Periods 1 and 2 could potentially result in it being included in the band, and reducing setting distance to settlement measurements to a maximum distance could perhaps alter the location slightly, but overall this output is clear, easily comprehensible and still potentially very useful, given the available data.

However, caution should be taken not to focus on this band and miss the whole picture. The band identifies an area for the optimisation of efforts, e.g. more rangers and stricter protection, but we are looking to conserve a migratory species, therefore we need to look at the whole range when planning conservation. There would be little point spending lots of money funding strict protection in the optimisation band if the saiga then migrated out of it to be caught by threats such as poaching and barriers to movement.

4.2.2 Protected area design

The first protected areas for saiga were introduced as far back as 1640 (Lushchekina & Struchkov, 2001), however, despite being the cornerstone of conservation efforts worldwide, protected areas suffer important issues with effectiveness. Whilst measuring PA effectiveness can be problematic (Joppa & Pfaff, 2010), examples such as Craigie et al's (2010) findings that populations of large mammals continued to decline despite their inclusion in African PAs show that PA provision does not necessarily correspond with species conservation, and that careful planning is needed to ensure success. Factors that need to be considered in PA design include: size, shape, location, connectivity and buffer zones. These design factors and how they are important to the saiga will be discussed briefly in turn.

(i) Size, shape and location

- Key points here are that the PA must be large enough to protect saiga, must be in the right place to protect it and boundary effects mean that a smaller boundary length to area ratio would be desirable (Woodroffe & Ginsberg, 1998). It is clear from out results that the saiga are migrating further south than the band identified as being optimal for strict protection and further south than the proposed Saigachy reserve extension boundaries, particularly in the January to March period (orange circles, results Fig. 6). During this time many saiga have been sighted within a day's drive from Jaslyk and thus very exposed to poaching, although this is perhaps an effect of monitoring bias too. The southerly migration is a major risk to the success of the PA project.

(ii) Connectivity

- Ignoring the issues of connectivity can result in the failure of a conservation programme for migratory species (Martin et al, 2007). Previous studies of PA design have highlighted that intermediate connectivity between designated PAs is often optimal (Salau et al, 2012); too little connectivity means that there are genetic barriers between isolated subpopulations, too much can result in spread of disease and predators (REF). However, the natural state for saiga is full connectivity, the Ustyurt population has had little limitations on its distribution for the last century, therefore too much connectivity is not likely to be an issue. Too little connectivity, on the other hand, could cause problems. Threats to connectivity between saiga PAs include the fence between Kazakhstan and Uzbekistan, roads that form a break in the proposed Saigachy PA, and also the political relations between Kazakhstan and Uzbekistan that may prevent them from working together to form a holistic approach to the conservation of the Ustyurt population.

(iii) Buffer zones

- Buffer zones are used for different reasons, sometimes to extend the protected area (thus reducing edge effects), sometimes as intermediate zone to integrate people and the reserves (Martino, 2001). The proposed Saigachy buffer zone seems to serve the purpose of linking the protected zones together to form a single, whole protected area and may also act as a form of compromise between ensuring fair resource use and protecting key areas. Given that we know that the saiga migrate throughout the whole area, not just in the protected zones, the buffer zone is likely to be essential in protecting the saiga and in ensuring connectivity. For that reason, ensuring sufficient protection and enforcement in the buffer zone will be important.

Overall, the likelihood of the proposed Saigachy reserve encountering PA effectiveness issues seems quite high. We know that the saiga are observed further south than the boundary of the reserve, we know that there are connectivity issues with Kazakhstan, the PA design means that the buffer zone is very important for saiga protection and there is considerable poaching pressure in the region (Esipov et al, 2009b). So how can we mitigate the impact of problems? The problem of connectivity with Kazakhstan will be addressed in Section 4.3, but options for addressing the remaining issues include community education, stakeholder engagement, alternative livelihoods and mobile PAs.

As described above, the SCA is already running a range of community education projects. By sharing knowledge and understanding of the saiga species and its importance in the landscape, it is hoped that the Ustyurt communities can be encouraged to care for the saiga, with the result of a decrease in poaching. Engaging members of local communities as well as other stakeholders, e.g. NGOs, local authorities and oil and gas companies working in the region, in the design process of the Saigachy reserve can help them feel involved in the project and respect the land use restrictions put in place, again potentially helping to reduce poaching pressure. Stakeholder engagement can also help to identify unforeseen issues with the placement of the reserve. Alternative livelihoods is a socio-economic approach that can help reduce poaching pressure by providing another source of income to locals, so that they need not resort to hunting.

In terms of addressing the problem of the saiga moving outside the boundaries of the PA, one option that has been suggested for migratory species is mobile PAs. These have been used in the past for saiga conservation in Kazakhstan (Robinson et al, 2009) and work by protecting different areas of the species range at different times. This could be in the form of protection during periods when the species is particularly vulnerable or protection that tracks the movement of the species (Bull et al, 2012; unpub). Bull et al (2012; unpub.) illustrate how a mobile PA that tracks the migration of the saiga into Uzbekistan in the winter and back to Kazakhstan in the summer might look, however the results of this study indicate the potential for an additional mobile protected area within Uzbekistan. A protected area located in the central part of the study region, just north of Jaslyk and east of Bostan, during Period 2 (January – March) would help to address the issue of saiga migrating out of the Saigachy reserve (and closer to the reach of poachers) during this time. Having a fixed PA in that location all year round would be costly and arguably not really as necessary, as there are far fewer sightings in the region during Periods 1 and 3. Alternatively, rather than designate a strict area for protection in Period 2, there could be a shift in focus of the rangers – they could move further south with the saiga to protect them.

4.2.3 Future work

Future work in protected area planning in the Uzbek Ustyurt should focus on evidence-based decision making. More saiga data would help ensure the reliability of conclusions on where is best to protect and a study focussed on identifying saiga calving sites might also be useful. The feasibility of a mobile protected area seems a promising area of investigation, and using science to calculate appropriate enforcement and penalties would help ensure success.

4.3 Fence impact

4.3.1 Predictions of fence impact

The results are unclear about whether the saiga are migrating in and out of Uzbekistan or not, as discussed above, however the literature indicates that there is at least some movement across the border (Zuther, 2012). Based on current results, mitigation efforts to combat fence impact would need to span the length of the fence, not just the eastern section. This is contradictory to studies of some other ungulates, where very small bottlenecks have been found (e.g. Berger et al, 2006), but the flat, relatively uniform landscape of the Ustyurt plateau is unlikely to result in bottleneck formation.

