Assessing the Potential Effects of Climate Change on Two Species of Rhinoceros, *Diceros bicornis* and *Rhinoceros unicornis*, Using Species Distribution Modelling

Jena Saffery

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Contents

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Abstract

The aim of this project was to assess the potential effects of climate change on two species of rhinoceros – the black rhinoceros (*Diceros bicornis*) and the Greater One-Horned rhinoceros (*Rhinoceros unicornis*) – through species distribution modelling.

Climate change will have a dramatic effect on most species on Earth, and threatened species, such as the black and Greater One-Horned rhinos, may suffer substantially. Save the Rhino International is an organisation fundraising to ensure the protection of rhinoceros species, and has an active interest in this study as a way of determining if current projects will still be valuable in the future.

The protected and historic ranges for both species were used in MaxEnt to determine the suitable climate areas for future climate prediction scenarios. These were then run through a series of statistical analyses in order to determine the best possible locations for protected areas. Results suggest that the current protected ranges were suitable in the future projections and that historic range was also a good guide to decide locations of protected areas.

At the moment, climate change is not a common deciding factor in conservation management plans, which could backfire in the future. By including climate change as a deciding factor, conservation managers could ensure the protection of rhinoceros species over the next 80 years, by conserving many sub-populations over a vast area, in order to mitigate the severe effects that climate change may have.

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1. Introduction

1.1. Motive for Research

There are many factors affecting wildlife populations across the globe, most of which have a connection to human activity. Some of these components have very simple solutions; for example, if we do not destroy a rainforest, we will conserve an area of habitat for an extremely diverse collection of species. Of course, the solutions are not always feasible – as the human population increases, the demands for resources increases. Other factors are not as simple to rectify, despite a very straightforward solution; as is the issue with climate change (Hughes, 2000). The solution to reducing climate change is to cease burning fossil fuels; however the fossil fuels that have been consumed are already having an impact on the planet.

Hughes (2000) reviewed many studies determining the change in species distribution, life cycles and physiology. He concluded that the study species may not have all been affected by increasing greenhouse gases, but those that affected have occurred with temperatures at only a fraction of those expected over the next century.

It is believed that the more severe impacts of climate change will be a consequence of interaction with other threats (Thomas *et al.*, 2004). Unfortunately, climate change is un avoidable (Thomas *et al.*, 2004), but by minimising greenhouse gas emissions, and increasing carbon sequestration , it may be possible to achieve the minimum expected climate change, and prevent a large number of terrestrial species from going extinct (Thomas *et al.*, 2004).

As the impacts of climate change become more evident, it is becoming a necessity for conservation managers to consider climate change as an influencing factor for conservation implementation. One organisation looking to improve the management of rhinoceroses is Save the Rhino International (SRI), wanting to ensure that funding is going into suitable areas that will be valuable to rhinoceros conservation in the future. Investing in land and infrastructure is costly, therefore the integration of climate change as one of the decision-making factors of conservation managers will likely aid the conservation of rhinoceros populations in the future.

By determining the potential areas of suitable climate, the research carried out may act as a way to determine the optimum areas to allocate funding for the conservation of rhinoceros species. In order to do this, climate change scenarios, created by the Intergovernmental Panel on Climate Change (IPCC, 2000), were used. However, despite four IPCC scenarios being created, only two were available as GIS datasets (WorldClim, 2009). The two scenarios that were used for this study are the worst case scenarios for the two different families (A and B). The A scenarios are based on the continual use of fossil fuels, while the B scenarios imply a more sustainable approach to energy consumption. For more details please see Section 2.1.

The focus of this study was on two species of rhinoceros – the black rhinoceros (*D. bicornis michaeli*) and the Greater One-Horned rhinoceros (*R. unicornis*) – and specific protected areas of each species, namely the Laikipia region in Kenya, and the Assam region in India. The protected areas used within this study, for Laikipia and Assam, are a selection of those being funded by SRI and contain important habitat for each species, respectively. The size and rhinoceros populations of the protected areas used can be seen in Table 1.1 and Table 1.2.

Location	**Area (km^2)**	***D. bicornis michaeli* population (as of 2006)**
Laikipia Nature Conservancy (Laikipia Ranching)	405	13
Lewa Wildlife Conservancy	250	53
Mugie Ranch	81	24
Ol Jogi Game Reserve	46.7	26
Ol Pejeta Wildlife Conservancy	87.2	49
Solio Game Reserve	69.4	94
Il Ngwesi	26.3	1

Table 1.1. The name, the current area and the population of *D. bicornis* in each reserve studied within the Laikipia region, adapted from Okita-Ouma *et al*, 2007.

Location	**Area (km2)**	***R. unicornis* population (as of 2008)**
Kaziranga National Park	429.9	1855 - 2000
Manas National Park	520.2	0 - 6

Table 1.2. The name, current area and *R. unicornis* population of the two study reserves within the Assam region of India, adapted from the International Rhino Foundation

The above mentioned protected areas in Laikipia (Table 1.1) have been used as the entire protected range of *D. b. michaeli*. However, for *R. unicornis*, all of the protected areas that make up its entire range have been used for modelling purposes (Figure 2.6). The reason for using only Laikipia as the protected range for *D.b.michaeli* is that there is no dataset that collates all of the areas that contain populations of the rhinoceros species.

By focusing on these areas, SRI will be able to establish if its funds are concentrated in regions that will be suitable in the future, depending on climate change, but also if more funds should be generated to create new protected areas in other regions of suitable climate for each rhinoceros species.

1.2 Aims and Objectives

The aims of this study were to determine if climate change will have an effect on protected populations of the Eastern Black rhinoceros (*D. b. michaeli*) and the Greater One-Horned rhinoceros (*R. unicornis*), and to discover if there would be suitable climate areas that may be of conservation value. As both species are under constant threat from poaching and human encroachment, this study could be useful for the conservation management of the species'.

The study consisted of the following objectives:

- To determine areas of suitable climate for the Eastern Black and Greater One-Horned rhinoceros populations within Laikipia and Assam using climate predictions for the future based on different climate scenarios, using maximum entropy modelling.
- To compare the suitability models of the specific study sites with the historic range of each species, to identify any potential suitable climate at a wider scale.
- To discover the important and influential variables of the climate models, that could be of use in conservation management.
- To determine if Save the Rhino International is allocating its resources into areas that will be of conservation importance in the future.

This study will allow conservation managers to implement climate change into their strategies, as a way of conserving the populations of *D. b. michaeli* and *R. unicornis*, by using the models produced as a guide for locating potential new protected areas, and assessing the viability of current locations.

1.3 Thesis Structure

Chapter 2 goes into detail about the impacts that climate change is having on the environment, as well as describing the various climate change scenarios available. It also describes the conservation status of each rhinoceros species – *D. bicornis* and *R. unicornis* – and the two main focus areas for this study, Laikipia and Assam.

The methods are explained in Chapter 3, describing the use of ArcMap and MaxEnt in modelling climate suitability. This is followed by the statistical tests carried out, which include calculating the accuracy of the models, identifying the influential environmental variables, and establishing a threshold of suitable climate.

Chapter 4 presents the results of the study, from the climate suitability models created to the graphs indicating the minimum climate suitability threshold.

Finally, Chapter 5 places the results in context for conservation management, examines the limitations of the study and discusses the potential for further research.

2. Background

2.1 Earth's Changing Climate

Atmospheric carbon dioxide (CO_2) has fluctuated throughout the Earth's history (IPCC, 2001a). This variation is believed to be the main cause of geological climate change (Berner, 1991; Tajika, 1998). However, since the industrial revolution in the late 18^{th} and early 19^{th} centuries, the amount of atmospheric greenhouse gases (GHGs) has increased (IPCC, 2001a), largely due to human activity (Crowley, 2000). GHGs include CO_2, methane, nitrous oxide, ozone, water vapour and chlorofluorocarbons (CFCs) (Crowley, 2000; IPCC, 2001a). Nevertheless it is CO_2 that has the biggest influence on climate change (IPCC, 2001a), due to the volume that is released.

Before anthropogenic influences caused the planet to warm up, animals and plants had evolved and adapted to the changing conditions (Thomas *et al*., 2004). Unfortunately, as the rate of climate change speeds up, the ability of the Earth's flora and fauna to adapt diminishes (Grabherr *et al.*, 1994; IPCC, 2001b). On the other hand, climate change is not the only problem. Further human impacts on the environment include human encroachment, habitat loss, overharvesting and invasive species (Millennium Ecosystem Assessment, 2005).

The main causes of increasing CO_2 are the burning of fossil fuels and the clearing of natural vegetation, such as rainforests (IPCC, 2001a). Deforestation removes an important carbon sink; an environmental reservoir that absorbs carbon which has been released into the atmosphere, thus removing it from the carbon cycle (Park, 2008). By destroying a carbon sink, the carbon stored in it is released into atmospheric CO_2. As the atmospheric carbon increases, it allows UV rays and heat to enter but prevents the rays and heat from escaping. This process is known as the greenhouse effect, and is causing global climate change.

The effects of climate change on Earth's flora and fauna has become an important research topic, with studies of climate range responses on plants (Grabherr *et al.*, 1994), butterflies (Parmesan, 1996; Hill *et al.*, 1999; Parmesan *et al.*, 1999), birds (Thomas and Lennon, 1999) and mammals (Hersteinsson and MacDonald, 1992). The general consensus from studies indicates that species are shifting their ranges north or towards the poles (Parmesan, 1996; Parmesan *et al.*, 1999; Thomas and Lennon, 1999). While there are several factors that may result in the range shift of the studied species, such as habitat loss, substantial evidence is indicating climate change as playing a major role (Grabherr *et al.*, 1994; Parmesan, 1996; Hill *et al.*, 1999; Parmesan *et al.*, 1999; Thomas *et al*., 2004).

As the impacts of climate change on the environment become more evident, the desire to model future potential outcomes increases. Climate change scenarios were created by the IPCC to study possible climate change, and have been used for species projections as well as many other research topics. Four scenarios – A1, A2, B1 and B2 – were created based on variables such as population growth, energy technology, and economic development (IPCC, 2000). Each scenario represents an alternative future, ranging from a fossil fuel intensive future to an environmentally sustainable world, described as follows:

- A1 scenario: very rapid economic growth, global population that peaks mid-century and then declines and rapid introduction of more efficient technologies.
- A2 scenario: regionally oriented economic development, continuously increasing global population (15 billion by 2100) and slow, fragmented technological change.
- B1 scenario: rapid change in economic structures towards service and information, similar global population trend as scenario A1, and introduction of clean and resource-efficient technologies.
- B2 scenario: intermediate levels of economic development, increasing global population at a lower rate than A2 (10.4 billion by 2100), and less rapid but more diverse technological change than B1 or A1.

A more detailed description of the four scenarios can be found in (IPCC 2000).

Many species are affected by climate change. One particular group of species that are being affected by climate change are the rhinoceroses. As mega herbivores, rhinoceroses need large areas of habitat in order to support viable populations (Amin *et al*, 2006). As an "umbrella" species, focusing on protecting the rhinoceros acts to conserve hundreds of other species within the same habitat (SRI, 2009).

2.2 Rhinoceros Study Species

2.2.1 *Diceros bicornis*

As the smaller of the two African species of rhinoceros, the black rhinoceros (*Diceros bicornis*) has several morphological differences from the white rhinoceros (*Ceratotherium simum*), such as a smaller head and a prehensile lip (Watt, 1998; Rhino Resource Centre, 2009). This is because *C. simum* is a grazer, while *D. bicornis* is a browser. The hooked lip allows *D. bicornis* to feed on woody plant species, such as Acacia (IUCN, 2009). *D. bicornis* (Figure 2.1) had a wide range of habitat from savannah and tropical bushland, to the desert areas of Namibia (IUCN, 2009) and subalpine heathlands (Amin *et al*, 2006).While there has been some debate about the inferred historic range of *D. bicornis* (Rookmaaker, 2004), the Global Mammal Assessment (IUCN, 2008) states that the native range of *D. bicornis* extended from South Africa and Namibia, along the east coast up to Kenya, and may include Cameroon, shown in Figure 2.2 (IUCN, 2009). However, currently, *D. bicornis* is constrained to a few scattered wildlife reserves and sanctuaries throughout Namibia, South Africa, Kenya, Zimbabwe and Tanzania (ZSL, 2009). There are an estimated 3,610 individuals of *D. bicornis* remaining (ZSL, 2009).

The main threat to *D. bicornis* is poaching for the valuable rhinoceros horn (IUCN, 2009). Due to the range constraints, the current threats, and the very low numbers, the four sub-species of *D. bicornis* are listed as "Critically Endangered" on the IUCN Red List (IUCN, 2009). *D. bicornis longipes* (Western Black Rhino) has a population of less than 50 and is listed as "Critically Endangered (Possibly Extinct)" (IUCN, 2009). The *D. bicornis michaeli* is found in small protected sanctuaries in Kenya, and is also listed as "Critically Endangered" (IUCN, 2009). *D. bicornis bicornis* is classified as "Vulnerable", the total number of mature adults is known to be less than 1000, and can be found in South-western Africa (IUCN, 2009). The final sub-species of *D. bicornis* – *D. bicornis minor* – is also listed as "Critically Endangered", and is mainly found in South Africa.

Figure 2.1: The black rhinoceros, *Diceros bicornis* (© Renaud Fulconis).

Figure 2.2: The historic range of *Diceros bicornis* (IUCN, 2009).

2.2.2 *Rhinoceros unicornis*

The Greater One-Horned rhinoceros (*Rhinoceros unicornis*), also known as the Greater One-Horned rhinoceros (Figure 2.3), was once found throughout the floodplains of the Ganges, Brahmaputra and Sindh rivers, as shown in Figure 2.4 (Amin *et al*, 2006). Now, *R. unicornis* is only found in protected areas in India and Nepal, with the majority of those in India found in the Assam region. There are an estimated 2,800 surviving individuals (IRF, 2009). *R. unicornis* prefers alluvial grasslands, but has also been found to occur in adjacent swamps and forests (IUCN, 2009). While the main food source is grass, fruit, leaves, shrub and tree branches do comprise a part of the diet. The IUCN Red List (IUCN, 2009) classifies *R. unicornis* as "Vulnerable", as the rhinoceros populations are under constant threat from human population growth and development of the alluvial plains, as well as from poaching of the rhinoceros horn for use in traditional Chinese medicine.

Figure 2.3: The Greater One-Horned rhinoceros, *Rhinoceros unicornis* (© Renaud Fulconis).

Figure 2.4: The *Rhinoceros unicornis* was once found in Northern India, Southern Nepal and Eastern Pakistan (Amin *et al*, 2006).

2.3 Save the Rhino International

Save the Rhino International (SRI) is a fundraising organisation which works to conserve populations of rhinoceroses in both Asia and Africa (Save the Rhino International, 2009). The main objectives of SRI include providing financial aid and in-kind support for in situ conservation projects, encouraging the sharing of skills and information between rhinoceros projects and to measure and improve the effectiveness of their grant-making activities. While SRI has traditionally concentrated on conserving *Diceros bicornis* (the black rhinoceros) in Africa, it has recently expanded its focus to include all five species of rhinoceros. The latest rhinoceros species to have funding aid from SRI is *Rhinoceros unicornis* –the Greater one-horned rhinoceros (Save the Rhino International, 2009).

SRI understands that the survival of wildlife is connected to the human communities that share the same habitat. As an organisation, SRI aim to deliver long-lasting benefits to rhinoceroses, ecosystems and to the people living in the area (SRI, 2009).

Due to SRI's history with *D. bicornis,* there are many more ongoing programmes involving the black rhinoceros, compared to the four other species. The conservation activities vary with each location; in Namibia the activities include monitoring, community conservation and translocations, while in Laikipia, Kenya, the focus shifts to environmental education, community conservation, local capacity building and tourism development; while virtually all the programmes supported by SRI include a heavy emphasis on anti-poaching and monitoring. This broad range of actions is a holistic approach, which leads to well-rounded conservation programmes, involving the local people to help protect the rhinoceros species.

The activities that SRI fund with regards to conserving the *R. unicornis* are equally diverse. Although SRI has only been working with the Greater One-Horned rhino since 2006, a large quantity of work has been carried out to ensure the protection of *R. unicornis,* through the "Indian Rhino Vision 2020" programme, a joint effort by Assam Department of Forests and Environment, Worldwide Fund for Nature-India, US Fish and Wildlife Service and the International Rhino Foundation (SRI, 2009). The programme primarily involves the translocation of *R. unicornis* into reserves that have low populations, or where former populations have been eradicated by poaching, yet community conservation is still present.

SRI is also committed to evaluating the allocation of their funding, and aim to ensure that substantial financial aid is being injected into the right areas, in order to conserve viable rhinoceros populations in Africa and Asia.

2.4 Study Sites

2.4.1 Laikipia, Kenya

D. bicornis can be found in various wildlife reserves and sanctuaries throughout southern and eastern Africa, such as the Hluhluwe-iMfolozi Game Reserve in South Africa, Lowveld Conservancies in Zimbabwe, the North Luangwa Conservation Programme in Zambia and the Selous Game Reserve in Tanzania. All of the above mentioned projects received funding from SRI. However, Laikipia has a conservation focus on the Eastern black rhinoceros (*D. b. michaeli*) and is vitally important, as it contains 50% of Kenya's black rhinoceros population. The focus in Laikipia is currently on environmental education and community conservation, in order to reduce the human-wildlife conflict over natural resources, such as access to water and land for agriculture, a common problem in Africa.

The Laikipia District is situated to the northwest of Mount Kenya, covers an area of 9,500km^2, and forms part of the Ewaso ecosystem; mountains, lower highlands and lowlands constitute the topography of this semi-arid river basin (Ngigi *et al.*, 2007). The land within the district is used for cattle-rearing, as a source of food and income (Laikipia Wildlife Forum, 2009). The terrain of the Laikipia District is a conversion of the well-watered central highlands to the south and the semi-arid steppe to the north (Mpala Community Trust, 2006). Figure 2.5 shows the location of Laikipia and the selected reserves, in relation to Africa.

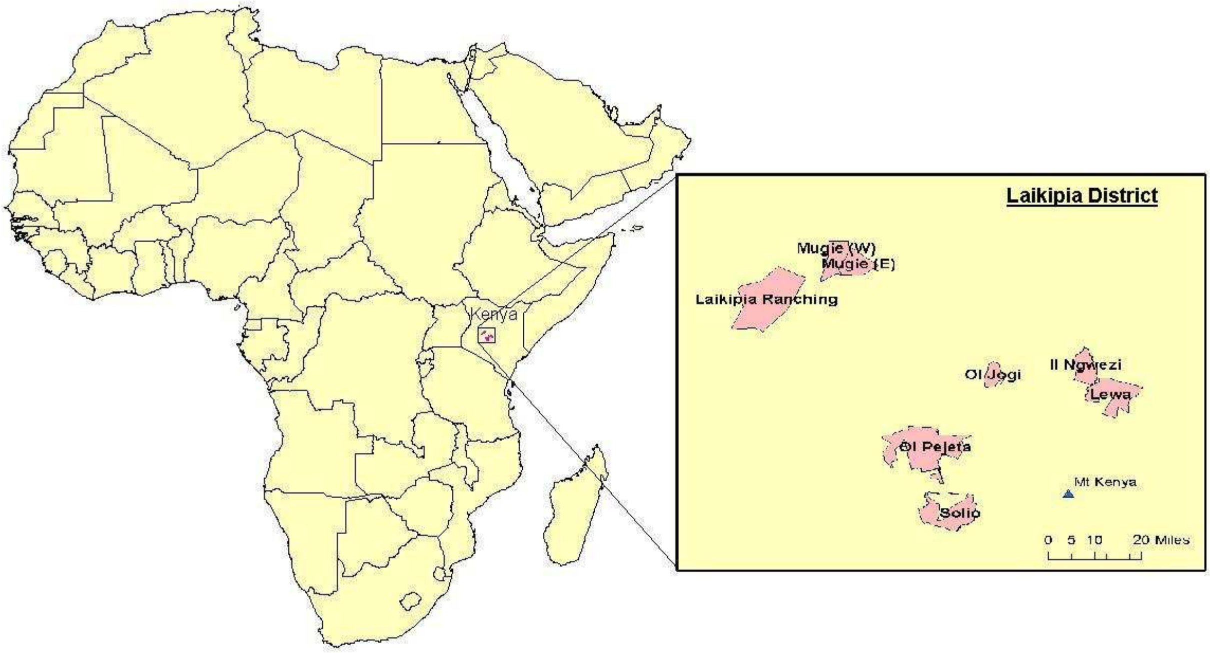


Figure 2.5: The location of the Laikipia region, in relation to Africa and the protected range of *D. b. michaeli* within Laikipia – Mugie Ranch, Laikipia Ranching, Ol Jogi, Il Ngwezi, Lewa and Solio.

2.4.2 Assam, India

The Assam region in India covers an area of 78,523km^2, composed of plains and river valleys (M'Cosh, 1837). The protected range of *R. unicornis* can be seen in Figure 2.6, with the SRI funded Manas and Kaziranga National Parks near Bhutan. As Kaziranga has one of the largest protected populations of *R. unicornis*, it is a valuable asset to Assam and SRI. Poaching revolving around ethnic conflicts and the subsequent poor law-enforcement (Save the Rhino International, 2009) led to the eradication of the entire Greater One-Horned rhinoceros population within Manas National Park (Table 1.2), during the 1990s (Syangden *et al.*, 2008). With an area as large as Manas National Park, a viable population of *D. bicornis* could be established, so long as strict anti-poaching and monitoring patrols were in place. The Indian Rhino Vision 2020 (Syangden *et al.*, 2008) aims to translocate 20 – 30 individuals from a source population into Manas, in order to create a viable sub-population within the National Park. The ultimate aim is to increase the population of *R. unicornis* in the Assam region from 2000 individuals to 3000 by 2020 (SRI, 2009).

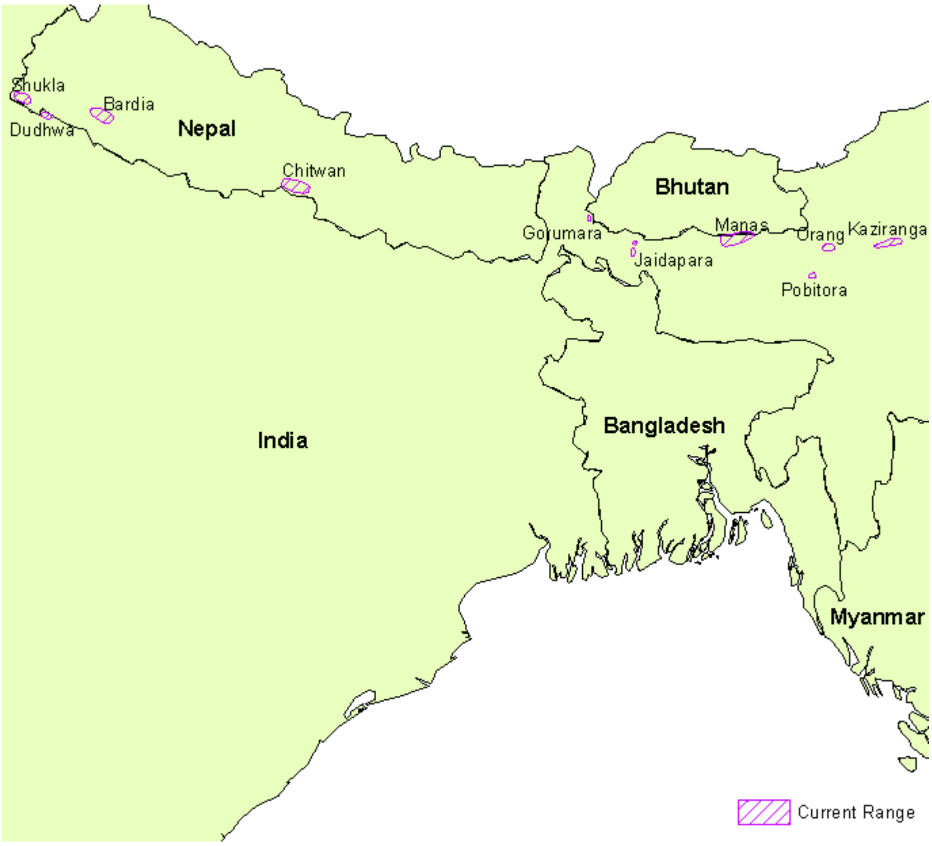


Figure 2.6: The current distribution of *R. unicornis* within the Indian sub-continent. The two reserves of particular interest to SRI are Manas and Kaziranga, in Assam, India.

2.5 Species Distribution Modelling

Relating species presence, or absence, to environmental variables enables species distribution models to provide comprehensive predictions of distributions (Elith *et al*., 2006). The ability to model the distribution of a species is an important technique that is required for several different applications for ecology and conservation (Graham *et al*., 2004), such as determining the impact of climate change (Thomas *et al*., 2004) or the spread of invasive species (Thuiller *et al*., 2005).

Several different modelling methods exist for habitat suitability. Most of these methods assume environmental equilibrium between the known species distribution and their environment, creating a static model (Guisan and Zimmermann, 2000). Statistical approaches to modelling habitat suitability are abundant, and include Generalised Additive Models (GAMs), Classification and Regression Tress (CART), environmental envelope models, such as BIOCLIM and maximum entropy modelling, such as MaxEnt (Guisan and Zimmerman, 2000; Elith *et al*., 2006; Phillips *et al.*, 2006; Lahoz Monfort, 2008). The difference between these approaches is the modelling technique. GAMS use regression analysis, CART uses classification techniques, BIOCLIM determines where a species-specific environmental envelope should be in environmental space, and MaxEnt uses entropy.

Many of these habitat suitability models have been tested and compared (Elith *et* al, 2006; Hernandez *et al*,2006), determining the best performing model for different situations, including small sample size and broad range predictive ability.

2.6 Forecasting Future Species Distribution

Species distribution models can be used to predict the distribution in the future. By using the current pattern of distribution, and the environmental data found at the presence points, the models attempt to map areas where high suitability is found in the future. Therefore, the model assigns a value to areas of high suitability, for the current distribution. Then, using this information, the model finds areas with the same value in the future, and qualifies them as high suitability. In order to do this, predicted environmental variables of future years are required.

2.7 Assessing Model Performance

Distribution models could be too general, where a species could be found everywhere, or too specific, where a species is only found in one place. In order to account for this, models need performance assessments, which can help determine how accurate the model is on predicting distribution patterns.

The Receiver Operating Characteristic (ROC) curve, originally used in signal processing (Swets, 1996) indicates the performance of a model between specificity and 1-sensitivity, or the omission error. (Swets *et al*, 2000). The specificity is also known as the true negative rate, while the sensitivity is sometimes referred to as the true positive rate (Gonen and Heller, 2006). However, the true negative rate is only used when absence data is available. If absence data is not available, then sample background data is used, which is also known as “pseudo-absence” (Stockwell and Peters, 1999). Ultimately, the ROC graph indicates the form of the trade-off between identifying true positives and true negatives (Swets *et al*, 2000).

Bamber (1975) determined that the Area Under the Curve (AUC), of the ROC, indicates the probability of the model ranking a pair of data points, such as species presence and background data. A value of 0.5 is assigned to the AUC of a random prediction model, with the value ranging from 0 – 1 (Phillips *et al.*, 2006). When only presence data is used, the maximum achievable AUC becomes less than 1 (Phillips *et al.*, 2006). The AUC can be used to determine how accurate the model is at predicting the appropriate outcome (Phillips *et al.*, 2006).

3. Methods

3.1 Mapping Reserves and Ranges

Current reserve locations, as extent of occurrence vector polygons, were obtained for each rhinoceros species. The locations of protected areas for *R. unicornis* were acquired from the World Data Base of Protected Areas (http://www.wdpa.org), while the current locations of *D. bicornis* were received as a shapefile of game reserves and sanctuaries from Mpala Research Centre and Centre for Training and Inegrated Research in ASAL Development (CETRAD).

The historic ranges of both *D. bicornis* and *R. unicornis* were also mapped using GIS. The historic range for *D. bicornis* was acquired from the Global Mammal Assessment (IUCN, 2008), while the range for *R. unicornis* was digitised from Amin et al, 2006.

3.2 BioClim Data

Global 10 arc-minute Bioclim (Houlder et al, 2000) and altitude layers were downloaded from the WorldClim website (http://www.worldclim.org), from the ESRI grid section. The two regions of interested, Africa (38N, 18W, 60E, 35S) and India (37N, 60E, 101E, 5N), were extracted from the global layer and saved as ascii grid files.

The future climate prediction data, created from the Hadley Climate Model version 3, was downloaded from the WorldClim website. Using a readily available script (Hijmans *et al*., 2005), from the WorldClim website (http://www.worldclim.org), the 19 Bioclim variables (Table 3.1) were calculated from the WorldClim monthly variables (maximum temperature, minimum temperature, mean temperature and precipitation). Isothermality is the mean diurnal range divided by the temperature annual range (Lees, 2007).

3.3 Species Occurrence in Cells

Species distribution within the 10 arc-minute grid were recorded by assessing the overlap of historic and protected range with grid cells. The identities of cells with species presence were recorded in CSV files, in order to be used in MaxEnt.

3.4 Maximum Entropy Climate Suitability Modelling

A common programme for modelling species distribution is MaxEnt. Maximum entropy distribution considers a species to be equally distributed across environmental variables. This equal distribution is then constrained to a particular range of environmental variables, such as temperature, based on presence data (Phillips *et al*., 2006). The constraints are established as the expected value of each environmental variable that should match its empirical average (Phillips *et al.*, 2006; Elith *et al.*, 2006). The effect of the constraints on the model can be controlled using regularisation, which determines how spread out the distribution can be, within the model.

BioClim Variable Code	Description
Temperature	
Bio1	Annual Mean Temperature
Bio2	Mean Diurnal Range
Bio3	Isothermality
Bio4	Temperature Seasonality
Bio5	Maximum Temperature of Warmest Month
Bio6	Minimum Temperature of Coldest Month
Bio7	Temperature Annual Range
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Precipitation	
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter

Table 3.1: The definitions of all 19 bioclim variables, used as environmental layers for modelling in MaxEnt.

MaxEnt, which is freely downloadable from http://www.cs.princeton.edu/~schapire/maxent, has been critically assessed and has been commended for its performance at species level and its ability to “fit complex functions between response and predictor variables” (Elith *et al*, 2006) It is also a highly-recommended programme for small data samples (Hernandez *et al*, 2006). For these reasons, MaxEnt was chosen to model habitat suitability for the two study species of rhinoceros.

Splitting the data into training and test data is a common practice (Phillips *et al.*, 2006). Training data is used to create the model, while test data is used to see if the data fits the model, in that presence points should be found in high suitability areas. Test data uses the true predictive power of MaxEnt, and gives a more accurate indication of how well the model performed. As described in Phillips *et al.*, 2006, environmental layers and sample data were input into MaxEnt, and a random test percentage of 25% was used. Future predictions were projected by inputting the appropriate folder name into “Projection Layers Directory”.

The jackknife option was selected, which determins the capability of the model with only and without each individual variable, indicating the most influential variable on the model created through MaxEnt. Jackknife works by sequentially dropping each variable from the model, to determine how much information the model can obtain without that particular variable, or with that single variable.

The ROC and AUC were also determined through MaxEnt. The graphs produced in MaxEnt for the ROC and AUC have an x axis (1-specificity) that shows the fraction of the area selected. As you move along the x axis, from left to right, you increase the area selected, which in turn will account for more and more of the presence observation data. Since the proportion of omitted data, along the y axis (1 – omission rate), decreases as area increases, the axis will rise until it reaches 1 (no observations omitted).

The climate suitability models are also affected by the model gain. The gain shows how closely the model is concentrated around the presence samples, indicating whether the average likelihood of the presence samples is higher than that of a random background pixel (Phillips, 2005). As MaxEnt runs, each step of the algorithm increases the model gain by adjusting the coefficient for a single feature, such as precipitation (Phillips *et al.*, 2006). MaxEnt then assigns the increase in gain to the environmental variable(s) that the feature depends on, creating a percentage of variable contribution.

For each environmental variable, a response curve is created. Response curves show how the variables affect the MaxEnt prediction, which indicate the values of each variable that is suitable for the study species – i.e. the optimum temperature or altitude.

3.5 Statistical Analysis

R (R Development Core Team, 2009) was also used to calculate a correlation accounting for spatial autocorrelation (Clifford *et al*, 1989), which includes spatial information when running statistical analysis. The correlation looked at the current high suitability areas and determined if they were still suitable in the future projections. In order to make use of this statistical test, the "R spatial projects" package was required (Pebesma and Bivand, 2005). The Clifford correction (Clifford *et al.*, 1989) of the correlation coefficient (r^2) for spatial autocorrelation was used to compare the current climatic conditions and habitat suitability with future predicted climatic conditions.

Cluster dendrograms were then created with R version 2.9.1 (R Development Core Team, 2009) to determine the different pieces of information being supplied by the environmental variables, using the "R spatial projects" package (Pebesma and Bivand, 2005). The dendrograms created showed which variables were supplying the model with similar information, and which of those were supplying entirely different information.

The Kappa threshold for habitat suitability was determined using R version 2.9.1 (R Development Core Team, 2009). Packages used in R, in order to run the Kappa script (see Appendix A), were the "R spatial projects" package (Pebesma and Bivand, 2005) and the "visualising categorical data" package (Meyer *et al.*, 2009). Kappa (Cohen, 1960) measures agreement between predicted and observed data using a confusion matrix. For this study, the Kappa determined whether the distribution data agreed with the model for species presence. This value is then projected onto an ROC curve at the point where agreement is highest.

4. Results

4.1 Maximum Entropy Climate Suitability Models

Several models were produced in MaxEnt, to determine the suitability of climate for *D. bicornis* and *R. unicornis* based on the current and historic ranges. These models show the range of climate from unsuitable to highly favourable, using a logistic output. The raw value of the model is an exponential function of the environmental variables (Phillips, 2005); hence logistical function was used, in order to keep climate suitability between 0 and 1.

The models, using the current climate envelope of the historic and protected ranges, project the areas of suitable climate in the future. The climate suitability values were separated into five classifications; 0 – 0.2, 0.2 – 0.4, 0.4 – 0.6, 0.6 – 0.8, and 0.8 – 1. These five classifications were chosen in order to supply enough detail about the suitability within the models, without making the model too complicated with many classifications. This was kept constant for all suitability models.

4.1.1 *Diceros bicornis* Climate Suitability

Figure 4.1 shows the climate suitability for *D. b. michaeli* based on its protected distribution, within Laikipia (Figure 4.1(a)), for the climate scenarios A2 and B2, for the years 2020 (Figure 4.1 (c) and (d)), 2050 (Figure4.1 (e) and (f)) and 2080 (Figure 4.1 (g) and (h)). These are contrasted with the climate suitability for *D. bicornis*, for the same climate scenarios, based on its historical distribution throughout Southern and East Africa (Figure 4.2).

The protected range of *D. b. michaeli* appears to have a severe constraint on the suitable climate in future projections (Figure 4.1). The highest suitability of climate is mainly concentrated around the protected range sites in Laikipia, but is also found in Ethiopia to the North. However, the area of highly suitable climate disappears rapidly, and only low climate suitability can be found by 2080, for both A2 and B2 climate scenarios (Figure 4.1 (g) and (h)). The B2 climate scenarios for 2020, 2050 and 2080 (Figure 4.1 (d), (f) and (h), respectively), indicate a much slower decrease in climate suitability area, compared to the A2 scenario (Figure 4.1 (c), (e) and (g)), with the suitable area in Ethiopia remaining larger, albeit with only average climate suitability.

This can be contrasted to the climate suitability maps for the historic range of *D. bicornis* (Figure 4.2), which show no areas of highest climate suitability. Instead, the maps indicate a large area of average climate suitability that covers Southern and Eastern Africa, with some patches of higher climate suitability. However in 2080, most of the high suitability areas have disappeared in the

A2 scenario, with the area of average climate suitability also shrinking; in the B2 scenario, the average climate suitability area has receded much less and a few higher suitability areas can still be found.