The models indicate that the saiga have the potential to survive north of the border, but this may change if (i) there is an unprecedentedly harsh winter, (ii) they try to cross and get entangled in the fence, and (iii) they are targeted by poachers. Other evidence shows that saiga have survived migration restrictions elsewhere (Milner-Gulland, 2012). The fence seems likely to isolate the Ustyurt population into two smaller sub-populations and would have an overall effect of a decreased recovery potential for the already suffering population (Milner-Gulland, 2012).

4.3.2 Potential courses of action moving forward

While the results of this study indicate a real cause for concern, the bias in the data and unreliability of the models mean that further research is necessary to supplement the findings in order to be sure that the correct decisions are made. Examples of useful future work might include: (i) collaring studies to investigate precisely where saiga are crossing the border, (ii) behavioural studies to investigate how the saiga are likely to react to the fence, (iii) models incorporating population dynamics to investigate how the Ustyurt population as a whole is likely to respond to the fence and (iv) studies of how the poaching patterns may change as a result of the change in saiga distribution.

A second potential future path might be to investigate policy-related action. As a signatory to the Memorandum of Understanding through the Convention on Migratory Species to protect the saiga, Kazakhstan is committed to not damaging the population of the saiga (CMS, 2010), therefore if sufficient evidence can be collected to prove that the fence is in fact doing just that, as is predicted, there may be a stronger political argument to be made for conservation action. However this is perhaps a little extreme, Kazakhstan generally has a proactive and enthusiastic attitude to saiga conservation. Presenting clear and reliable evidence that Kazakhstan's commitments under its Customs Union with Russia and Belarus are clashing with its commitments to the CMS, perhaps through the CMS as an intermediary, could be enough to persuade the Kazak authorities that action to mitigate the fence impact needs to be taken.

Another policy-related area of investigation is whether a fence is really required to meet Kazakhstan's commitments of border demarcation. Questions need to be answered about whether a series of well-spaced posts could mark the border line instead and if so why this method wasn't chosen.

A third future course of action would be to investigate potential mitigation measures. Criteria that options to mitigate the impact of the fence must meet include: (i) they must be easily visible (Bissonette & Cramer, 2008), saiga are crossing the fence during periods of heavy snowfall and need to be able to see where/how to cross safely, (ii) they enable safe border crossing without entanglement, and (iii) they must not alarm the saiga into avoiding trying to cross at all. Crossing structures such as overpasses and underpasses are one option, but the Ustyurt landscape is very flat and uniform - it seems possible that the saiga would try to avoid anything that looks like an obstruction rather than try to cross via them. A trial run might help establish whether such structures would be effective. The structures are also expensive (Olson, 2012) and more knowledge on where the saiga are crossing in and out of Uzbekistan would be needed before they could be implemented, in order to be certain that the money was being well-spent. However, there is not time to gain more data or to run pilots, the saiga will be migrating towards the fence at the end of this year – a simpler option that can be implemented almost immediately is required.

Wildlife-friendly fencing looks a more promising mitigation option. The lowest strand of wire on the fence could be removed or raised in order to allow saiga to pass underneath (CMS, 2011; Milner-Gulland, 2012). Removing the wire could have the added benefit of recovering some of the costs through reselling the metal as scrap (Olson, 2012). Milner-Gulland (2012) also suggests adding flags or streamers to the fence so that the saiga can see it in the snow and do not run straight into it.

Summary and conclusions

This study has highlighted a number of points of interest concerning saiga in Uzbekistan. Overall, the data quality on the saiga is poor and more effective monitoring programmes are needed. This has made it difficult to draw clear and reliable conclusions, however the existing data support the theory that the saiga migration is driven by the need to find vegetation, which is hampered by snow further north in winter, then temperature in the south in summer. Models indicate a clear band across the north-east of the study region that is important for saiga throughout the year, and may even be home to a permanent population, and this area would benefit from strict protection. However, the movement of the saiga in the region means that additional protection would be needed further south during the early months of the year. In terms of the impact of the new border fence, models suggest that the saiga would be able to survive north of the fence during the winter but that they are at risk of entanglement trying to cross it. The isolation of two sub-populations will also further limit the recovery potential of the Ustyurt saiga population. Mitigation measures are needed across the length of the fence.

The three subject areas, knowledge of saiga in Uzbekistan, protected area planning and fence impact, have mostly been treated separately throughout this study, however it is important to recognise that in reality they are very much interlinked. The success of the proposed Saigachy reserve extension depends a huge amount on whether successful mitigation measures can be introduced to ensure that the saiga can still migrate in and out of the region and the reserve planning can be enhanced by more reliable knowledge of saiga distribution. Similarly, predictions of the impact of the fence could be made more reliable by better supporting data and models. In moving forward, an integrated approach to addressing all three issues could be more efficient, more cost-effective and more valuable. Protected area planning should incorporate the need for fence impact mitigation, as well as recognising the weaknesses in the supporting data and promoting efforts to improve them. For example, considering the status of the existing data, it would be unscientific to design the protected area based on information from biased sampling efforts, but rangers undertaking regular surveying of areas to look for poachers could be a very good source of saiga data.

This study has met its objectives but is greatly limited by data quality. Future work must begin by addressing this issue. Following that, future investigations that may be of value to saiga conservation in Uzbekistan include exploring the potential of collaring data, extending MaxEnt models to include more factors and creating models incorporating population dynamics to more thoroughly assess the fence impact, as well as looking into the feasibility of new conservation options such as mobile protected areas.

In conclusion, action to protect the saiga antelope in Uzbekistan has never been needed more urgently. With the border fence now completed, the coming year could see many saiga deaths due to entanglement and the already suffering population driven further towards extinction. This study has shown that the data on saiga in Uzbekistan are very poor and so the science-based conservation decision-making that is so desperately required is difficult to achieve, however the results provide some knowledge contribution and also act as a basis upon which further work can be carried out. It is hoped that by addressing the three areas of concern examined in this study in an integrated manner, successful conservation programmes can be implemented by the appropriate parties to protect the saiga before it is too late.

References

Azimov, U., Sheraliev, N., Horst, M. & Sokolov, V. (2006*) The Republic of Uzbekistan National Report: Within the framework of UNEP support for achieving the Johannesburg Plan of implementation target of "Integrated Water Resources Management andEfficiency Plans by 2005, with support to developing countries"* Tashkent, CAWater Info. [Online] Available from: http://www.cawater-info.net/ucc-water/pdf/ucc_water_report_uzb_en.pdf [Accessed 20th August 2012].

Bekenov, A., Grachev, I. A. & Milner-Gulland, E. (1998) The ecology and management of the saiga antelope in Kazakhstan. *Mammal Review.* 28 (1), 1-52.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. (2012) Impacts of climate change on the future of biodiversity. *Ecology Letters.* 15 (4), 365-377.