4.1.2 *Rhinoceros unicornis* Climate Suitability

The climate suitability for *R. unicornis*, based on its protected distribution, is shown in figure 4.3, for both predicted climate scenarios – A2 and B2 - and years – 2020, 2050, and 2080. The suitable climate areas for *R. unicornis,* based on its historic distribution, for each predicted climate scenario, are shown in Figure 4.4.

The protected range of *R. unicornis* does not appear to have as much of a constraint on the suitable climate areas (Figure 4.3) as seen in *D. bicornis* (Figure 4.1). There is quite a substantial amount of high suitability climate suitability along the protected area region, which appears to increase in some areas – such as in Assam between current climate and projections for 2080. The A2 scenario (Figure 4.3 (c), (e) and (g)) has a larger area of high suitability habitat compared to the B2 scenario (Figure 4.3 (d), (f) and (h)) for the protected areas of *R. unicornis*.

This is comparable to the climate suitability maps based on the historic range of *R. unicornis* (Figure 4.4) which show a similar trend to the historic range suitability maps of *D. bicornis* (Figure 4.2) in that there is no high suitability climate suitable habitat throughout the region, but a vast area of average suitability with a few patches of higher suitability prominent throughout the historic range. By 2080 for both the A2 (Figure 4.4 (g)) and B2 (Figure 4.4 (h)), the area of suitable area has diminished dramatically, covered by mostly low climate suitability. Despite the similar trend for the A2 and B2 scenario, by 2080 the B2 scenario has a larger area of average habitat, than the A2 scenario; B2 also has a few patches of higher climate suitability, while A2 has none.

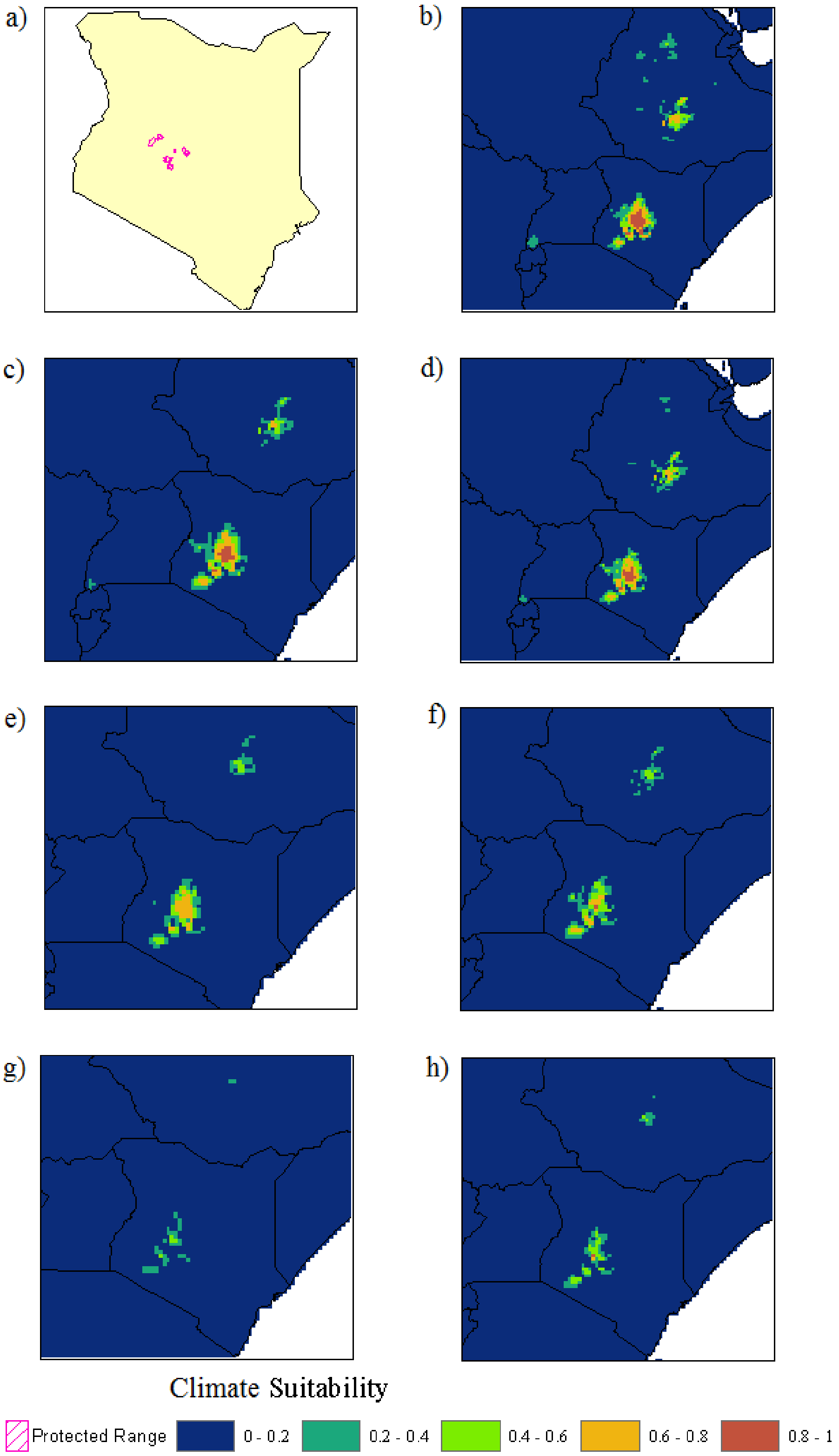


Figure 4.1: The protected range of *D. b. michaeli* within the Laikipia District (a) is comparable to the current climate envelope (b) of the rhinoceros populations. The suitable climate for these rhinoceros based on the protected range for each climate scenario has been determined; (c) A2 2020, (d) B2 2020, (e) A2 2050, (f) B2 2050, (g) A2 2080 (h) B2 2080.

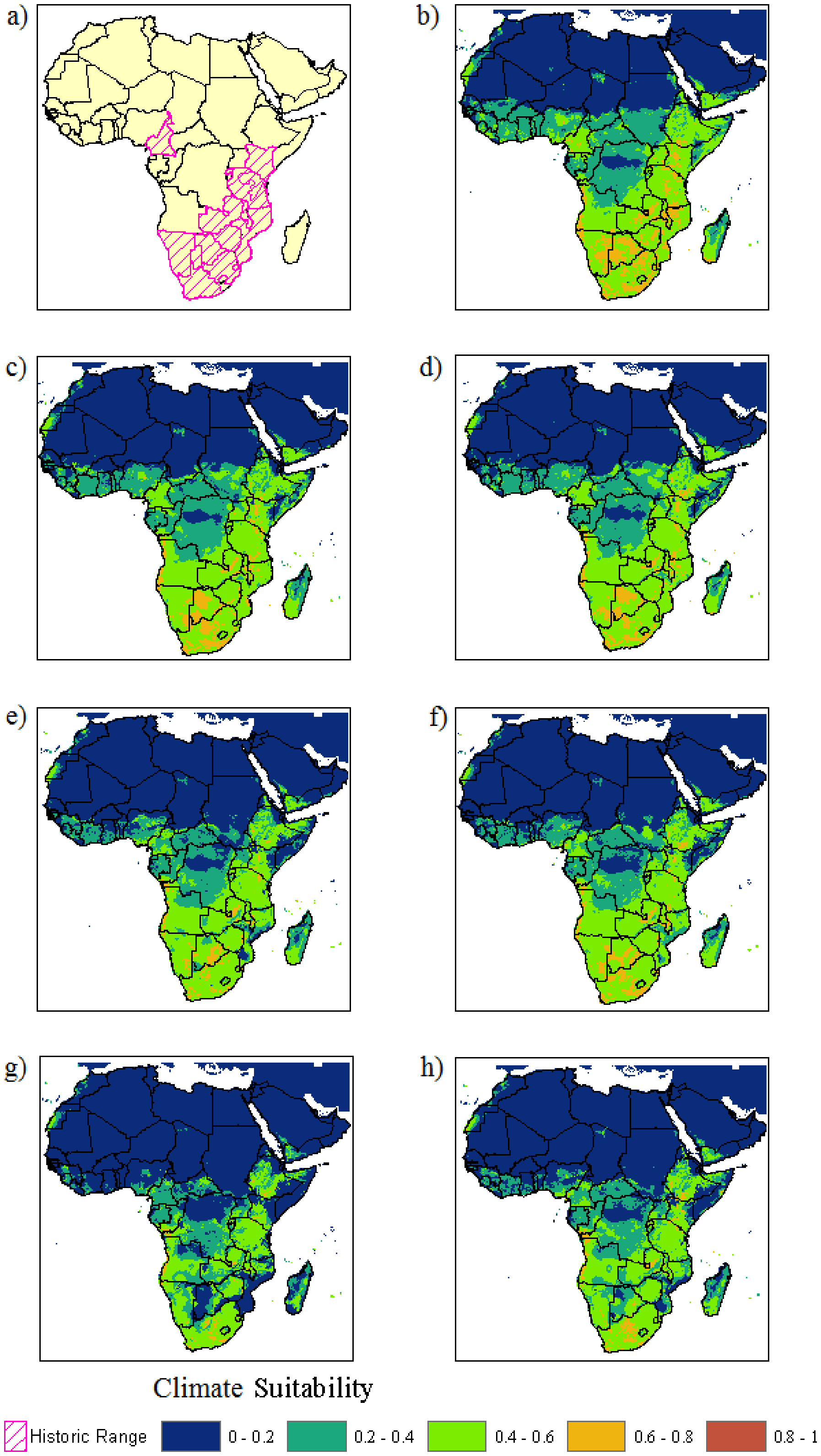


Figure 4.2: The historic range of *D. bicornis* within the Laikipia District (a) is comparable to the current climate envelope (b) of the entire range. Each climate scenario model indicates the most suitable climate for the *D. bicornis* based on the historic range; (c) A2 2020, (d) B2 2020, (e) A2 2050, (f) B2 2050, (g) A2 2080 (h) B2 2080.

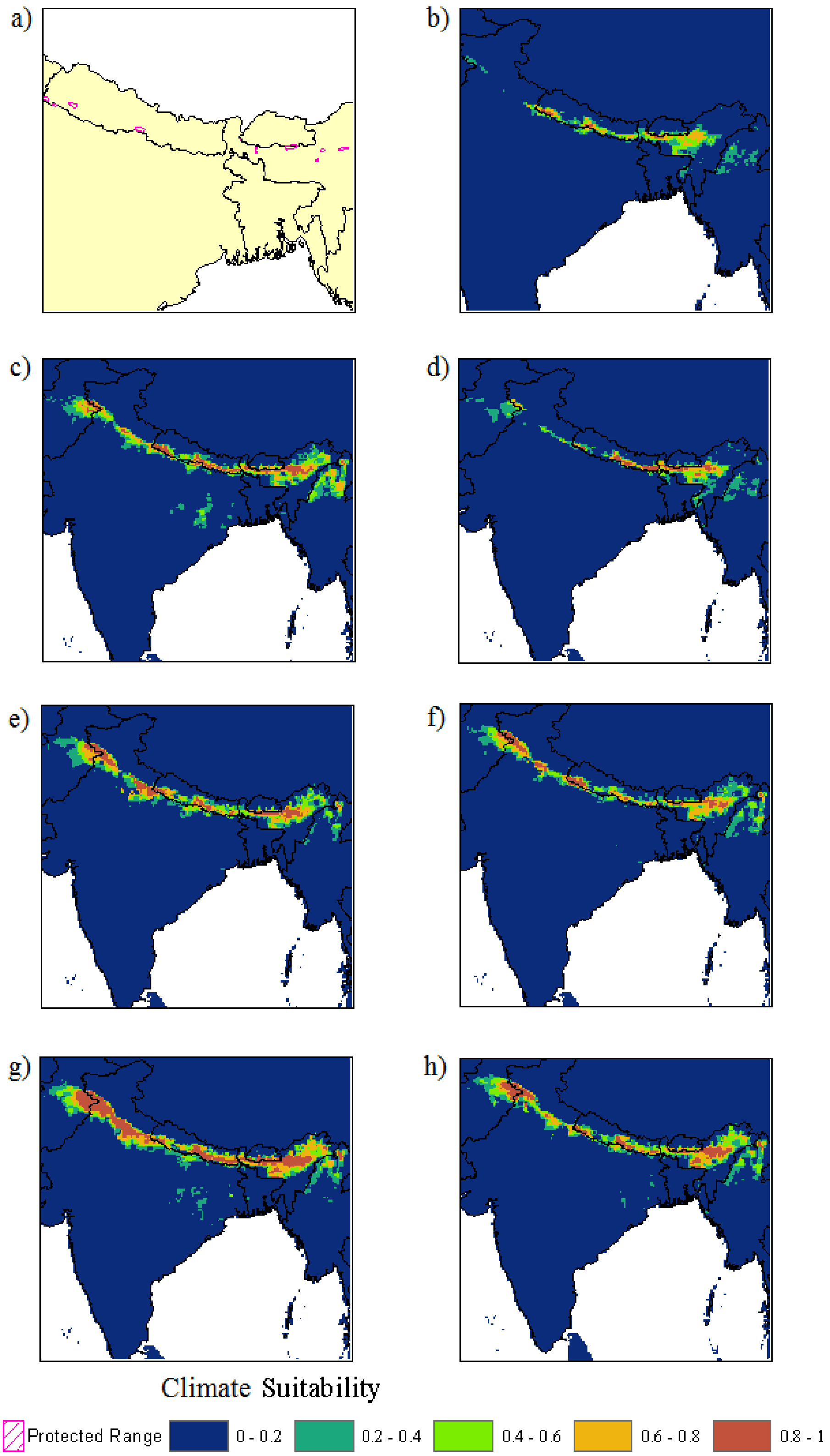


Figure 4.3: The protected range of *R. unicornis* within the Indian sub-continent is shown in (a). The current climate envelope of the rhinoceros populations (b) is compared to the different climate scenario models produced; (c) A2 2020, (d) B2 2020, (e) B2 2050, (f) B2 2050, (g) A2 2080 (h) B2 2080.

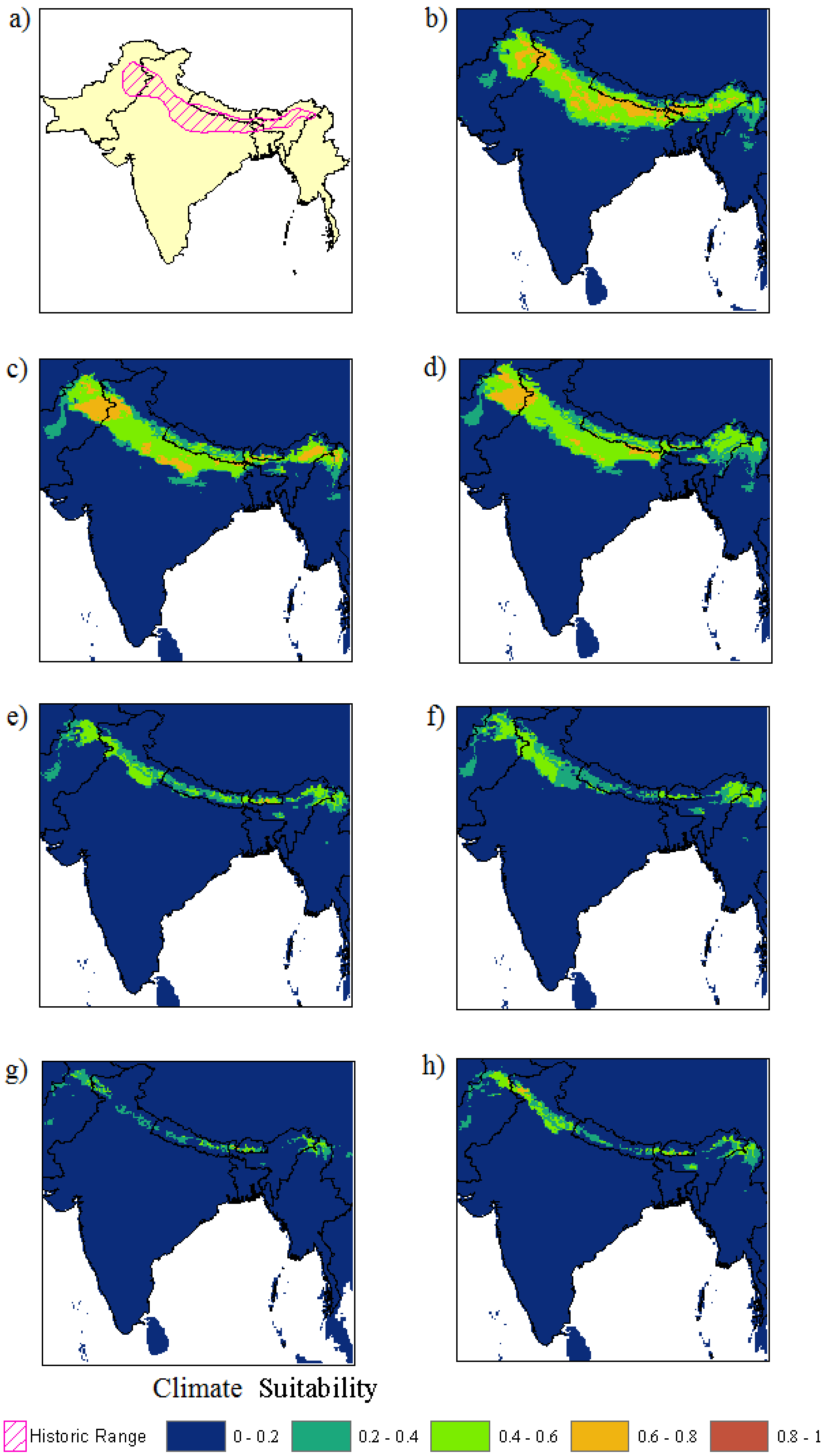


Figure 4.4: The historic range of *R. unicornis* is shown in (a), while the current climate envelope (b) is compared to the climate scenario models created based on the historic range of *R. unicornis*; (c) A2 2020, (d) B2 2020, (e) A2 2050, (f) B2 2050, (g) A2 2080 (h) B2 2080.

4.2 Statistical Analysis

4.2.1 Receiver Operating Characteristic (ROC) and Area under the Curve (AUC)

The ROC was determined using MaxEnt for each species using both protected and historic range, based on the current climate envelope (Figure 4.5). This distinguishes the performance of the model at all thresholds (Phillips *et al*., 2006), simply showing the trade-off between area selection and accuracy of the model to make predictions as the observed area increases.

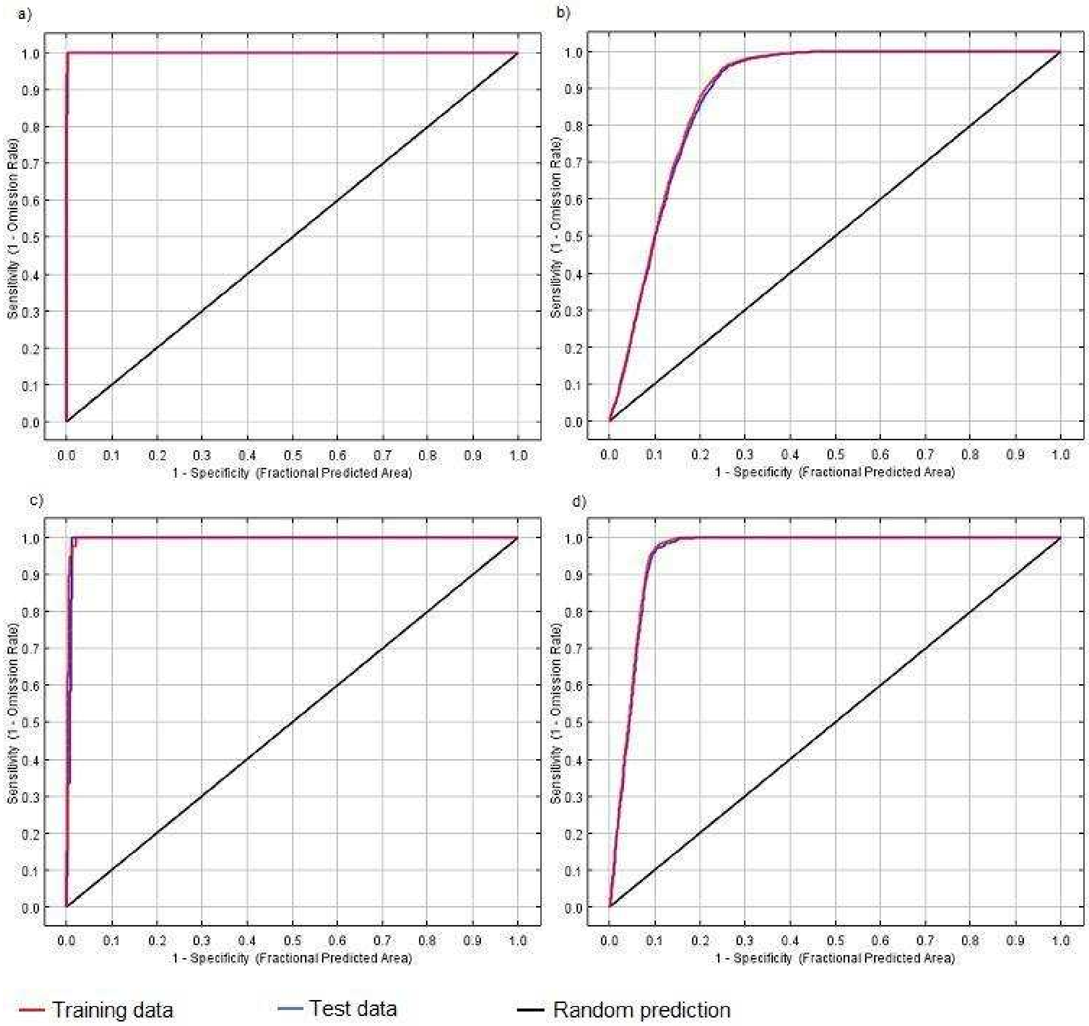


Figure 4.5: The receiver operating characteristic (ROC) curves for *D. bicornis* protected range (a), *D. bicornis* historic range (b), *R. unicornis* protected range (c), and *R. unicornis* historic range (d). The red line indicates the ROC of the training data, the blue line shows the ROC of the test data, and the black line is the value of random prediction.

Figure 4.5 (a) and (c) show that the model is able to include all the data within a small fraction of the total study area. This is most likely due to the small sample size for the protected presence data of both *D. bicornis* and *R. unicornis*.

The AUC is a single number that is a product of the ROC analysis (Table 4.1), by calculating the area under the ROC curve. As no absence data was used in this study, the fraction of absences predicted is replaced with the fraction of the total study area predicted (Phillips, 2005). Phillips *et al.* (2005) describe the AUC as a measure of model performance, independent of any particular threshold. This means, that a higher AUC value indicates a better performing model, based on the information provided. The high AUC values of >0.9 (Table 4.1) indicate that the model was exceedingly accurate in predicting habitat suitability.

Species	**Range**	**AUC value**	
		Train	**Test**
D. bicornis	Protected	0.9999	0.9998
	Historic	0.8873	0.8844
R. unicornis	Protected	0.9971	0.9943
	Historic	0.9557	0.9540

Table 4.1: The Area under the Curve (AUC), calculated from the receiver operating characteristic (ROC), that defines the performance of the model at all available thresholds.

4.2.2 Variable Importance

The jackknife statistical test was run through MaxEnt, to measure variable importance for each climate suitability map, as explained in Section 3.5. This shows how well the model runs without a particular variable, or with only a particular variable. The jackknife test was run on the protected and historical models for the current climate variables, for both *D. bicornis* and *R. unicornis* (Figure 4.6). Figure 4.6(a) indicates that the single most influential variable for the model of protected distribution of *D. bicornis* is temperature seasonality (bio4), while the variable that provides the most information to the model is precipitation of coldest quarter (bio19). The single most influential variable for the model of historic distribution of *D. bicornis* is precipitation of warmest quarter (bio18), this is the same variable that supplies the most information to the model (Figure 4.6(b)). In the model for the protected distribution of *R. unicornis* annual mean temperature (bio1) is the single most influential variable, and precipitation of driest month (bio14) is the variable that contains the most information (Figure 4.6(c)). For the historic distribution of *R. unicornis*, the jackknife statistical test indicates that the most important variable for the model is mean temperature of the coldest quarter (bio11), while all variables have a similar amount of information for the model (Figure 4.6(d)).

The general pattern seen in Figure 4.6 is that no singular variable is crucial to the model, as the information supplied by each variable is of similar importance. However, some variables perform reasonably well individually, indicating a sufficient amount of information is present in these particular variables to allow the model to perform.

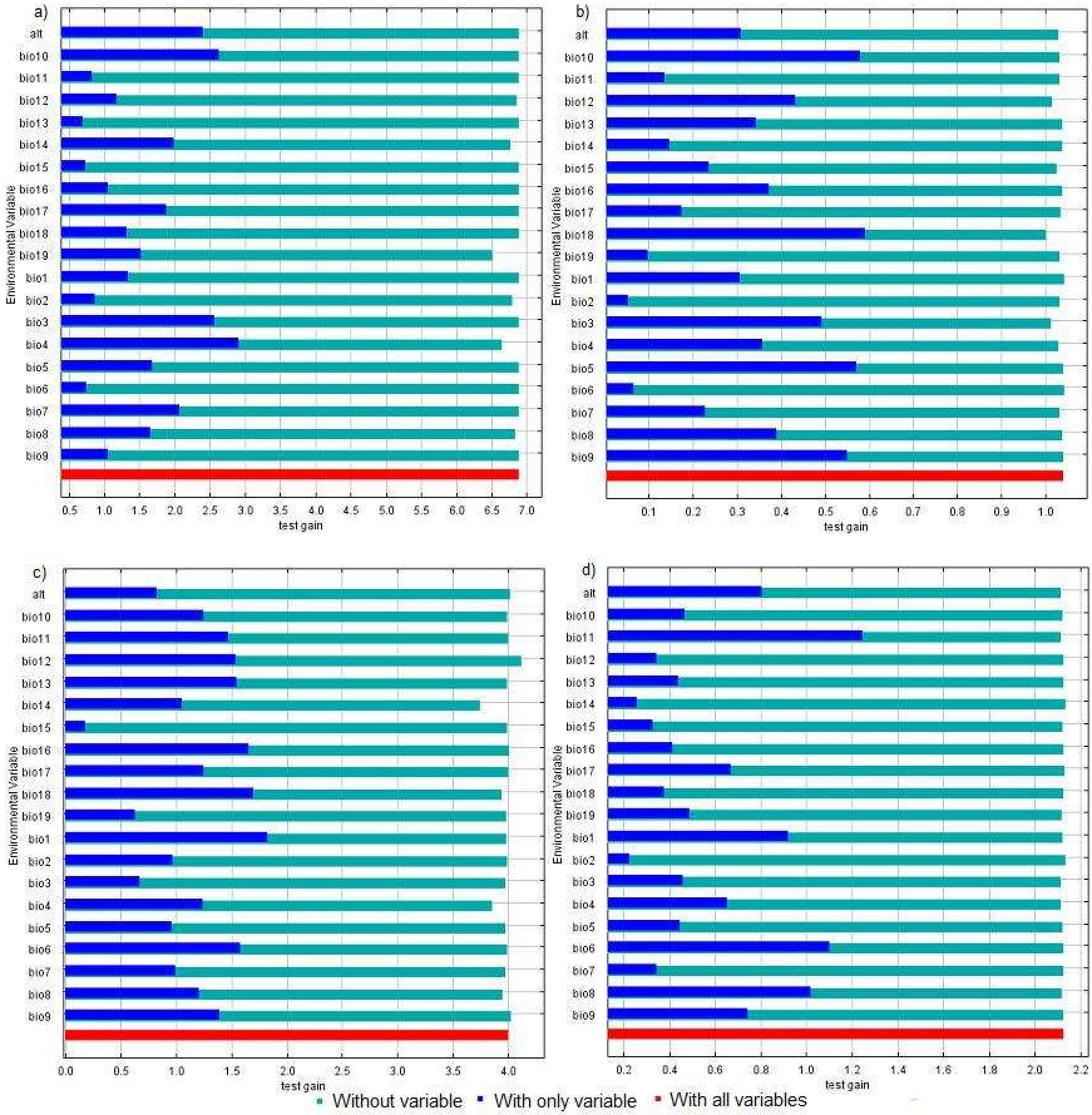


Figure 4.6: The Jackknife variable importance statistic outcomes from MaxEnt, for *D. bicornis* protected (a) and historic (b) range, and *R. unicornis* protected (c) and historic (d) ranges, based on the current climate envelope. These graphs indicate the variables that supply the most information to the model, by sequentially dropping each variable and determining the performance of the mode. The light blue indicates the model performance without that particular variable, while the dark blue shows the model performance using only that variable.

The percentage of variable contribution was assigned through the model gain, in MaxEnt. These varied between the historic and protected ranges of both species. The two highest contributing environmental variables for both ranges of each species can be seen in Table 4.2.

Species	**Range Distribution**	**Highest Contributing Variable**	**Second Highest Contributing Variable**
Diceros bicornis	Protected	Bio14 (31.3%)	alt (30.1%)
	Historic	Bio3 (31.8%)	Bio5 (28%)
Rhinoceros unicornis	Protected	Bio18 (25.5%)	Bio16 (16.5%)
	Historic	Bio8 (37.5%)	Bio11 (24.2%)

Table 4.2: The two highest contributing variables of the suitability models, used in MaxEnt, for protected and historic range of each species, see Table 3.1 for definitions.

The response curves for all environmental variables, for both historic and protected ranges of each species can be seen in Appendix B. The response curves created for the two variables of highest contribution can be seen in Figures 4.7 – 4.10. The protected range of *D. bicornis* is considered to have a high probability of presence between 35 and 160mm of rain, while there is no constraining value of altitude (Figure 4.7). The historic range of *D. bicornis* is shown to have highest presence probability at 5.5°C for isothermality, and between 9.0°C and 13.0°C for maximum temperature of the warmest month (Figure 4.8). Figure 4.9 shows that the protected range of *R. unicornis* has a probability of presence between 700mm and 3450mm for precipitation of the warmest quarter, while precipitation of the wettest quarter has the same presence value for its entire range (Figure 4.9). The historic range of *R. unicornis* has a probability of presence range of 29°C – 42°C for the mean temperature of wettest quarter, while the highest presence probability range for mean temperature of the coldest quarter is -30°C to 12°C.

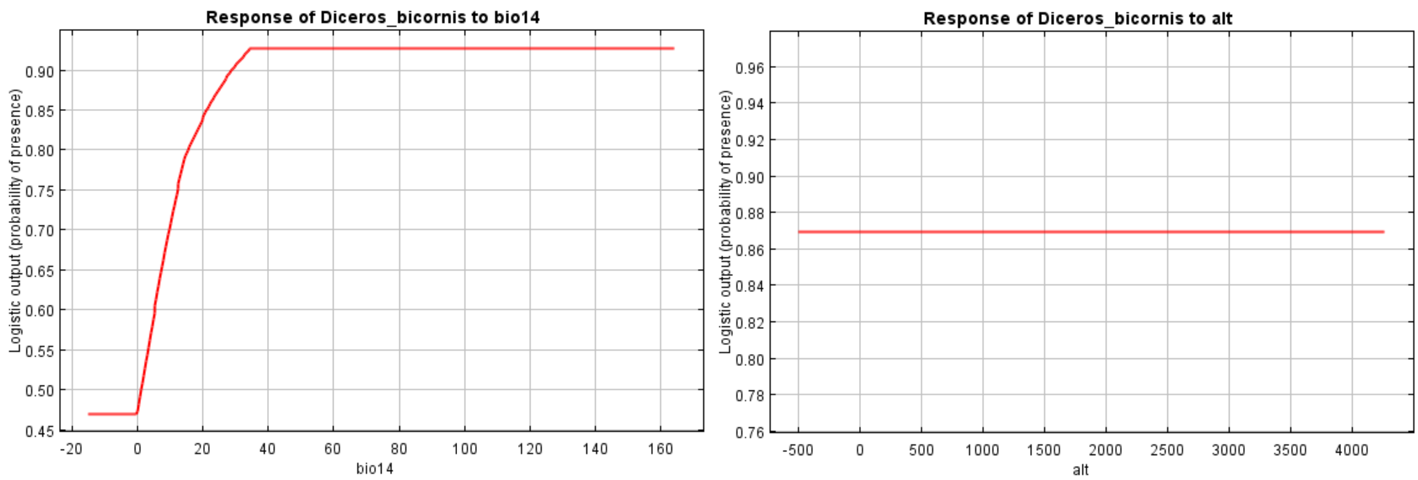


Figure 4.7: The response curves for precipitation of driest month (bio14), shown in millimetres, and altitude (alt), in metres, show the environmental variable values at which the presence probability is highest for the protected range of *D. bicornis*.

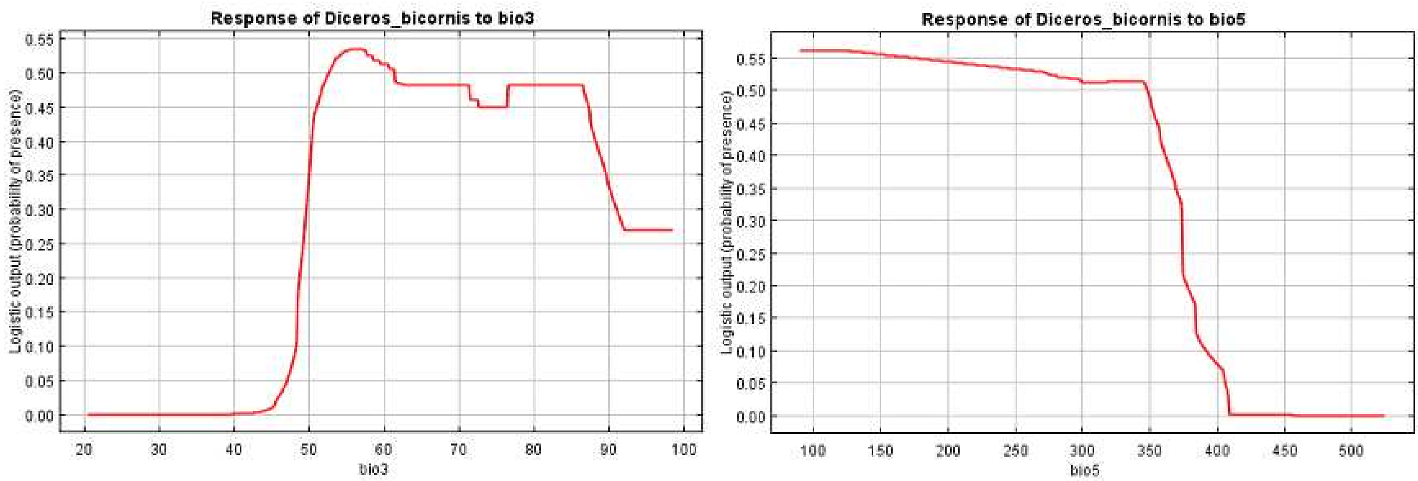


Figure 4.8: The response curves for the historic range of *D. bicornis*, for isothermality (bio 3) and maximum temperature of the warmest month (bio5), indicating the point or range of highest probability of presence for each variable. Temperature is shown in °C.

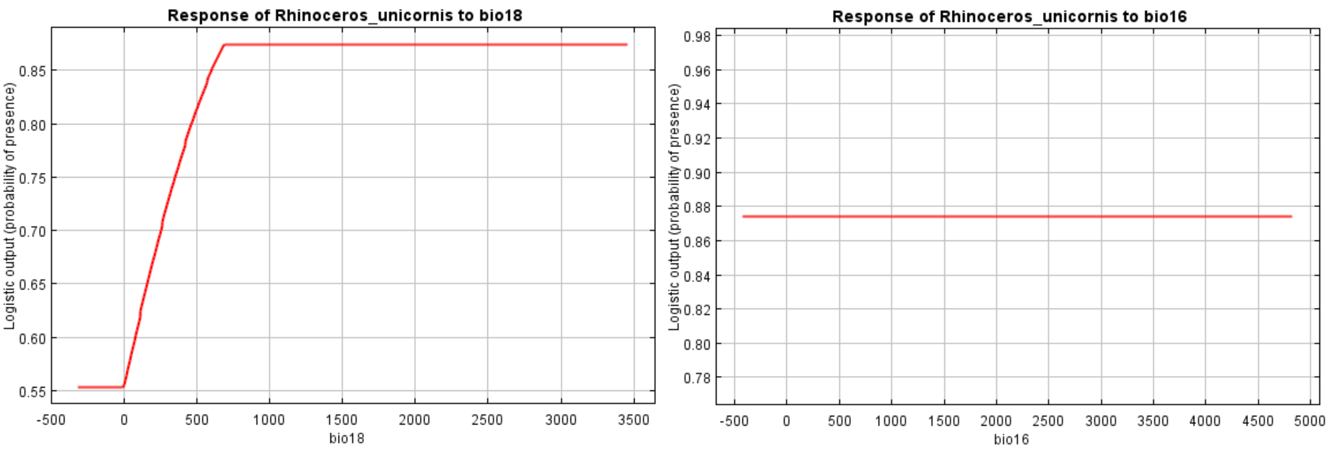


Figure 4.9: The response curves for the protected range of *R. unicornis* indicate the highest probability of presence for precipitation of warmest quarter (bio18) and precipitation of wettest quarter (bio16). Precipitation is shown in millimetres.