Berger, J. (2004) The last mile: How to sustain long-distance migration in mammals. *Conservation Biology.* 18 (2), 320-331.

Berger, J., Cain, S. L. & Berger, K. M. (2006) Connecting the dots: an invariant migration corridor links the Holocene to the present. *Biology Letters.* 2 (4), 528-531.

Bissonette, J. A. & Cramer, P. C. (2008) *Evaluation of the use and effectiveness of wildlife crossings.* , Transportation Research Board.

Boakes, E. H., McGowan, P. J. K., Fuller, R. A., Chang-qing, D., Clark, N. E., O'Connor, K. & Mace, G. M. (2010) Distorted views of biodiversity: spatial and temporal bias in species occurrence data. *PLoS Biology.* 8 (6), e1000385.

Bolger, D. T., Newmark, W. D., Morrison, T. A. & Doak, D. F. (2008) The need for integrative approaches to understand and conserve migratory ungulates. *Ecology Letters.* 11 (1), 63-77.

Bull J.W., Suttle K.B., Singh N.J. & Milner-Gulland E.J. (2012) Conservation when nothing stands still: moving targets and biodiversity offsets. *Unpublished*

Buuveibaatar, B., Fuller, T. & Fine, A. (2012). Survival and spatial ecology of saiga calves in Mongolia. *Saiga News.* [Online] 15, 15. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Bykova, E. (2012). A new documentary film about the saiga has been screened in the Ustyurt villages. *Saiga News.* [Online] 14, 9. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Bykova, E., Arylov, Y. & Klimanova, O., (2011). A new documentary film about the saiga has been screened in the Ustyurt villages. *Saiga News.* [Online] 13, 1. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Bykova, E. & Esipov, A. (2011). Results of a participatory monitoring programme in Uzbekistan in years 2009-2010. *Saiga News.* [Online] 12, 16. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Chilton, H. (2011). The where and why of saiga antelope distribution in West Kazakhstan. MSc thesis. [Online] Imperial College London, Imperial College Conservation Science. Available from: www.iccs.org.uk [Accessed 20th June 2012].

CMS (2011). *Barriers to migration: Case study in Mongolia. Analysing the Effects of Infrastructure on Migratory Terrestrial Mammals in Mongolia*. Convention on Migratory Species, Bergen.

CMS (2010). *Medium International Work Programme on the Saiga Antelope (2011-2015)*. [Online] Convention on Migratory Species, Ulaanbaatar. Available from: http://www.cms.int/species/saiga/2ndMtg_Mongolia/Mtg_Rpt/Annex_5_MTIWP_2011_2015_E.pdf [Accessed 14th August 2012].

Collier, B. A., McCleery, R. A., Calhoun, K. W., Roques, K. G. & Monadjem, A. (2011) Detection probabilities of ungulates in the eastern Swaziland lowveld. *South African Journal of Wildlife Research.* 41 (1), 61-67.

Craigie, I. D., Baillie, J. E. M., Balmford, A., Carbone, C., Collen, B., Green, R. E. & Hutton, J. M. (2010) Large mammal population declines in Africa's protected areas. *Biological Conservation.* 143 (9), 2221-2228.

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., Alviola, P., Balete, D. S., Blomley, T. & Brashares, J. (2009) Local participation in natural resource monitoring: a characterization of approaches. *Conservation Biology.* 23 (1), 31-42.

DIVA-GIS (n.d.). *DIVA-GIS*. [Online] Available from: http://www.diva-gis.org/gdata/ [Accessed 9th July 2012].

EDGE (n.d.). *131. Saiga/mongolian Saiga (Saiga tatarica)*. [Online] Available from: http://www.edgeofexistence.org/mammals/species_info.php?id=62 [Accessed 21st June 2012].

Elith, J., Graham*, C. H., Anderson, R. P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R. J., Huettmann, F., Leathwick, J. R. & Lehmann, A. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography.* 29 (2), 129-151.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E. & Yates, C. J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions.* 17 (1), 43-57.

Elliott, G. (2011). Mapping the spring and winter distribution of Kalmykia's saiga population. [Online] Imperial College London, Imperial College Conservation Science. Available from: www.iccs.org.uk [Accessed 20th June 2012].

Esipov, A., Bykova, E., Chernogaev, A., Rabbimov, A., Mitropolsky, O., Nuridjanov, A. & Yagodin, V. (2009a). *Justification of the reorganisation of the zakaznik "Saigachy".* Unknown publisher and report.

Esipov, A. V., Golovtsov, D. A. & Bykova, E. A. (2009b). The impact of climate factors on the Ustiurt saiga population in Uzbekistan. IUGB, Moscow.

ESRI (2009). *ArcGIS Desktop.* Release 9.3. [Software] Redlands, CA: Environmental Systems Research Institute.

ESRI (2011). *ArcGIS Desktop*. Release 10. [Software] Redlands, CA: Environmental Systems Research Institute.

Flesch, A. D., Epps, C. W., CAIN III, J. W., Clark, M., Krausman, P. R. & MORGART, J. R. (2010) Potential Effects of the United States-Mexico Border Fence on Wildlife. *Conservation Biology.* 24 (1), 171-181.

Fynn, R. W. S. & Bonyongo, M. C. (2011) Functional conservation areas and the future of Africa's wildlife. *African Journal of Ecology.* 49 (2), 175-188.

Gadd, M. E. (2012) Barriers, the Beef Industry and Unnatural Selection: A Review of the Impact of Veterinary Fencing on Mammals in Southern Africa. *Fencing for Conservation.* , 153-186.

Gazprom International (n.d.). *Countries: Uzbekistan*. [Online] Available from: http://gazprom-international.com/en/operations/country/uzbekistan [Accessed 21st August 2012].

Google Inc (2012). *Google Earth (Version 6.2.1.6014)*. [Software] Available from: http://www.google.com/earth/index.html [Accessed 9th July 2012].

Google Maps (2012). *Uzbekistan and Central Asia*. [Online] Available from: https://maps.google.co.uk/maps?hl=en [Accessed 10th September 2012].

Grilo, C., Bissonette, J. A. & Cramer, P. C. (2010) Mitigation measures to reduce impacts on biodiversity. , .

Guisan, A. & Thuiller, W. (2005) Predicting species distribution: offering more than simple habitat models. *Ecology Letters.* 8 (9), 993-1009.

Hall, D. K., Riggs, G.A. & Salomonson, V.V. (2006, updated monthly). MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG V005, [Online]. Boulder, Colorado USA, National Snow and Ice Data Center.