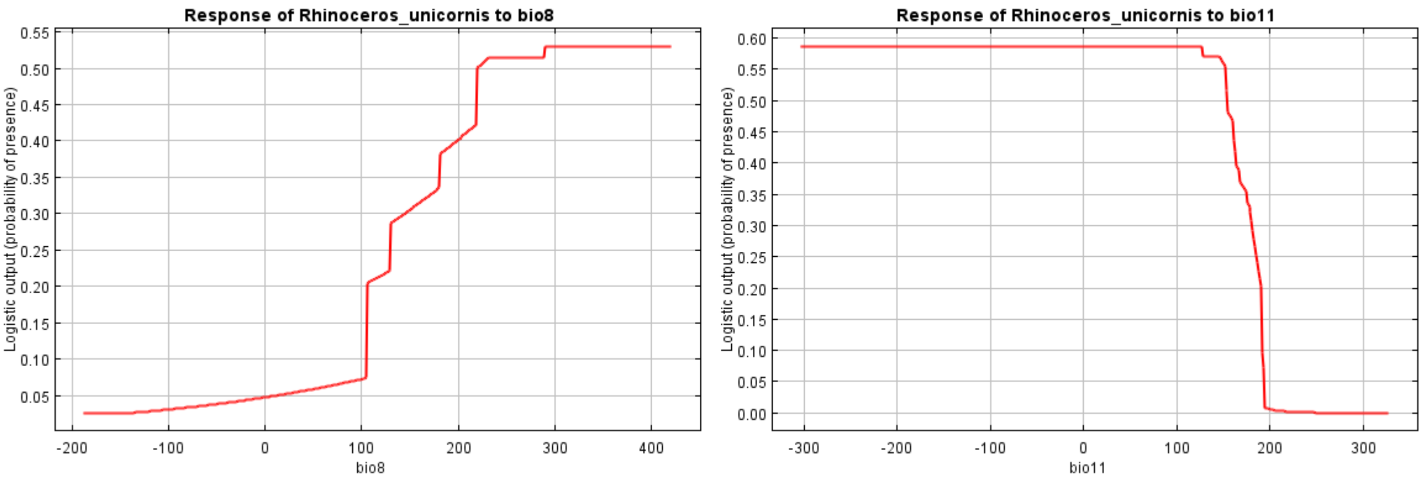


Figure 4.10: The highest probability of presence of *R. unicornis*, based on the historic range, for mean temperature of the wettest quarter (bio8) and mean temperature of coldest quarter (bio11) can be seen in these response curves. Temperature is shown in °C.

Cluster dendrograms can be used to determine which environmental variables supply different pieces of information to the suitability model. Dendrograms are more commonly used in genetics to determine similarities and distance between genes, however the information supplied by the clustering dendrogram was still indicating the similarities between the environmental variables, and the distance between them as well. As seen in Figure 4.11, the environmental variables supplying different information to the model alter slightly between the two species of rhinoceros.

For *D. bicornis* (Figure 4.11(a)), the environmental variables providing different information from the main cluster of variables are temperature seasonality, altitude and annual precipitation, although altitude and annual precipitation share similar information to each other. The environmental variables supplying the model with different information for *R. unicornis* (Figure 4.11(b)) are the same as *D. bicornis*, with the addition of precipitation of the wettest quarter. However, in contrast to *D. bicornis*, altitude is providing very different information than annual precipitation, while in fact annual precipitation has similar information to precipitation of the wettest quarter, for the *R. unicornis* model.

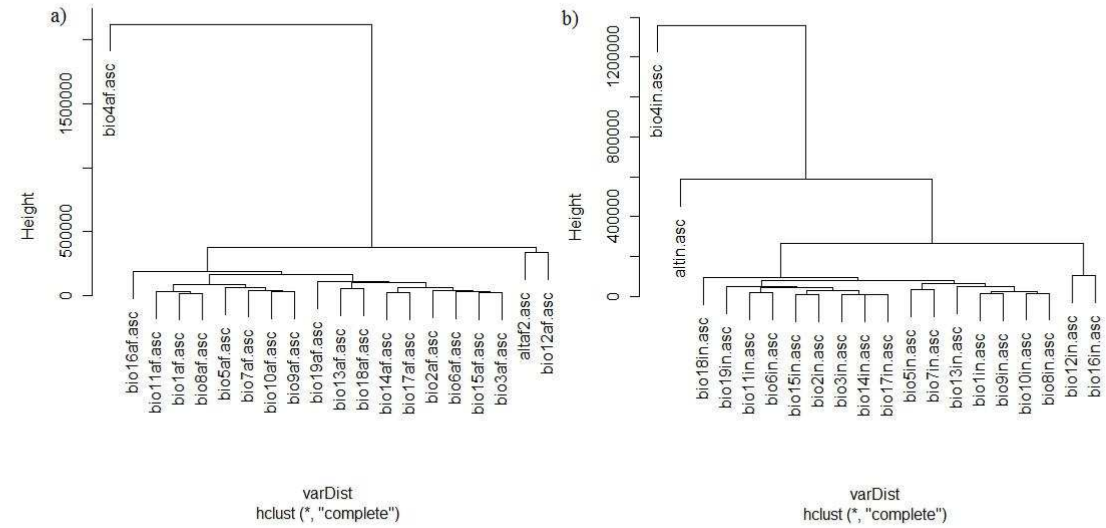


Figure 4.11: Cluster dendrograms indicate the environmental variables that supply different information to the suitability models for *D. bicornis* (a) and *R. unicornis* (b). The variables that are clustered together share analogous information.

4.2.3 Spatial correlation

Using R (R Development Core Team,2009), the Clifford correction (Clifford et al, 1989) of the correlation coefficient (r2) for spatial autocorrelation was used on all models, comparing the current climatic conditions with future predicted areas of suitable climatic conditions. This determines the correlation of the suitability of the current distribution with the suitability of the same area in the future prediction models, while accounting for the fact that unsuitable climate is likely to be surrounded by unsuitable climate, rather than treating each cell as independent. The correlation determines how similar the current distribution pattern is to the predicted future distribution patterns. Figure 4.12 shows the difference in r^2 between the A2 scenario and B2 scenario, for each species' range. Graphs showing the correlation between each prediction year, for both scenarios of the protected and historic range of *D. bicornis* and *R. unicornis* can be seen in Appendix C.

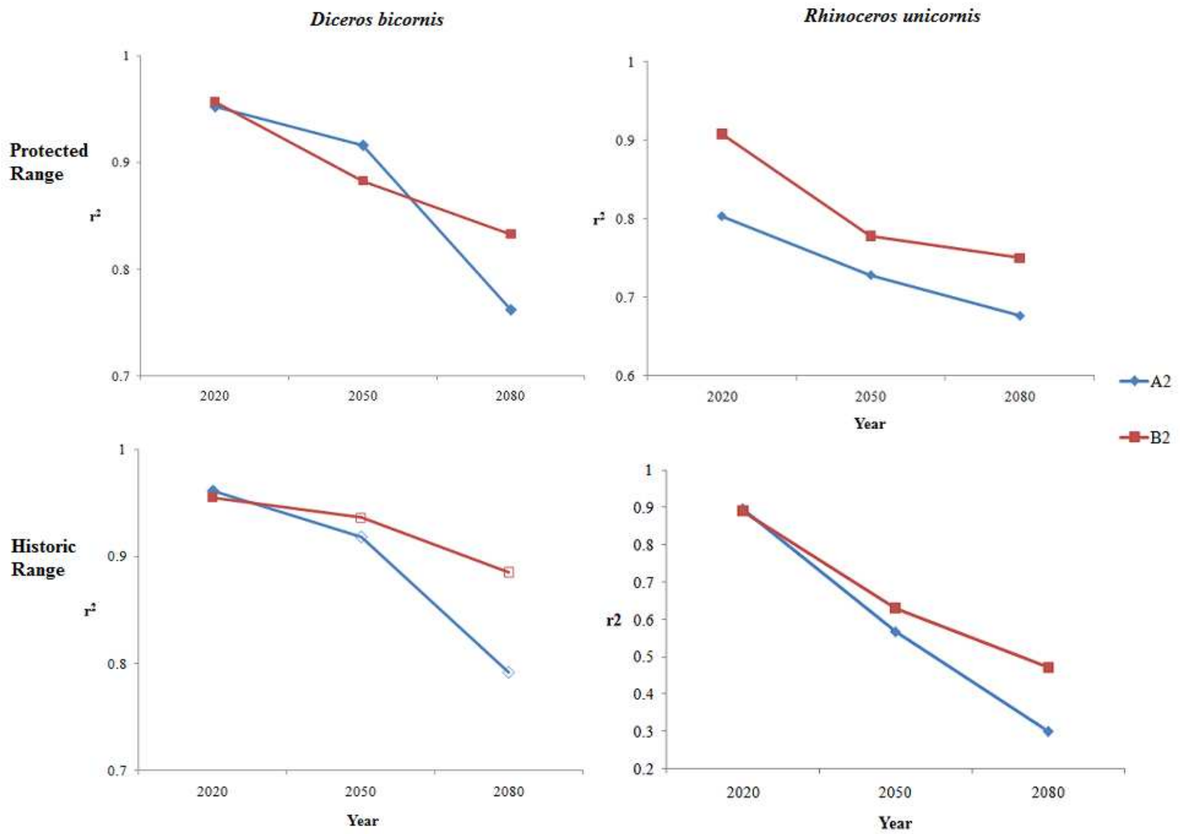


Figure 4.12: The change in the correlation coefficient (r^2) over the course of predicted years, for each climate scenario – A2 and B2, can be seen for both the historic and protected ranges of *D. bicornis* and *R. unicornis*. Open data points indicate insignificant results, while filled data points show significant outcomes.

The difference in the correlation coefficient (r^2) can be seen in Figure 4.12 for both the protected and historic ranges of *D. bicornis* and *R. unicornis*. The significant outputs show that the current distribution pattern is similar in the future. Although the correlation coefficient decreases over time, due to climate change, the protected distribution remains similar and therefore suitable in future years, indicating their value to conservation. The same can be said for the historic range of *R. unicornis*. However, the insignificant outputs for the historic range of *D. bicornis* imply that after 2020 there are no similarities between the inferred historic range and the historic range in the future. Therefore, due to a shift in climate, the current suitable locations, based on the historic distribution, will not be suitable after 2020.

4.2.4 Determining a Threshold

The climate suitability maps (Figures 4.1 – 4.4) represent a detailed range of suitable climate for both *D. bicornis* and *R. unicornis*. However, the distribution of logistic values of these maps varies between range estimates and species. In order to determine a minimum climate suitability that the rhinoceros species would be able to survive on, the Kappa threshold statistic can be used. While there are many ways of setting a threshold, the graphs produced indicate one of the thresholds that could be used as a conservation measure. The graphs show the highest level of agreement between predicted and observed data, over the width of the ROC curve (Figure 4.13).

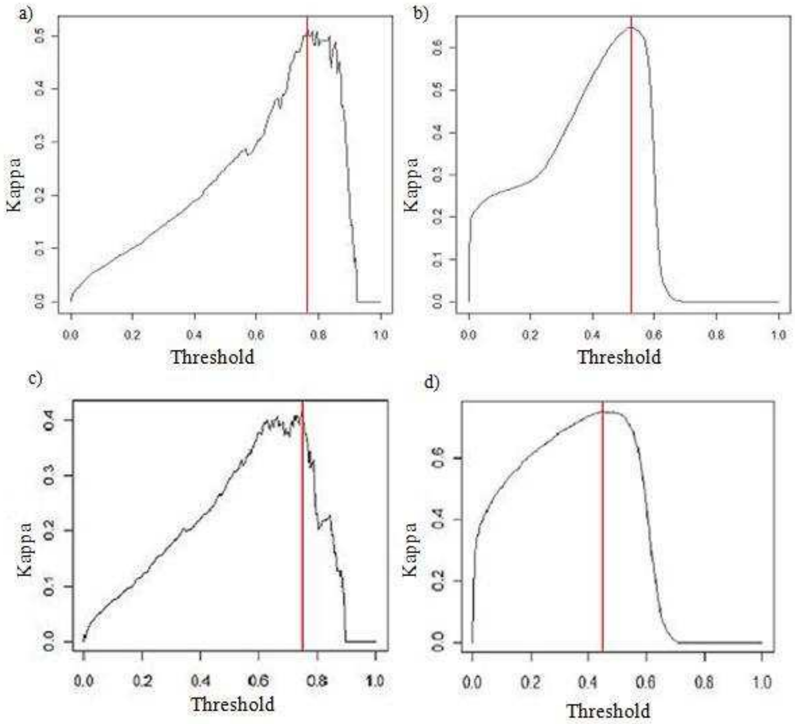


Figure 4.13: The Kappa Threshold for *Diceros bicornis*' protected (a) and historic (b) range, and the protected (c) and historic range (d) of *Rhinoceros unicornis*. The red line indicates the minimum value of climate suitability (threshold), taken from the climate suitability maps, that the species could be present on.

For the protected ranges of *D. bicornis* and *R. unicornis*, the Kappa threshold is set at approximately 0.75, implying that the agreement between observed and predicted ranges is greatest at high logistic values – precise models – as expected from the restricted distribution (Figure 4.13 (a) and (c)). This is greatly reduced for the historical ranges of *D. bicornis* (Figure 4.13 (b)) – approximately 0.525 – and *R. unicornis* (Figure 4.13 (d)) – 0.425.

Based on the Kappa figures, maps were created that indicated the potential distribution of both *D. bicornis* and *R. unicornis* using both protected and historical range (Figure 4.14). The potential areas of presence for the protected is extremely constrained compared to the historical ranges.

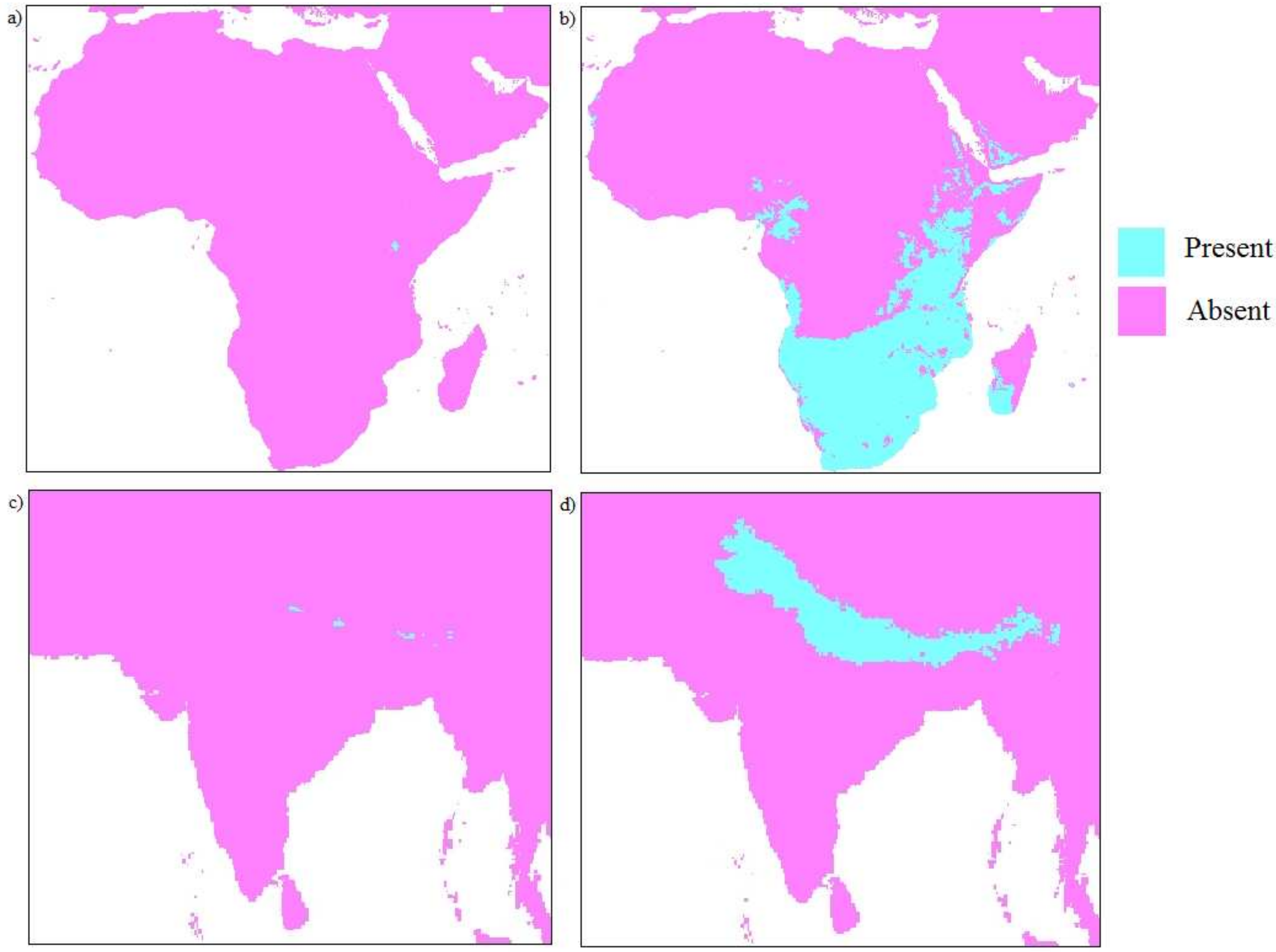


Figure 4.14: Presence/absence maps created based on the Kappa threshold value, for the protected range (a) and historic (b) range of *D. bicornis*, and *R. unicornis*' protected (c) and historic (d) ranges. The areas of potential presence for both species of rhinoceros vary greatly between the historic and protected ranges.

5. Discussion

This study determined the areas of suitable climate for both *Diceros bicornis* and *Rhinoceros unicornis*, highlighting areas that may have important conservation potential.

5.1 Climate Suitability in the Future

A rather unexpected outcome of the climate suitability map is that MaxEnt produced a model indicating that the protected areas within Laikipia were the only places that had suitable climate for *D. bicornis*, with the exception of the small area of climate suitability in Ethiopia (Figure 4.1). While the model was using a restricted area of current protection, it seems unlikely that the environmental envelope of the Laikipia region cannot be found anywhere else in Africa. This may be simply due to the fact that the environmental envelope of Laikipia is so specific, that MaxEnt could not recognise any other areas with Africa that had a similar climate, or areas that would have a similar climate in the future projections.

On the other hand, the climate suitability models for the protected range of *R. unicornis* and the historic range of both species show larger areas of climate suitability (Figure 4.3). The model for the protected range of *R. unicornis* shows a suitable habitat extending along the border of the Himalayas. When one considers that *R. unicornis* inhabits alluvial grasslands, having the population being constrained by a mountain range is understandable. However, the protected range suitability model for *R. unicornis* shows more areas of high suitability than the historic range suitability model.

The historical range suitability maps for both species broadly follow the location of the historical range themselves. Such wide-ranging species as rhinoceroses cover an assortment of climates, which can be seen in the models (Figures 4.2 and 4.4). For *D. bicornis* and *R. unicornis* to have once been found over such a vast area of land indicates the potential for the species' to survive in varying climates, creating a model that has a wide area of "average" climate suitability. The fluctuating climate that both species historically survived in may explain why many different variables had an influence on the model.

Interpreting the important and influential variables for the models is necessary to understand how the rhinoceros populations may be constrained. The influential, informative and contributing variables alternate between both the historic and protected ranges of each species.

The protected range of *D. bicornis* was influenced by temperature seasonality, mean temperature of the warmest quarter, isothermality and altitude (Figure 4.6). One possible reason for the influence of altitude could be the relationship between elevation and climate, as *D. bicornis* is found at varying altitudes, therefore elevation is unlikely to be a constraining factor. Laikipia is semi-arid and has an annual average rainfall of 550mm (Odadi *et al*., 2007); one would expect precipitation to be a constraint on the areas of suitable climate, which is not the case from the jackknife statistics. However, the precipitation of the driest month does contribute the most to the model, assigned from the model gain (Table 4.2), which implies that precipitation does have an influence over the suitable climate areas for *D. bicornis* based on its protected range. In addition to this, annual precipitation supplies different information to the model compared to many of the other environmental variables. Based on these results, it can be determined that precipitation has a large impact on the climate suitability model for the protected range of *D. bicornis*.

The influential variables for the historic range of *D. bicornis* included precipitation of warmest quarter, mean temperature of warmest quarter and the maximum temperature of warmest month (Figure 4.6). None of these variables match those that were supplying the model with different pieces of information (Figure 4.7); on the other hand they do reflect the highest contributing variables (Table 4.2), which were isothermality and maximum temperature of warmest month. The influential variables imply that temperature is a key environmental factor when determining the areas of climate suitability, using the historic range. This is understandable as, mentioned above *D. bicornis* is a wide-ranging species. The diversity of climates that *D. bicornis* can survive in may simply be only connected through temperature. This could explain why the historic range suitability maps show a limited amount of high suitability. However, the Kappa threshold indicates that there is a vast area of suitable climate in which *D. bicornis* could happily survive, extending across the historic range of the species.

The model created for *R. unicornis*, using the protected range, was greatly influenced by annual mean temperature, precipitation of wettest quarter and precipitation of warmest quarter (Figure 4.6); these coincide with the highest contributing variables which were also precipitation of wettest and precipitation of warmest quarters (Table 4.2). The obvious impact of precipitation on the climate suitability models is most likely related to the fact that *R. unicornis* inhabit alluvial grasslands (IUCN, 2009), as a change in precipitation could lead to a dramatic shift in the availability of these wet grassland areas.

In contrast, the historic range model of *R. unicornis* was more influenced by the mean temperature of the coldest quarter, minimum temperature of coldest month and mean temperature wettest quarter. The highest contributing variables were also mean temperature of the wettest quarter and mean temperature of the coldest quarter. The effect that temperature, in cold quarters, has on the model could be related to the relationship between altitude and temperature, as *R. unicornis* will be constrained to lower altitudes, based on their preferred habitat.

For all climate suitability models, temperature seasonality provided information to the model that no other environmental variable could. This is most likely due to the wide-ranging species that *D. bicornis* and *R. unicornis* once were, as temperature will fluctuate along the different climate regions. Altitude and annual precipitation were also supplying different information than other environmental variables; however they were providing similar information to each other for the *D. bicornis* suitability models. The reason altitude is presenting different information varies among the two models. Altitude is most likely a constraining factor for *R. unicornis*, due to their preferred habitat of alluvial grasslands. On the other hand, as altitude and annual precipitation are providing similar information for the models of *D. bicornis,* which could be due to the varying altitudes that the species is found at, as well as the constraint of precipitation on a species that lives in a semi-arid climate. A final factor that supplied the *R. unicornis* model with different information, precipitation of wettest quarter, could be attributed to the increase in wet grassland areas and swamps with an increase in precipitation.

Precipitation appears to have an effect on all of the suitability models, but is likely to have different influences on each rhinoceros species. There is a high probability that the impact of precipitation on the models for *D. bicornis* is due to the potential increase in droughts that may occur across Africa, thereby limiting the amount of water readily available to the species. In contrast, a possible increase in flooding throughout the Indian sub-continent could lead to an increase in available swamps and alluvial grasslands, which expands the potential range of *R. unicornis*. This could likely cause an increase in human-wildlife conflict, as access to fresh water fluctuates.

The Clifford correction (Clifford *et al.*, 1989) of the correlation coefficient (r^2) for spatial autocorrelation shows the value of the protected and historic ranges for both species, based on the changing climate. The protected ranges for *D. b. michaeli* and *R. unicornis* indicate a high correlation between the current distribution pattern and the future predicted distribution pattern (Figure 4.12), thereby implying the high suitability of the protected areas in future years. The historic range of *R. unicornis* can also be used as a guide to decided suitable locations for conservation programmes. In contrast, after 2020, the historic range of *D. bicornis* should not be used as a guide to areas of suitable climate, most likely due to a shift in the climate.

The insignificant correlations contradict the modelling results; the models indicate areas of future suitable climate, similar to the current areas of suitable climate, but the correlations show that these areas may not be suitable. However, it should be taken into consideration that while the species distribution models (Figure 4.2), and the Kappa threshold (Figure 4.13 and 4.14), show that there are segments of relatively suitable areas, for *D. bicornis* in the future, the correlation (Figure 4.12) may simply indicating that the suitable areas may not be exactly within the historic range.

As a whole, the results indicate that there are many suitable locations for potential new conservation areas, as well as showing that the current distributions are valuable in the future, in regards to climate change.

5.2 Limitations

When creating the climate suitability models, several factors were not included, such as vegetation indices and habitat data. The exclusion of these variables has limited the models to only determine climate suitability, based on environmental variables and altitude, and not establish suitable habitat or vegetation. While there is some theory as to the potential shift of vegetation and habitat, in regards to climate change, extensive research revealed no decent maps of future habitat distributions are available. Modelling future projections of habitat and vegetation is not feasible, and therefore no datasets have been created for future predictions, and hence, no models can be created.

The obvious lack of highly suitable habitat within Africa for the protected range of *D. bicornis* must be placed in context with the fact that only a few selected reserves from Laikipia were used for analysis. With such a small sample size, it is inevitable that MaxEnt modelled the habitat suitability on the exclusive environmental envelope that surrounds the protected ranges in Laikipia. A detailed database of all the current protected areas that contain *D. bicornis* populations would be useful in order to potentially create a habitat suitability model with a wider perspective. However, for the requirements of SRI, and therefore this study, looking at the selected reserves allows for SRI to assess whether any funding needs to be re-locating or added to, in order to further aid conservation of *D. bicornis*. In light of this, the historic range is the more meaningful choice with respect to climate, when determining the optimum locations to allocate funds.

The historical range may also be considered as a limitation, for *D. bicornis*, as there is some confusion as to where the black rhinoceros once occurred (Rookmaaker, 2004). On the other hand, the historical data was obtained from the IUCN Global Mammal Assessment (IUCN, 2008), which attempted to retrieve all past and present information about Earth's mammals in order to compile a comprehensive list of endangered mammal species. This is the "best guess" of historic data available for the species. The historical range is also, as stated, for the *D. bicornis* species, and is not separated for *D. b. michaeli*, due to no good historical range of the sub-species being available. In this case, the suitable habitat created from the historic range may be too wide, and should be used with caution when implementing management plans.

For *R. unicornis* the current and historic ranges were obtained from Amin *et al* (2006), and matched with the range data from the IUCN Red List (IUCN, 2009). This suggests that, as globally recognised ranges, there should be no constraints to the data. However, again, this is only a “best guess” scenario, and therefore should not be taken as

5.3 Recommendations for Further Study

Further studies could evaluate the climate suitability for the entire protected range of *D. bicornis*, in order to gain a wider perspective of the effects that climate change could have. This could be used as an important guide for all areas containing populations of *D. bicornis*, which does not simply describe the potential effects in Laikipia.

Another study could potentially use climate layers from the past, if such data exists, to determine if the lack of very high climate suitability was based on the historic range not corresponding well with the current climate data, or it is simply that each rhinoceros species is wide-ranging, and therefore no “perfect” climate can be determined.

Other factors, such as population density or growth, as well as hydrology could be researched, and a climate suitability model could be produced, that may show lakes increasing in size, due to continual flooding, or shrinking due to human encroachment or reclaimed land. If a suitable map is created for the prediction vegetation change, this could be used to determine species distribution to correspond with climate change. An increase in population modelled against potential suitable climate areas would enable conservation managers to establish the best locations for creating new protected areas, and manage existing ones, in order to ensure the survival of each rhinoceros species.

The above mentioned research could also be carried out using different modelling techniques, such as BIOCLIM, CARP and GAMs. These may produce different, or similar, results that could be compared.

All of the research suggested here would add to the results shown in this study, through creating more detailed climate suitability maps, which would further aid conservation managers in the planning process.

5.4 Climate Change and Conservation

In the past, climate change has not been one of the key topics discussed when it comes to conservation planning and implementation (Moller, R., *pers. comm.*). As we begin to understand the impact that climate change will have on our environment, it becomes imperative that conservation strategies include climate change as a key factor (Hannah *et al.*, 2002a). One of the potential consequences is losing protected ranges for all species, which can be mitigated by creating new protected areas (Hannah *et al.*, 2002b). Extreme weather conditions – namely, drought and flooding – could cause conservation strategies, which do not consider climate change, to be worthless, as species distribution and migration can be directly influenced by these extreme conditions (Hannah *et al.*, 2002b).

In light of this, the climate suitability models created in this study could come as a useful tool for conservation managers. The models may be used as a guide to indicate the potential areas that will be suitable for rhinoceros populations. While the protected areas of *D. bicornis* in Laikipia may appear to be unsuitable in the protected range model (Figure 4.1), the historic range model indicates that Laikipia is in an area of relatively suitable climate (Figure 4.2), which could be valuable for rhinoceros conservation.

The suitable climate locations for *R. unicornis* extend far beyond the current protected range, which is extremely different to the protected range model of *D. bicornis*. The projected future climate suitability maps for *R. unicornis*, based on the protected range, show a large area of potentially very suitable climate, along the border of the Himalayas (Figure 4.3). However, the future projection models using the historic range of *R. unicornis* seem to indicate that the Assam region will contain lower suitability climate but the Kappa threshold is much lower (Figure 4.9).

In terms of conservation strategies, the historic range models would be of better use due to the wide-ranging species' that *D. bicornis* and *R. unicornis* are. In such a case, it may be of more value to use the Kappa threshold as a conservation tool. The presence/absence maps (Figure 4.9) created using the Kappa threshold could be used as a guide, indicating where the climate is suitable for each species, and potentially highlighting regions where more protected areas could be created.

The newly created protected areas would help to mitigate the potential effects of climate change, by maintaining separate populations of each rhinoceros species; as the sub-populations of each species increases, the chance of climate change having an effect on the metapopulation of the species decreases.

With this in mind, it can be said that SRI is currently aiding rhinoceros conservation in the best possible way, through funding many different areas within Africa to help maintain viable sub-populations of *D. bicornis*, particularly if the populations within the Laikipia region increase in those areas that are not yet at carry capacity.

The involvement that SRI has with *R. unicornis*, in the Assam region, will benefit the species, however ensuring successful translocations into Manas (Syangden, *et al*., 2008) could potentially decrease the effects of climate change on *R. unicornis*. Indian Rhino Vision 2020 aim to create viable populations in seven protected areas by 2020, within Assam, to ensure long term viability; this goal will also help to ensure that *R. unicornis* is not globally eradicated due to the potential effects of climate change on one area. It may also be worth, depending on the feasibility, to create some new protected areas within North-western India and Eastern Pakistan as they are also areas of high climate suitability.

When deciding the best way to ensure the survival of a particular species, most research will mention the use of habitat corridors (such as Halpin, 1997; Williams *et al*., 2005; Hannah, 2008). However, the cost effectiveness of using corridors has been assessed by Simberloff *et al* (1992), with the conclusion being that funds to create corridors must be weighed against the costs and benefits of alternative uses. In many areas, it is simply not feasible to create movement corridors, due to the large human population, and the area they inhabit. This is especially relevant for areas such as Africa and India that have a high population growth rate (UN, 2003).

While this study focused on climate change and rhinoceros species, the effect that climate change has on the human population should also be considered. As severe weather becomes more prevalent, humans will migrate (Perch-Nielson *et al.*, 2008). It would make sense that in droughts, people will travel to areas with water (El-Hinnawi, 1985); in floods, people will move to higher ground (Haque, 1997). However, these mass migrations have been considered “common sense” ideas, as opposed to there being an explicit link (Black, 2001; Castles, 2002). Either way, the movements of humans in response to climate change may have a huge influence on wildlife.

The potential infringement of human populations in to areas used by wildlife, such as rhinoceroses, will greatly increase conflict between humans and wildlife. In Kenya, local people resent wildlife for destroying crops, and damaging property (Okello, 2005), with the traditional resolution being to kill the “problem” individual (Treves *et al.*, 2006). The number of people killed by wildlife is insignificant to those killed by disease and famine, however this number is vital to understand the tolerance of local people to wildlife (Woodroffe *et al.*, 2005).

Education is a key factor to ensuring the long-term survival of threatened species. Involving the local communities, and gaining their full support is the only way that conservation programmes can be successful, and by running education projects across a particular region, the support of local people could be gained in large numbers. As many local people see wildlife as pests that destroy their crops (Okello, 2005), the need to change the perception is crucial. While informing the local people about climate change and the effects that it has on the wildlife may not be successful in changing the mind-set about wildlife, explaining the economic value of species such as rhinoceroses, through tourism, might have an influence. By creating an understanding of the importance of the environment, human-wildlife conflict may be eased in such a way that the local people no longer feel the need to kill any species that may cause them problems, such as crop-raiding.

It is because of this resentment towards wildlife that leaves conservation managers with very few options for protecting species. While it has been shown that exclusionary protected areas are not always successful in achieving conservation objectives (Brown, 2002; du Toit, 2006), secure areas of dynamic habitat may be the most feasible way of protecting particular species, such as the rhinoceros. In this case, translocations are a suitable way to increase rhinoceros populations in protected areas that are of low numbers, such as Manas National Park. The genetic flow between the rhinoceros populations would be inhibited through fenced protected areas, which would likely lead to inbreeding depression. However, a feasible way to counter-act this is to exchange individuals between protected areas, through translocations. The genetic diversity of the exchanged rhinoceroses would have be significant, in order to prevent sub-populations of identical genetics. In the face of climate change and a loss of suitable locations for the rhinoceros populations to live without conflict, translocations between protected areas, for genetic purposes may be the only option.

Currently, conservation management plans do not extend beyond 10 years (Hannah *et al.*, 2002; Vasu, 2002; Okita-Ouma, 2007; Bonal, 2008). In order to accommodate the effects that climate change may have on wildlife, management plans need to have a 30 – 50 year horizon, at the very least (Hannah *et al.*, 2002). Other conservation management suggestions have been to incorporate additional areas into existing National, or creating conservancies for community-involved conservation (du Toit, 2006).

While management ideas may be freely available, funds in order to carry out conservation work are not. There have been some controversial, but feasible suggestions to raise financial aid, such as controlled sport hunting of surplus Southern White rhinoceroses (*Ceratotherium simum simum*) and selling surplus rhinoceroses to the private sector (du Toit, 2006). With a population of over 17,500 individuals, *C. simum simum*¸ have continued to thrive despite sport hunting in South Africa (IUCN, 2009). If new protected areas are needed to ensure the survival of both *D. bicornis* and *R. unicornis*, funds will be needed to pay for anti-poaching and monitoring patrols, fences to ensure the area is protected, and equipment to ensure successful translocations.

There are currently disagreements over how distinct each sub-species of *D. bicornis* is from one another. They are presently treated as separate entities, and mixing of the sub-species is not performed. However, as climate change begins to constrain natural resources, conservation managers may be faced with the desire to inter-breed in order to maintain viable populations. While this is a controversial conservation strategy, until a definite genetic distinction is made between the sub-species, it could become a viable solution, should the rhinoceros populations need a boost in numbers, which cannot be supplied from their own sub-species.