Harris, G., Thirgood, S., Hopcraft, J. G. C., Cromsigt, J. P. G. M. & Berger, J. (2009) Global decline in aggregated migrations of large terrestrial mammals. *Endangered Species Research.* 7 (1), 55-76.

Hijmans, R.J., & van Etten, J. (2012). *Raster: Geographic analysis and modeling with raster data.* R package version 2.0-08. Available from: http://CRAN.R-project.org/package=raster.

Holdo, R. M., Fryxell, J. M., Sinclair, A. R. E., Dobson, A. & Holt, R. D. (2011) Predicted impact of barriers to migration on the Serengeti wildebeest population. *PloS One.* 6 (1), e16370.

Islam, M., Ismail, K. & Boug, A. (2010) Catastrophic die-off of globally threatened Arabian Oryx and Sand Gazelle in the fenced protected area of the arid central Saudi Arabia. *Journal of Threatened Taxa.* 2 (2), 677-684.

Ito, T. Y., Okada, A., Buuveibaatar, B., Lhagvasuren, B., Takatsuki, S. & Tsunekawa, A. (2008) One-Sided Barrier Impact of an International Railroad on Mongolian Gazelles. *The Journal of Wildlife Management.* 72 (4), 940-943.

Ito, I.,Y., Masato, S., Esipov, A., Grachev, Y., Singh, N., & Milner-Gulland, E.J. (2010). Satellite tracking of saigas starts in Ustyurt. *Saiga News.* [Online] 10, 10. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Jarnemo, A. (2008) Seasonal migration of male red deer (Cervus elaphus) in southern Sweden and consequences for management. *European Journal of Wildlife Research.* 54 (2), 327-333.

Joppa, L. & Pfaff, A. (2010) Reassessing the forest impacts of protection. *Annals of the New York Academy of Sciences.* 1185 (1), 135-149.

Jordhøy, P. (2008) Ancient wild reindeer pitfall trapping systems as indicators for former migration patterns and habitat use in the Dovre region, southern Norway. *Rangifer.* 28 (1), 79-87.

Justice, C. O., Townshend, J., Holben, B. & Tucker, C. (1985) Analysis of the phenology of global vegetation using meteorological satellite data. *International Journal of Remote Sensing.* 6 (8), 1271-1318.

Kaczensky, P., Kuehn, R., Lhagvasuren, B., Pietsch, S., Yang, W. & Walzer, C. (2011) Connectivity of the Asiatic wild ass population in the Mongolian Gobi. *Biological Conservation.* , .

Kušta, T., Keken, Z. & Ježek, M. (2011) Evaluation of changes in the landscape management and its influence on animal migration in the vicinity of the D1 motorway in Central Bohemia. *Journal of Forest Science.* 57 (7), 312-320.

Large Herbivore Network (n.d.). *Factsheet: Saiga antelope*. [Online] Available from: http://www.lhnet.org/saiga-antelope/ [Accessed 21st June 2012].

Leon, J. (2009). Evaluating the use of local knowledge in species distribution studies: A case study of Saiga antelope in Kalmykia, Russia. [Online] Imperial

College London, Imperial College Conservation Science. Available from: www.iccs.org.uk [Accessed 9th September 2012].

LP DAAC (n.d.a). *MODIS/Terra Land Surface Temperature and Emissivity Monthly L3 Global 0.05Deg CMG: MOD11C3* [Online]. Available from: https://lpdaac.usgs.gov/products/modis_products_table/mod11c3 [Accessed 12th July 2012].

LP DAAC (n.d.b). *Vegetation Indices Monthly L3 Global 1km MOD13A3* [Online]. Available from: https://lpdaac.usgs.gov/products/modis_products_table/mod13a3 [Accessed 12th July 2012].

LP DAAC, (n.d.c.); *MRT Tool.* [Online]. Available from: https://lpdaac.usgs.gov/tools/modis_reprojection_tool_swath [Accessed 12th July 2012].

Lushchekina, A. & Struchkov, A. (2001) The saiga antelope in Europe: once again on the brink? *The Open Country.* 3, 11-24.

Lushchekina, A. A., Neronov, V. M., Amgalan, L. & Dulamtseren, S. (1999) The status and prospects for conservation of the Mongolian saiga Saiga tatarica mongolica. *Oryx.* 33 (1), 20-29.

Makash & Husainov (n.d.) To save remaining saiga. Unknown publisher, Kazahstan.

Mallon, D.P. (2008). Saiga tatarica. In: IUCN Red List of Threatened Species. Version 2012.1. [Online] IUCN. Available from: www.iucnredlist.org [Accessed 10th May 2012].

Martin, T. G., Chadès, I., Arcese, P., Marra, P. P., Possingham, H. P. & Norris, D. R. (2007) Optimal conservation of migratory species. *PLoS One.* 2 (8), e751.

Martino, D. (2001) Buffer zones around protected areas: a brief literature review. *Electronic Green Journal.* 1 (15), 1-19.

Mattiuzzi, M., Verbesselt, J., Hengl, T., Klisch, A., Evans, B., & Lobo, A. (2012). *MODIS: MODIS download and processing package*. R package version 0.3-27/r206. Available from: http://R-Forge.R-project.org/projects/modis/.

McNeely, J. A., Kapoor-Vijay, P., Zhi, L., Olsvig-Whittaker, L., Sheikh, K. M. & Smith, A. T. (2009) Conservation biology in Asia: the major policy challenges. *Conservation Biology.* 23 (4), 805-810.

Milner-Gulland, E.J. (2012). The implications of the border fence on the Ustyurt plateau for the saiga antelope, and options for mitigation. *Saiga News.* [Online] 15, 20 Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Milner-Gulland, E., Kholodova, M., Bekenov, A., Bukreeva, O., Grachev, I. A., Amgalan, L. & Lushchekina, A. (2001) Dramatic declines in saiga antelope populations. *Oryx.* 35 (04), 340-345.

Monterroso, P., Brito, J., Ferreras, P. & Alves, P. (2009) Spatial ecology of the European wildcat in a Mediterranean ecosystem: dealing with small radio-tracking datasets in species conservation. *Journal of Zoology.*279 (1), 27-35.

Nichols, J. D. & Williams, B. K. (2006) Monitoring for conservation. *Trends in Ecology & Evolution.* 21 (12), 668-673.

Norton-Griffiths, M. & McConville, A. J. (2007) *Republic of Kazakhstan: Technical Evaluation of the Aerial Survey Programme for Saiga Antelope (Saiga tatarica) with recommendations for improvements.* ZGF. Project number: 1293/02

Offord, S. (2011). An Evaluation of Potential Monitoring Strategies for Saiga Antelopes on the Ustyurt Plateau. MSc thesis. [Online] Imperial College London, Imperial College Conservation Science. Available from: www.iccs.org.uk [Accessed 5th January 2012].

Olson, K. (2012) *Wildlife crossing options along existing and planned Mongolian railway corridors.* Mongolian Discussion Papers, East Asia and Pacific Sustainable Development Department. Washington, D.C., World Bank.

Olson, K. (2011). Development of a population monitoring program for saiga (Saiga tatarica) in Uzbekistan: Recommendations from a monitoring workshop and attempted pilot survey. Final Report to Fauna and Flora International.

Olson, K. A., Mueller, T., Leimgruber, P., Nicolson, C., Fuller, T. K., Bolortsetseg, S., Fine, A. E., Lhagvasuren, B. & Fagan, W. F. (2009) Fences impede long-distance Mongolian gazelle (Procapra gutturosa) movements in drought-stricken landscapes. *Mongolian Journal of Biological Sciences.* 7 (1-2), 45-50.

Pennycuick, C. & Western, D. (1972) An investigation of some sources of bias in aerial transect sampling of large mammal populations. *African Journal of Ecology.* 10 (3), 175-191.

Pettorelli, N., Ryan, S., Mueller, T., Bunnefeld, N., Jedrzejewska, B., Lima, M. & Kausrud, K. (2011) The normalized difference vegetation index (NDVI): unforeseen successes in animal ecology. *Climate Research.* 46, 15-27.

Phillips, S. (n.d.). *A brief tutorial on MaxEnt.* Unknown [Online] AT&T Research, NJ. Available from: www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc. [Accessed 13th July, 2012].

Phillips, S. J., Anderson, R. P. & Schapire, R. E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling.* 190 (3), 231-259.

Phillips, S. J. & Dudík, M. (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography.* 31 (2), 161-175.

R Core Team (2012). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. [Software] Available from: http://www.R-project.org/.

Reimers, E., Dahle, B., Eftestøl, S., Colman, J. E. & Gaare, E. (2007) Effects of a power line on migration and range use of wild reindeer. *Biological Conservation.* 134 (4), 484-494.

Robinson, A., Crick, H. Q. P., Learmonth, J. A., Maclean, I. M. D., Thomas, C. D., Bairlein, F., Forchhammer, M. C., Francis, C. M., Gill, J. A. & Godley, B. J. (2009) Travelling through a warming world: climate change and migratory species. *Endangered Species Research.* 7, 87-99.

Rodríguez, J. P., Brotons, L., Bustamante, J. & Seoane, J. (2007) The application of predictive modelling of species distribution to biodiversity conservation. *Diversity and Distributions.* 13 (3), 243-251.

Salau, K., Schoon, M. L., Baggio, J. A. & Janssen, M. A. (2012) Varying effects of connectivity and dispersal on interacting species dynamics. Ecological Modelling. 242, 81-91.

Salemgareev, A., Shaimukhanbetov, O., Zuther, S., & Skylarenko, S. (2010). Results of the satellite collaring programme in Betpak-dala, 2009/10. *Saiga News.* [Online] 12, 11. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

SCA (n.d.). *Saiga Conservation Alliance*. [Online] Available from: http://www.saiga-conservation.com [Accessed 10th May 2012].

Singh, N. J. & Milner-Gulland, E. (2011a) Monitoring ungulates in Central Asia: current constraints and future potential. *Oryx.* 45 (01), 38-49.

Singh, N. J. & Milner-Gulland, E. J. (2011b) Conserving a moving target: planning protection for a migratory species as its distribution changes. *Journal of Applied Ecology.* 48 (1), 35-46.

Singh, N., Grachev, I. A., Bekenov, A. & Milner-Gulland, E. (2010a) Tracking greenery across a latitudinal gradient in central Asia–the migration of the saiga antelope. *Diversity and Distributions.* 16 (4), 663-675.

Singh, N., Grachev, I., Bekenov, A. & Milner-Gulland, E. (2010b) Saiga antelope calving site selection is increasingly driven by human disturbance. *Biological Conservation.* 143 (7), 1770-1779.

Solano, R., Didan, K., Jacobson, A. & Huete, A. (2010) *MODIS Vegetation Index User's Guide(MOD13 Series)* Tuscon, AZ, University of Arizona. [Online] Available from: http://vip.arizona.edu/documents/MODIS/MODIS_VI_UsersGuide_01_2012.pdf [Accessed 12th July 2012].

Solberg, E. J., Rolandsen, C. M., Heim, M., Linnell, J. D. C., Herfindal, I. & Sæther, B. E. (2010) Age and sex-specific variation in detectability of moose (Alces alces) during the hunting season: implications for population monitoring. *European Journal of Wildlife Research.* 56 (6), 871-881.

Tambling, C. J. & Du Toit, J. T. (2005) Modelling wildebeest population dynamics: implications of predation and harvesting in a closed system. *Journal of Applied Ecology.* 42 (3), 431-441.

Vistnes, I. & Nellemann, C. (2008) The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. *Polar Biology.* 31 (4), 399-407.

Western, D., Groom, R. & Worden, J. (2009) The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation.* 142 (11), 2538-2546.

Woodroffe, R. & Ginsberg, J. R. (1998) Edge effects and the extinction of populations inside protected areas. *Science.* 280 (5372), 2126-2128.

Young, J. K., Murray, K. M., Strindberg, S., Buuveibaatar, B. & Berger, J. (2010) Population estimates of Endangered Mongolian saiga Saiga tatarica mongolica: implications for effective monitoring and population recovery. *Oryx.* 44 (02), 285-292.

Zuther, S. (2010). Tracking saigas in Kazakhstan. *Saiga News.* [Online] 10, 9. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Zuther, S. (2012). Construction of a fence along the border between Kazakhstan and Uzbekistan. *Saiga News.* [Online] 15, 3. Available from: http://www.saiga-conservation.com/saiga_news.html [Accessed 10th September 2012].

Zweifel-Schielly, B., Kreuzer, M., Ewald, K. C. & Suter, W. (2009) Habitat selection by an Alpine ungulate: the significance of forage characteristics varies with scale and season. *Ecography.* 32 (1), 103-113.