Ultimately, the most likely way to ensure that climate change does not have a detrimental effect on an entire species is to ensure that there are many different populations scattered around various locations. This prevents "putting all the eggs in one basket", therefore if one population is devastated, the other sub-populations would be unaffected and some individuals could be translocated to help rebuild the damaged population. Save the Rhino International are currently allocating funds sensibly, as being involved with many different projects ensures the protection of rhinoceros sub-populations in many areas. However, the need for new, or larger protected areas, remains essential to warrant the survival of *D. bicornis* and *R. unicornis*, and mitigate against the potential effects of climate change.

References

Amin, R., Thomas, K., Emslie, R.H., Foose, T.J. and Van Strein, N. (2006) An overview of the conservation status of and threats to rhinoceros species in the wild. *International Zoo yearbook* 40: 96-117.

Bamber, D. (1975) The Area Above the Ordinal Dominance Graph and the Area Below the Receiver Operating Characteristic Graph. *Journal of Mathematical Psychology* 12: 387 – 415.

Berner, R.A. (1991) A model for atmospheric CO_2 over Phanerozoic Time. *American Journal of Science* 291: 339 – 376.

Black, R. (2001) Environmental Refugees: Myth or Reality? *United Nations High Commissioner for Refugees Working Papers* 34: 1- 19.

Bonal, B.S., Talukdar, B.K., and Sharma, A. (2008) Indian Rhino Vision (IRV) 2020 – Training Cum Translocation of Rhinos within Assam, the First Phase. *Indian Rhino Vision 2020*, Assam, India.

Brown, K. (2002) Innovations for Conservation and Development. *The Geographical Journal* 168: 6 – 17.

Castles, S. (2002) Environmental Change and Forced Migration: Making Sense of the Debate. *United Nations High Commissioner for Refugees Working Papers* 70: 1 – 14.

Clifford, P., Richardson, S., and Hemon, D. (1989) Assessing the Significance of the Correlation between Two Spatial Processes. *Biometrics* 45: 123 – 134.

Cohen, J. (1960) A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement* 20: 37 – 46.

Crowley, T.J. (2000) Causes of Climate Change Over the Past 1000 Years. *Science* 289: 270 – 277.

du Toit, R., ed. (2006) Guidelines for Implementing SADC Rhino Conservation Strategies. *SADC Regional Programme for Rhino Conservation*, Harare, Zimbabwe.

El-Hinnawi, E. (1985) Environmental Refugees. *United Nations Environment Programme,* Nairobi.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J. McC., Peterson, A.T., Phillips, S.J., Richardson, K.S., Scachetti-Pereira, R., Schapire, R.E., Soberón, J., Williams, S., Wisz, M.S. and Zimmerman, N.E. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129 – 151.

Gonen, M., and Heller, G., (2006) Lehmann Family of ROC Curves. *Memorial Sloan-Kettering Cancer Center Department of Epidemiology and Biostatistics Working Paper Series.* Working Paper 11. [Available at: http://www.bepress.com/mskccbiostat/paper11].

Grabherr, G., Gottfried, M., and Paull, H. (1994) Climate Effets on Mountain Plants. *Nature* 369: 448.

Graham, C.H., Ferrier, S., Huettman, F., Moritz, C., and Townsend Peterson, A. (2004). New developments in museum-based informatics and applications in biodiversity analysis. *Trends in Ecology and Evolution* 19: 497 – 503.

Hannah, L., Midgley, G.F., and Millar, D. (2002a) Climate change-integrated conservation strategies. *Global Ecology and Biogeography* 11: 485 – 495.

Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., and Woodward, F.I. (2002b) Conservation of Biodiversity in a Changing Climate. *Conservation Biology* 16: 264 – 268.

Haque, C.E. (1997) *Hazards in a Fickle Environment: Bangladesh*. Dordrecht: Kluwer Academic Publishers.

Hernandez, P.A., Graham, C.H., Master, L.L., and Albert, D.L. (2006) The Effect of Sample Size and Species Characteristics on Performance of Different Species Distribution Modelling Methods. *Ecography* 29: 773 – 785.

Hersteinsson, P. and MacDonald, D.W. (1992) Interspecific Competition and the Geographical Distribution of Red and Arctic Foxes *Vulpes vulpes* and *Alopex lagos*. *Oikos* 64: 505 – 515.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. (2005) Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.

Hill, J.K., Thomas, C.D. and Huntley, B. (1999) Climate and Habitat Availability Determine 20th Century Changes in a Butterfly's Range Margin. *Proceedings of the Royal Society of London: Biological Sciences* 266: 1197 – 1206.

Houlder, D. J., Hutchinson, M. F., Nix, H. A. & McMahon, J. P. (2000) *Anuclim v. 5.1*. Canberra: Centre for Resource and Environmental Studies, Australian National University.

Hughes, L. (2000) Biological Consequences of Global Warming: Is the Signal Already Apparent? *Trends in Ecology and Evolution* 15: 56 – 61.

IPCC (2000) IPCC Special Report: Emissions Scenarios. *Intergovernmental Panel on Climate Change Summary for Policymakers*.

IPCC (2001a) Climate Change 2001: The Scientific Basis. *Intergovernmental Panel on Climate Change*, Geneva, Switzerland.

IPCC (2001b) Climate Change 2001: Synthesis Report. *Intergovernmental Panel on Climate Change*, Geneva, Switzerland, 2001.

IRF (2009) International Rhino Foundation; http://www.rhinos-irf.org [Accessed 2nd September 2009]

IUCN, (2009); http://www.iucnredlist.org [Accesssed 28th July, 2009].

IUCN, Conservation International, Arizona State University, Texas A&M University, University of Rome, University of Virginia, Zoological Society London. (2008). An Analysis of Mammals on the 2008 IUCN Red List, available at: http://www.iucnredlist.org/mammals. [Accessed 18th August, 2009].

Lahoz Monfort, J. (2008) Habitat suitability modelling for the Alaotran gentle lemur (Hapalemur alaotrensis). Unpublished Thesis (M.Sc), *Imperial College London*.

Laikipia Wildlife Forum (2009); http://www.laikipia.org [Accessed 19th August, 2009].

Lees, B. (2007) BIOCLIM Isothermality; http://sres-associated.anu.edu.au/pathfinder/isothem.html [Accessed 2nd September 2009]

M'Cosh, J. (1837) *Topography of Assam*. Calcutta: Bengal Miltary Orphan Press.

MaxEnt, (2009); http://www.cs.princeton.edu/~schapire/maxent [Accessed 4th July 2009].

Meyer, D., Zeileis, A., and Hornik, K. (2009) *vcd: Visualising Categorical Data*. R Package version 1.2-4.

Millennium Ecosystem Assessment (2005a) *Ecosystem and Human Wellbeing: Synthesis*. Washington DC, Island Press.

Millennium Ecosystem Assessment (2005b) *Ecosystem and Human Wellbeing: Scenarios: Millennium Ecosystem Assessment Series Volume 2*. Washington DC, Island Press.

Mpala Community Trust, (2006); http://www.mpala.org/mct [Accessed 28th July, 2009].

Ngigi, S.N., Savenije, H.H.G., and Gichuki, F.N. (2007) Land use changes and hydrological impacts related to up-scaling of rainwater harvesting and management in upper Ewaso Ng'iro river basin, Kenya. *Land Use Policy* 24: 129 – 140.

Odadi, W.O., Young, T.P., and Okeyo-Owuor, J.B. (2007) Effects of Wildlife on Cattle Diets in Laikipia Rangeland, Kenya. *Rangeland Ecology and Managements* 60: 179 – 185.

Okello, M.M. (2005) Land Use Changes and Human-Wildlife Conflicts in the Amboseli Area, Kenya. *Human Dimensions of Wildlife* 10: 19 – 28.

Okita-Ouma, B., Amin, R., and Kock, R. (2007) Conservation and Management Strategy for the Black Rhino, and Management Guidlines for the White Rhino. *Rhinos Stakeholder's Workshop*, Naivasha, Kenya.

Park, C., (2008), *Oxford Dictionary of Environment and Conservation*, Oxford University Press, Oxford.

Parmesan, C. (1996) Climate and Species' Range. *Nature* 382: 765 – 766.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A. and Warren, M. (1999) Poleward Shifts in Geographical Ranges of Butterfly Species Associated with Regional Warming. *Nature* 399: 579 – 583.

Pebesma, E.J., and Bivand, R.S. (2005).Classes and methods for spatial data in R. R News 5 (2), available at: http://cran.r-project.org/doc/Rnews/.

Perch-Nielsen, S.L., Bättig, M.B., and Imboden, D. (2008) Exploring the Link Between Climate Change and Migration. *Climatic Change* 91: 375 – 393.

Phillips, S.J. (2005) A Brief Tutorial On MaxEnt. *AT&T Research* Available from: http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc.

Phillips, S.J., Anderson, R.P., and Schapire, R.E. (2006) Maximum Entropy Modelling of Species Geographic Distributions. *Ecological Modelling* 190: 231 – 259.

R Development Core Team (2009). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. Available at: http://www.R-project.org.

Reale, D., McAdam, A.G., Boutin, S. and Berteaux, D. (2003) Genetic and Plastic Responses of a Northern Mammal to Climate Change. *Proceedings of the Royal Society of London: Biological Sciences* 270: 591 – 596.

Rhino Resource Centre, (2009); http://www.rhinoresourcecenter.com/species/black-rhino [Accessed 10th August 2009].

Save The Rhino International, (2009); http://www.savetherhino.org [Accessed 19th August, 2009].

Stockwell, D., and Peters, D. (1999) The GARP Modelling System: Problems and Solutions to Automated Spatial Prediction. *International Journal of Geographical Information Science* 13: 143 – 158.

Swets, J.A. (1996) *Signal detection theory and ROC analysis in psychology and diagnostics: Collected Papers*. Mahwah, NJ: Erlbaum.

Swets, J.A., Dawes, R.M., and Monahan, J. (2000) Psychological Science Can Improve Diagnostic Decisions. *Psychological Science in the Public Interest* 1: 1 – 26.

Syangden, B., Sectionov, Ellis, S., Williams, A.C., van Strien, N.J., and Talukdar, B.K. (2008) *Report on the Regional Meeting for India and Nepal IUCN/SSC Asian Rhino Specialist Group (AsRSG).* Kaziranga National Park, Assam India.

Tajika, E. (1998) Climate Change during the Last 150 Million Years: Reconstruction From a Carbon Cycle Model. *Earth and Planetary Science Letters* 160: 695 – 707.

Thomas,C.D., and Lennon, J.J (1999) Birds Extend Their Ranges Northwards. *Nature* 399: 213.

Thomas, C., Cameron, A., Green, R., Bakkenes, M., Beaumont, L., Collingham, Y., Erasmus, B., Ferreira de Siquiera, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A., Midgley, G., Miles, L., Ortega-Huerta, M., Townsend Peterson, A., Phillips, O. And Williams, S., (2004), Extinction Risk from Climate Change, Nature, 427: 145 – 148.

Thuiller, W., Richardson, D., Pyšek, P., Midgley, G., Hughes, G., and Rouget, M. (2005) Niche-based Modelling as a Tool for Predicting the Risk of Alien Plant Invasions at a Global Scale. *Global Change Biology* 11: 2234 – 2250.

Treves, A., Wallace, R.B., Naughton-Treves, L., and Morales, A. (2006) Co-Managing Human-Wildlife Conflicts: A Review. *Human Dimensions of Wildlife* 11: 383 – 396.

United Nations (2003) Long-Range World Population Projections: Based on the 1998 Revision. *United Nations Population Division*, New York.

Vasu, N.K. (2002) Management Plan 2003/2004 – 2012/2013 for Kaziranga National Park. *Kaziranga National Park Forest Department*, Assam, India.

Watt, M.E. (1996) *Black Rhinos*. Calgary: Weigl Educational Publishers Ltd.

WDPA (2009); http://www.wdpa.org [Accessed 18th August 2009].

Woodruffe, R., Thirgood, S., and Rabinowitz, A., eds. (2005) *People and Wildlife: Conflict or Co-Existence?* New York: Cambridge University Press.

WorldClim (2009); http://www.worldclim.org [Accessed 10th August, 2009].

ZSL (2009) Edge of Existence; http://www.edgeofexistence.org [Accessed 2nd September, 2009].

Appendix A

Kappa Threshold Script for R

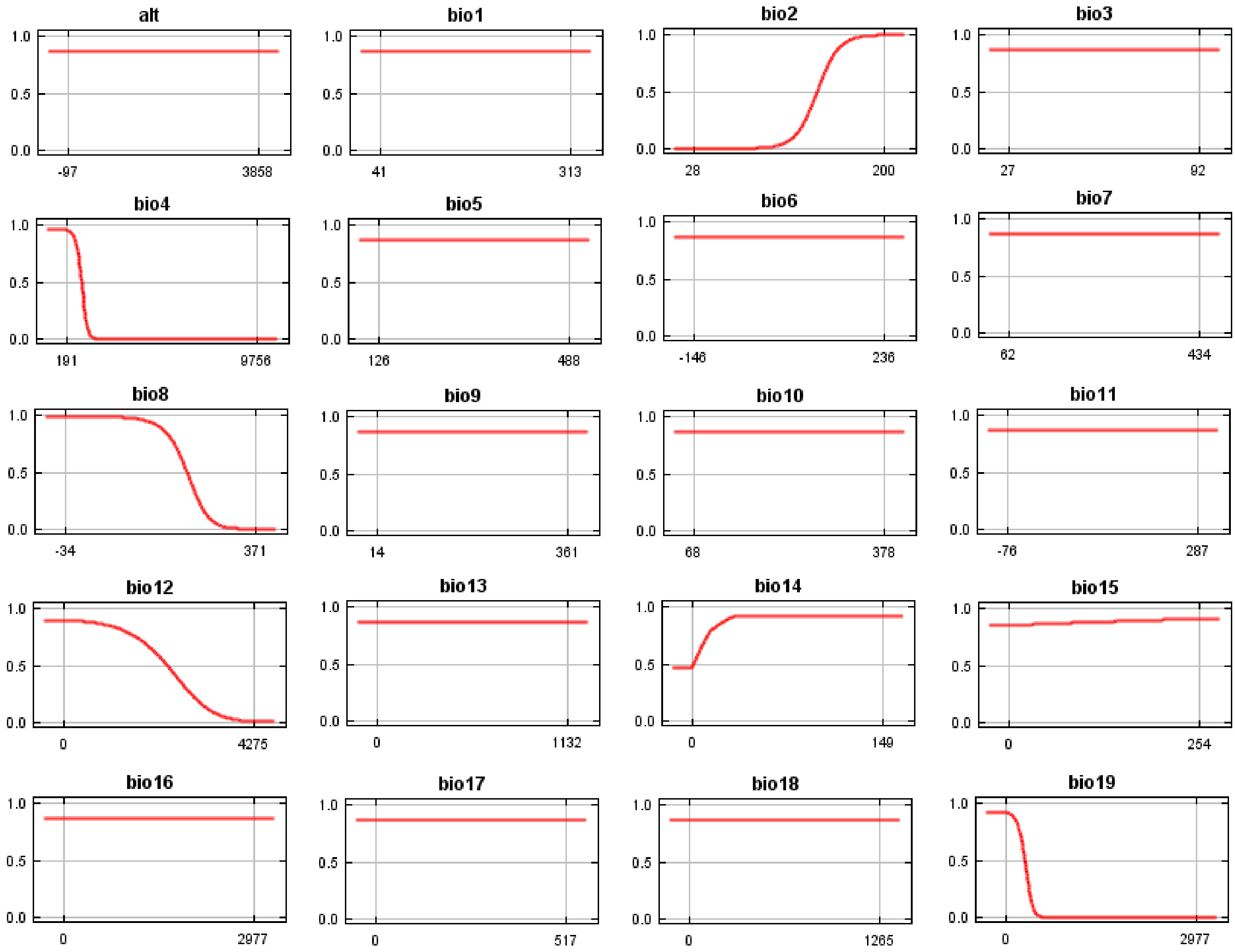
```
library(sp)

library (vcd)

setwd("working directory here")

omissionFile <- read.csv(file = "omission file name here.csv", header = TRUE, stringsAsFactors =
FALSE)

samplesFile <- read.csv(file = "sample prediction file name here.csv", header = TRUE,
stringsAsFactors = FALSE)

mapData <- read.asciigrid(fname = "asciigrid file name here.asc")

# Produce the ROC curve #

plot(1 - Training.omission ~ Fractional.area , data=omissionFile, type='l', col='red', ylim=c(0,1),
xlim=c(0,1))

abline(a=0, b=1) with(omissionFile, lines(Fractional.area, 1 - Test.omission, col='blue'))

# Calculate the AUC #

omissionFileAUC <- function(omissionFile, type='Train'){ type <- match.arg(type, c('Train','Test'))

omissionFile <- omissionFile[order(omissionFile$Raw.value),]

if(type == 'Train'){yvar <- omissionFile$Training.omission} else
{if(all(is.na(match(names(omissionFile), 'Test.omission')))) {stop('No test point omission data in ',
substitute(omissionFile))} else {yvar <- omissionFile$Test.omission}}

x <- c(1,omissionFile$Fractional.area,0)

yvar <- c(0, yvar, 1)

xDelta <- abs(diff(x))

yMeanHeight <- filter(1 - yvar, c(0.5,0.5), side=1)[-1]

return(sum(xDelta*yMeanHeight))}

omissionFileAUC(omissionFile, type='Train')

omissionFileAUC(omissionFile, type='Test')
```

```
# Combining the Sample Presence with the Map to get Background #

samplesToMapData <- function(samplesFile, mapData, tol=0.00001){samplesFile$gridIndex <-
getGridIndex(samplesFile[,1:2], mapData@grid)

ret <-  data.frame(score=mapData@data[,1])

uniqueLogScore <- unique(ret$score)

ret$trainingPresence <- ifelse(is.na(ret$score), NA, 0)

trainData <- subset(samplesFile, Test.or.train == 'train')

ret$trainingPresence[trainData$gridIndex] <- 1

if(any(samplesFile$Test.or.train == 'test')){ret$testPresence <- ifelse(is.na(ret$score), NA, 0)

testData <- subset(samplesFile, Test.or.train == 'test')

ret$testPresence[testData$gridIndex] <- 1}

samplesFile$score <- ret$score[samplesFile$gridIndex]

scoreDiff <- abs(samplesFile$score - samplesFile$Logistic.prediction)

if(any(scoreDiff > tol)){warning('Maxent values in map do not match logistic predictions in
samplesFile\n', '  - Tolerance =', tol, '\n  - Maximum absolute difference = ', max(scoreDiff), '\n',
'  Possibly raw or cumulative map output selected in MaxEnt?')}

ret <- ret[complete.cases(ret), ]

return(ret)}

mapPresence <- samplesToMapData(samplesFile, mapData)

# Confusion Matrices for a Given Threshold #

mapPresenceConfusion <- function(mapPresence, threshold=0.5, type='Train'){

type <- match.arg(type, c('Train','Test'))

mapPresence$pred <- factor(with(mapPresence, score >= threshold), levels=c(FALSE, TRUE))

if(type == 'Train'){conf <- with(mapPresence, table(pred, trainingPresence))} else {
if(all(is.na(match(names(mapPresence), 'testPresence')))){stop('No test point omission data in ',
substitute(omissionFile))} else {conf <- with(mapPresence, table(pred, trainingPresence))}}

dimnames(conf) <- list(Predicted=c("Absent", "Present"), Observed=c("Absent", "Present"))

return(conf)}

mapPresenceConfusion(mapPresence)
```

```
# Kappa Calculation from Different Thresholds #

kappaData <- data.frame(thresh <- seq(0,1,by=0.005), Kappa=NA, KappaASE=NA)

for(ind in seq(along=kappaData$thresh)){currConfusion <- mapPresenceConfusion(mapPresence,
kappaData$thresh[ind])

currKappa <- Kappa(currConfusion)

kappaData[ind, 2:3] <- currKappa$Unweighted}

plot(Kappa ~ thresh, type='l', data=kappaData)

maxKappa <- with(kappaData, thresh[which.max(Kappa)])

abline(v=maxKappa, col='red')

mapData$maxKappa <- factor(mapData@data[,1] >= maxKappa, levels=c(FALSE, TRUE),
labels=c("Absent", "Present"))

spplot(mapData, 'maxKappa')
```