Appendix A: Sensitivity analysis

Outcomes of sensitivity analysis

Test	Why	How output contributed to final model selection
Removing roads	Test runs of model showed saiga probability of saiga presence was much higher around roads and this was predicted to be caused by biased saiga data collection	Removing roads gave a much more evenly distributed model output. Distance to roads is such a strong predictor of saiga presence that it obscures the effect of all the other variables. Considering that its effect is likely to be this strong due to bias in collection, it was decided that this variable should be excluded from the final models in order to better understand the effects of the other variables.
Removing railways	Maps of the study area show that three of the four settlements are located on the railway line, indicating the potential for co-variance	Removing railways had no significant effect on model AUC and jacknifes showed it contained no information that was not already included in other variables. It was therefore decided that it should not be included in the final models as uninformative variables can just obscure the effects of others.
Including distance to border	It was noted that distance to settlement was more important in Periods 1 and 3, when the saiga are on the move, suggesting that it could perhaps be migration driving the importance of the factor rather than the settlements themselves. This would be better explained by the distance to the Uzbek border.	Including distance to border in the models resulted in a decrease in model AUC and a Pearson Product Moment Correlation Coefficient matrix indicated that the factor showed significant correlation with NDVI ($r=-0.807$) and some correlation with temperature ($r=0.651$) and distance to settlement ($r=-0.628$). This factor was therefore not included in the final models.
Changing time periods	It was thought that splitting the data into two snow (December to March) and non-snow (April to June) periods might be more biologically realistic, as well as boosting the number of saiga sightings by extending Period 2 to include an extra month.	AUC decreased despite these additional sightings. One possible explanation is that perhaps too large a time period (four months) was being averaged into a single value for the environmental data. The original three time periods were kept for the final model.
Using only transect data	As discussed in section 2.1.1, some saiga data were collected via a more reliable method than others. Tests were run to establish whether the models could be improved by only using data collected via	The permutation importance of roads was actually higher (PI=12.8) in the transect data model than in the non-transect data model (PI=10.3). This could be a result of monitors not sticking to transects or an artefact of a small sample size. It was thus decided that data from the four different

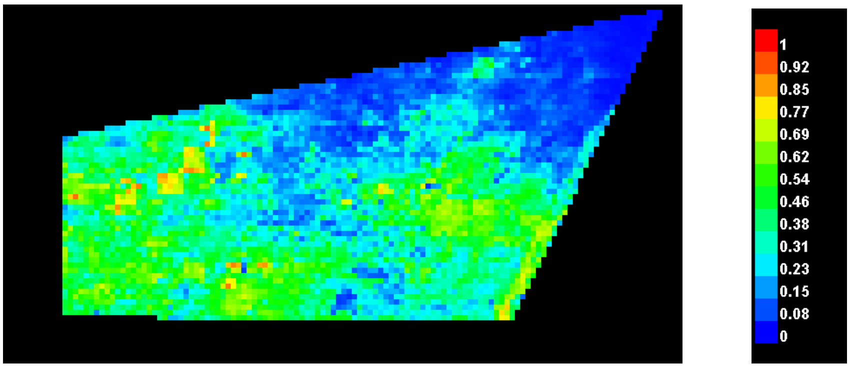
	distance sampling transects, thereby hopefully reducing bias due to roads. One model was run using only April and May 2012 (i.e. transect data) and another using non-transect data for period 3.	collection types would all be included in the models.

Appendix B: MaxEnt outputs for medium and small sites

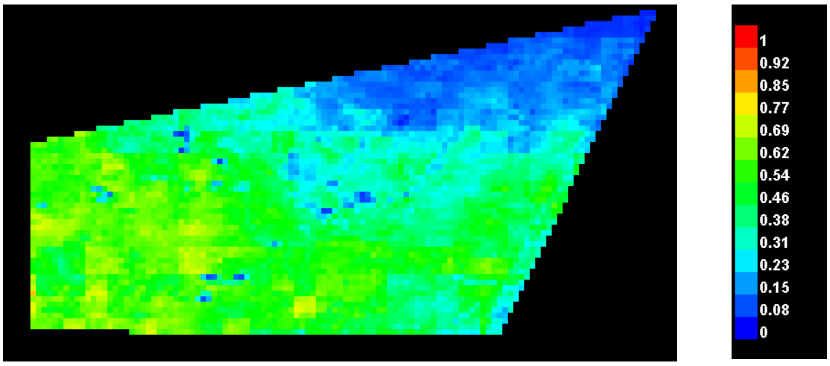
Factors included in the model were snow cover, temperature, NDVI and distance to nearest settlement, and model outputs are an average of 10 replicates. Pixel values of 1 (red) indicate a high probability of saiga presence and values of 0 indicate a low probability of presence (blue).

Medium site

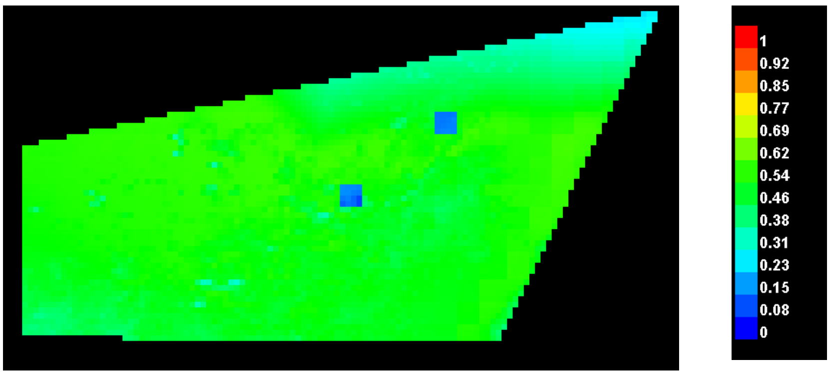
Period 1: AUC = 0.670



Period 2: AUC = 0.673

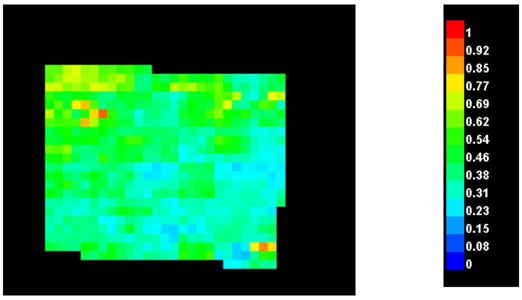


Period 3: AUC = 0.452

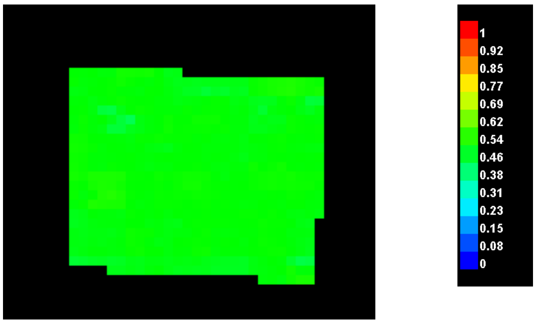


Small site

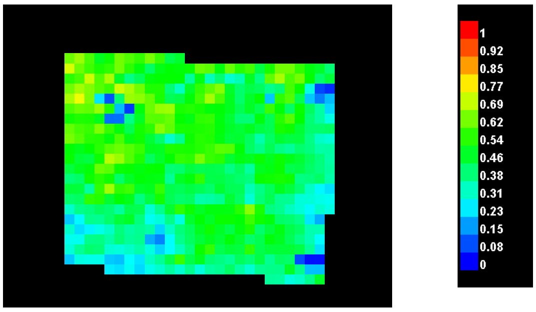
Period 1: AUC = 0.794



Period 2: AUC = 0.276



Period 3: AUC = 0.625



Appendix C: Jacknifes of model training gain

Dark blue bars show the model training gain when only that particular variable is included, therefore how much of the variation the variable explains by itself. Light blue bars show the model training gain when that particular variable is excluded, therefore how much unique information that variable contains. Red bars show the model training gain when all the variables are included.

Full_distsett = Distance to nearest settlement

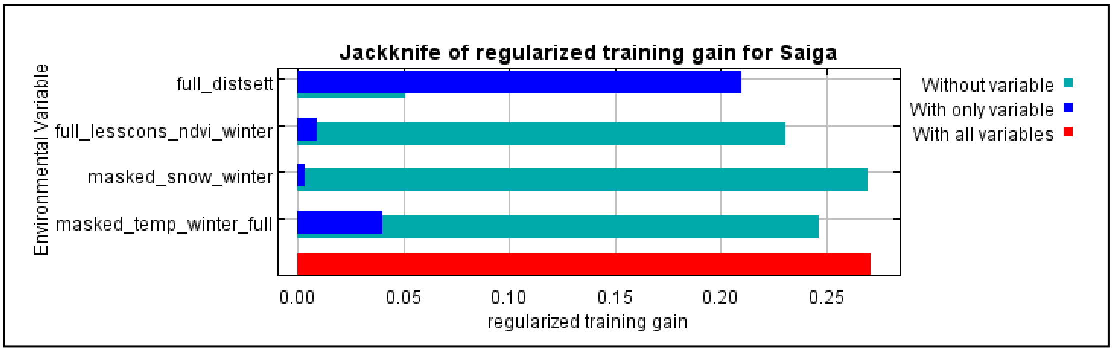
Full_lesscons_ndvi = NDVI

Masked_snow = Snow cover

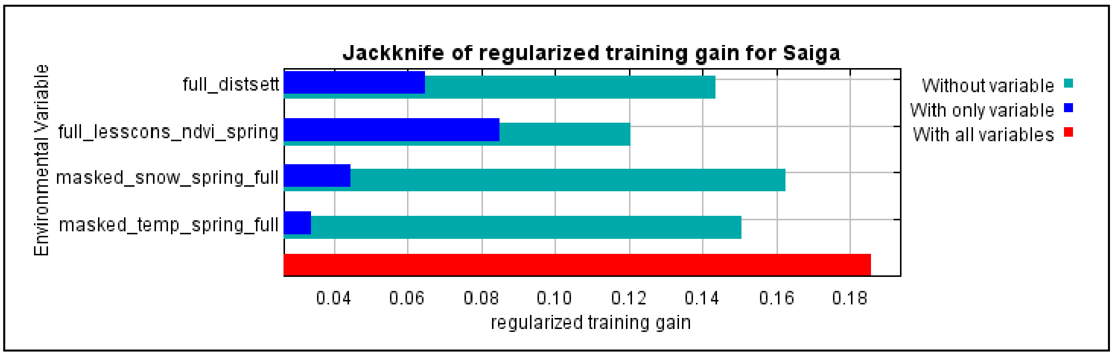
Masked_temp = Temperature

Full site

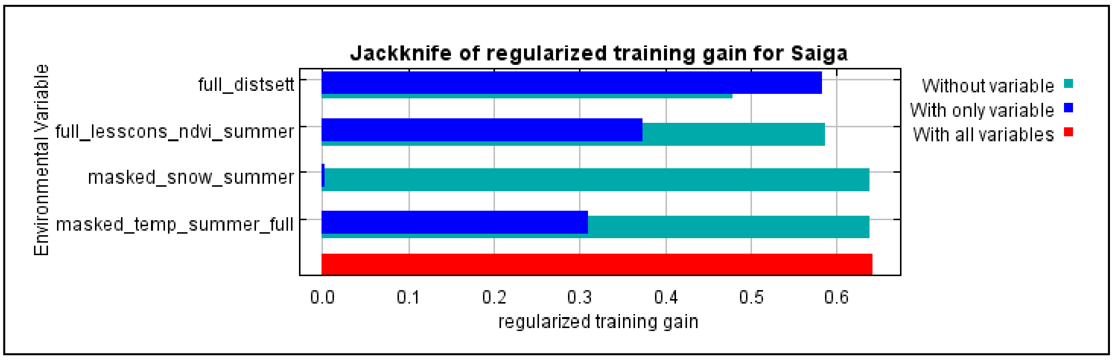
Period 1:



Period 2:

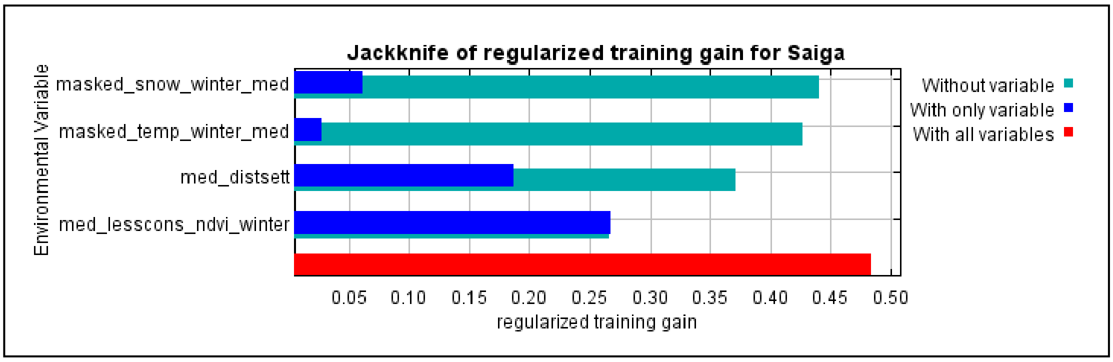


Period 3:

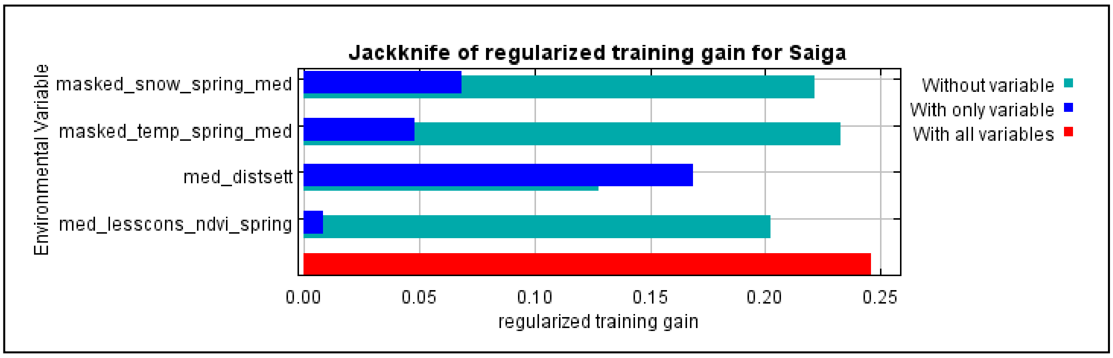


Medium site

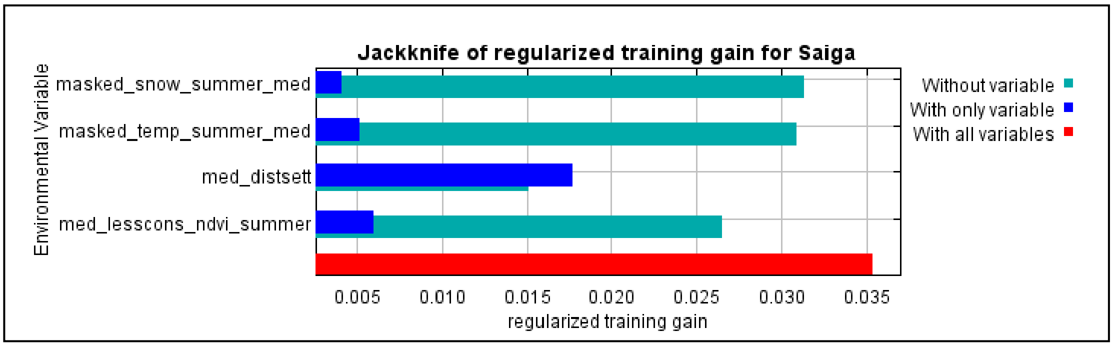
Period 1:



Period 2:

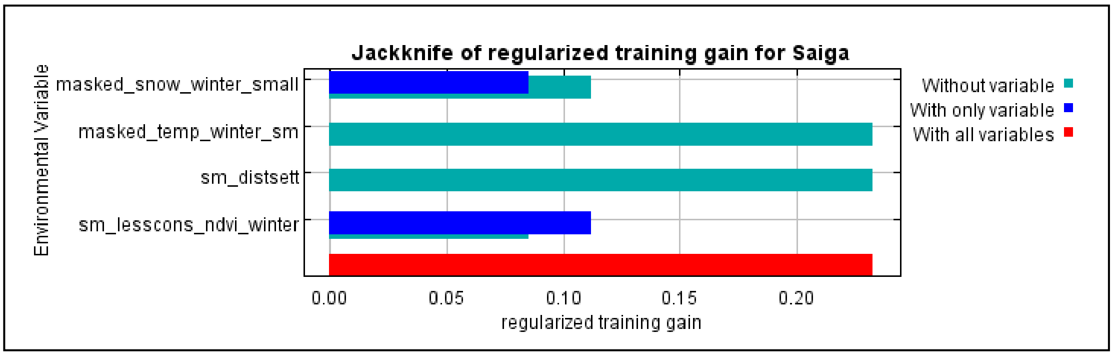


Period 3:

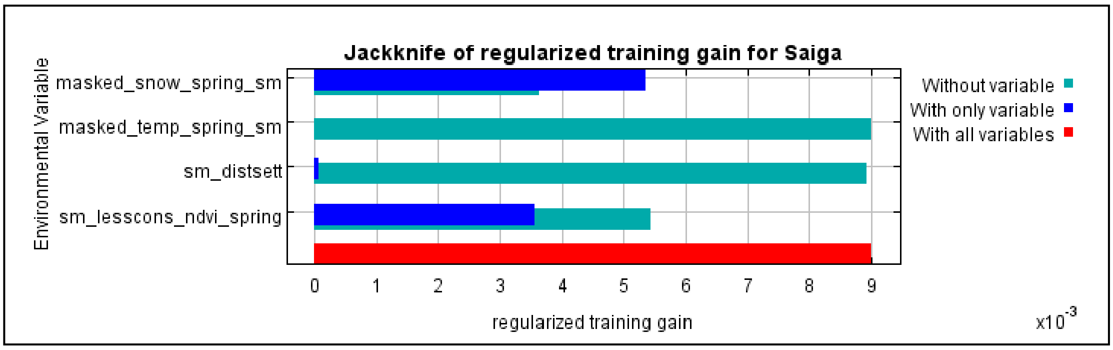


Small site

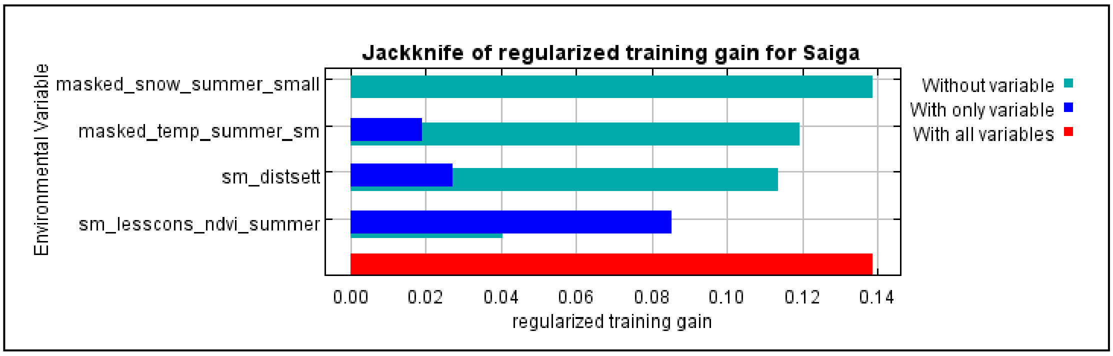
Period 1:



Period 2:



Period 3:


Jackknife of regularized training gain for Saiga
Environmental Variable
masked_snow_summer_small
masked_temp_summer_sm
sm_distsett
sm_lesscons_ndvi_summer
Without variable
With only variable
With all variables
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
regularized training gain