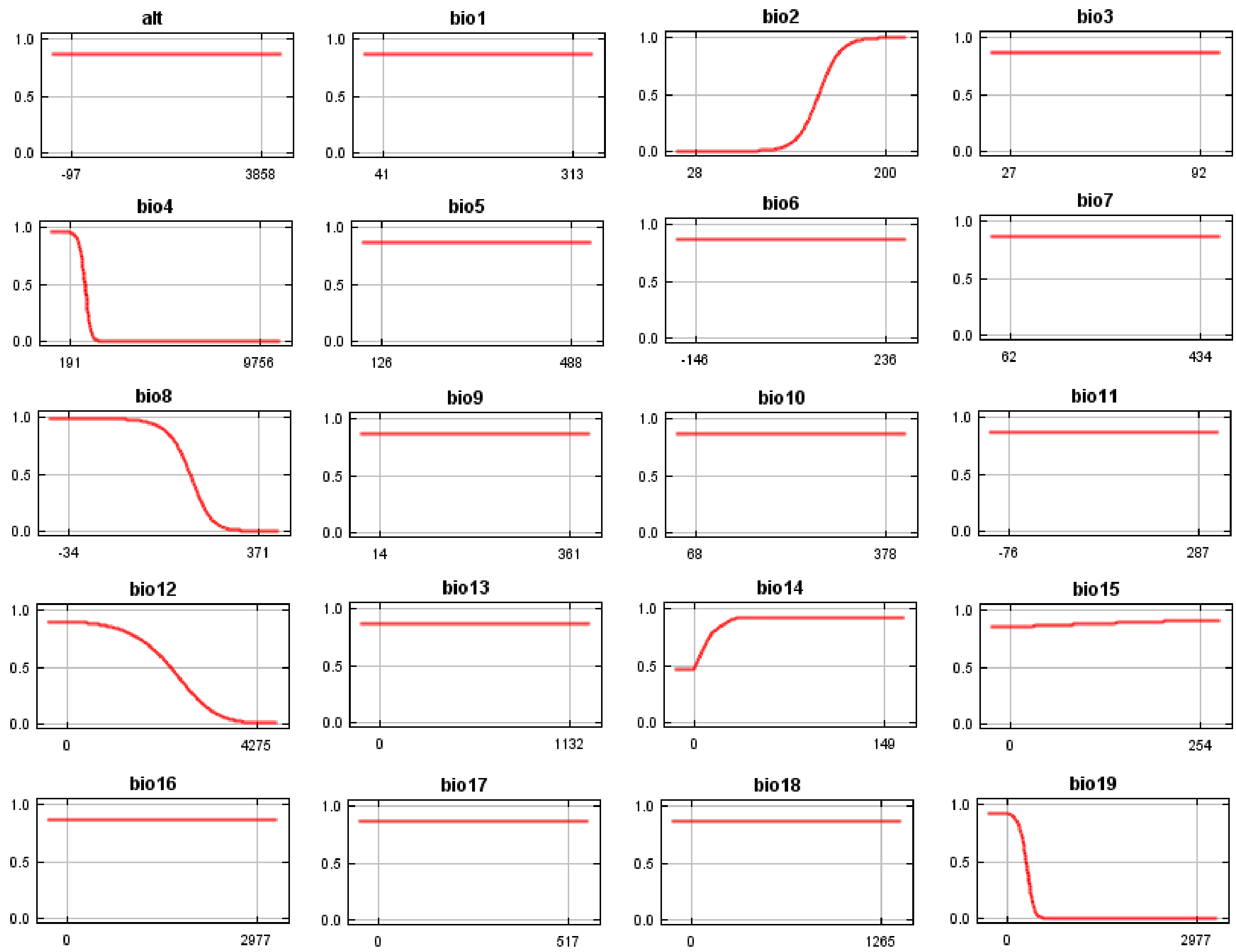
Appendix B

Response Curves for *D. bicornis michaeli*, based on the protected range



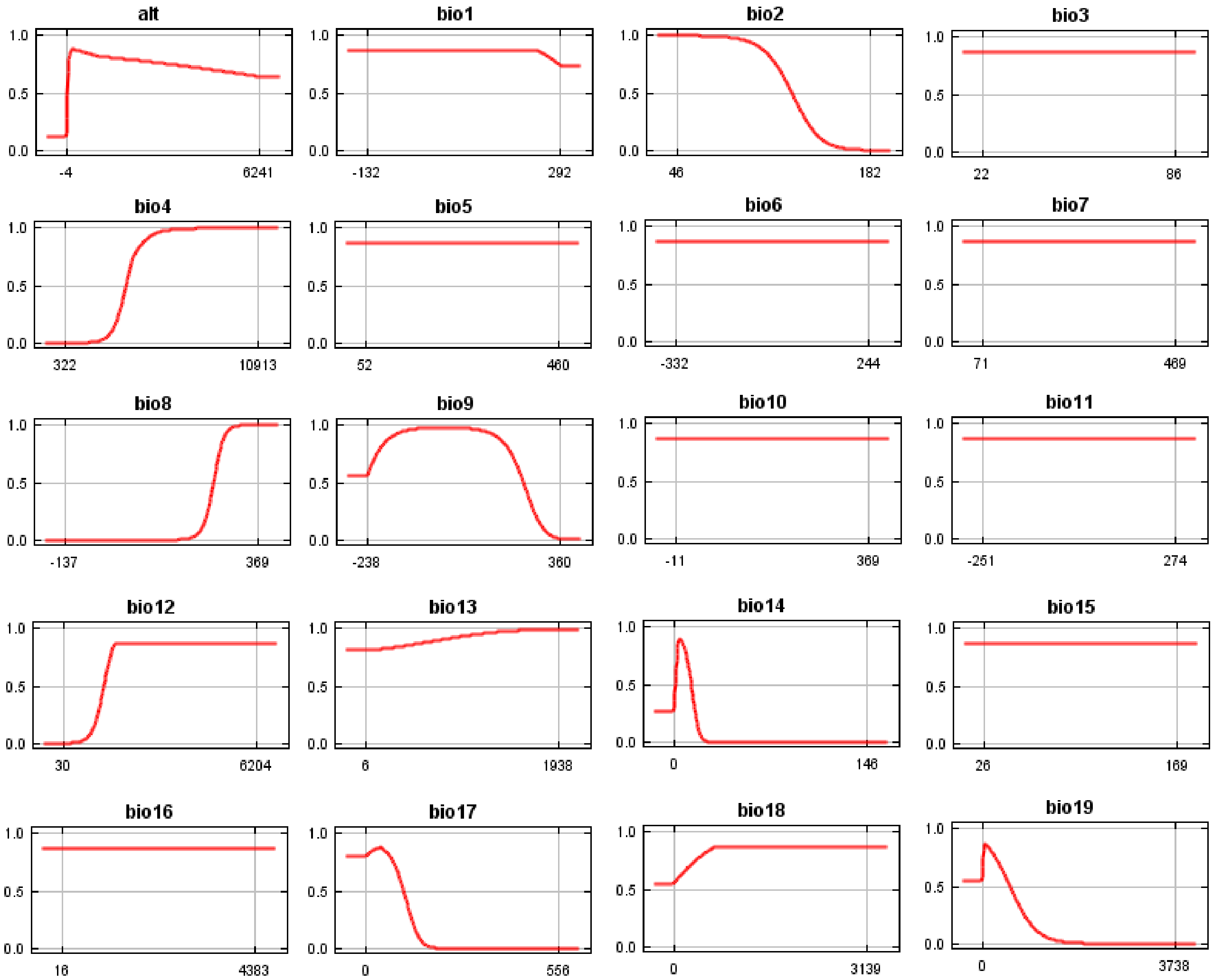
The response curves for each environmental variable used in MaxEnt, and the probability of presence of *D. bicornis michaeli* based on its protected range in Laikipia. The temperature values are in °C (Bio1 – Bio11) – e.g. 41 = 4.1°C, as seen in Bio1. The precipitation values (Bio12 – Bio19) are in millimetres (mm) – e.g. 2977 = 297.7mm, as seen in Bio16. Altitude (alt) is shown in metres (m).

Response Curves for *D. bicornis michaeli*, based on the historic range



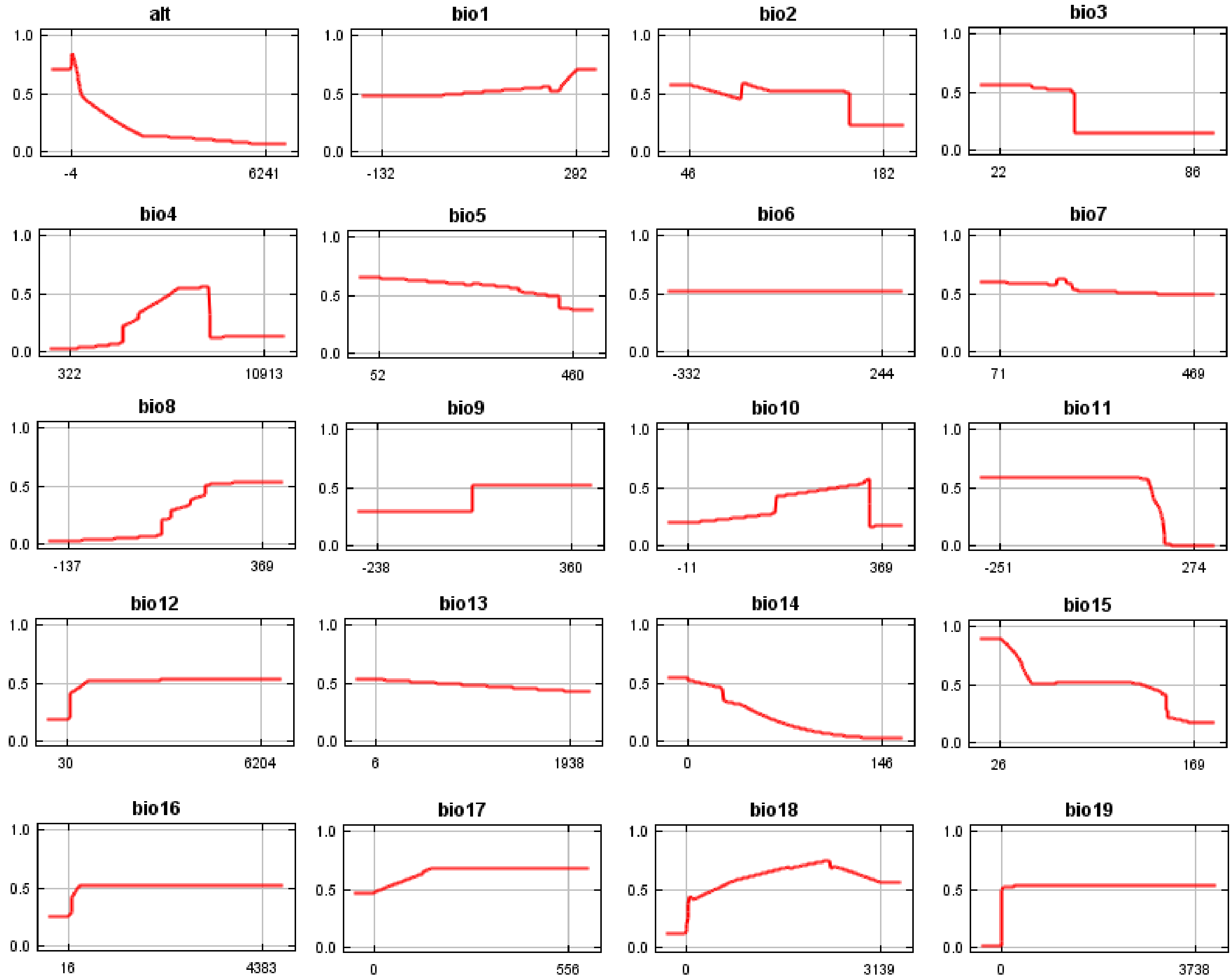
Response curves of each environmental variable used in the species distribution model, indicating the constraining values of each variable. Temperature (Bio1 – Bio11) are shown in °C, while precipitation (Bio12 – Bio19) are shown in millimetres (mm), and altitude (alt) is shown in metres (m).

Response curves for the protected range of *R. unicornis*



The environmental variable response curves indicate the probability of presence at differing values, indicating the constraining range of temperature, altitude or precipitation, based on the protected range of *R. unicornis*. Temperature (Bio1 – Bio11) is shown in °C, precipitation (Bio12 – Bio19) in millimetres (mm) and altitude (alt) in metres (m).

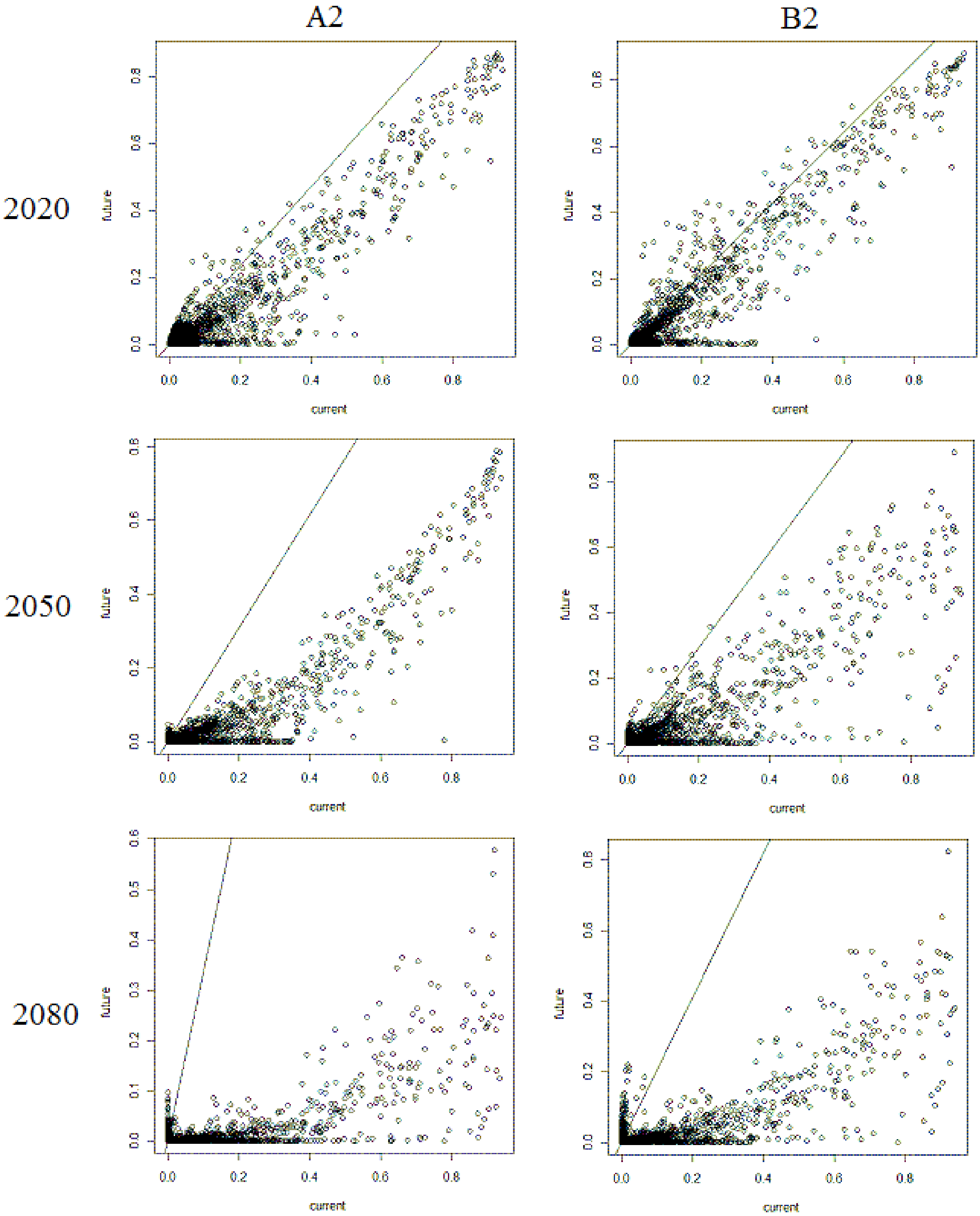
Response curves, based on the historic range, of *R. unicornis*



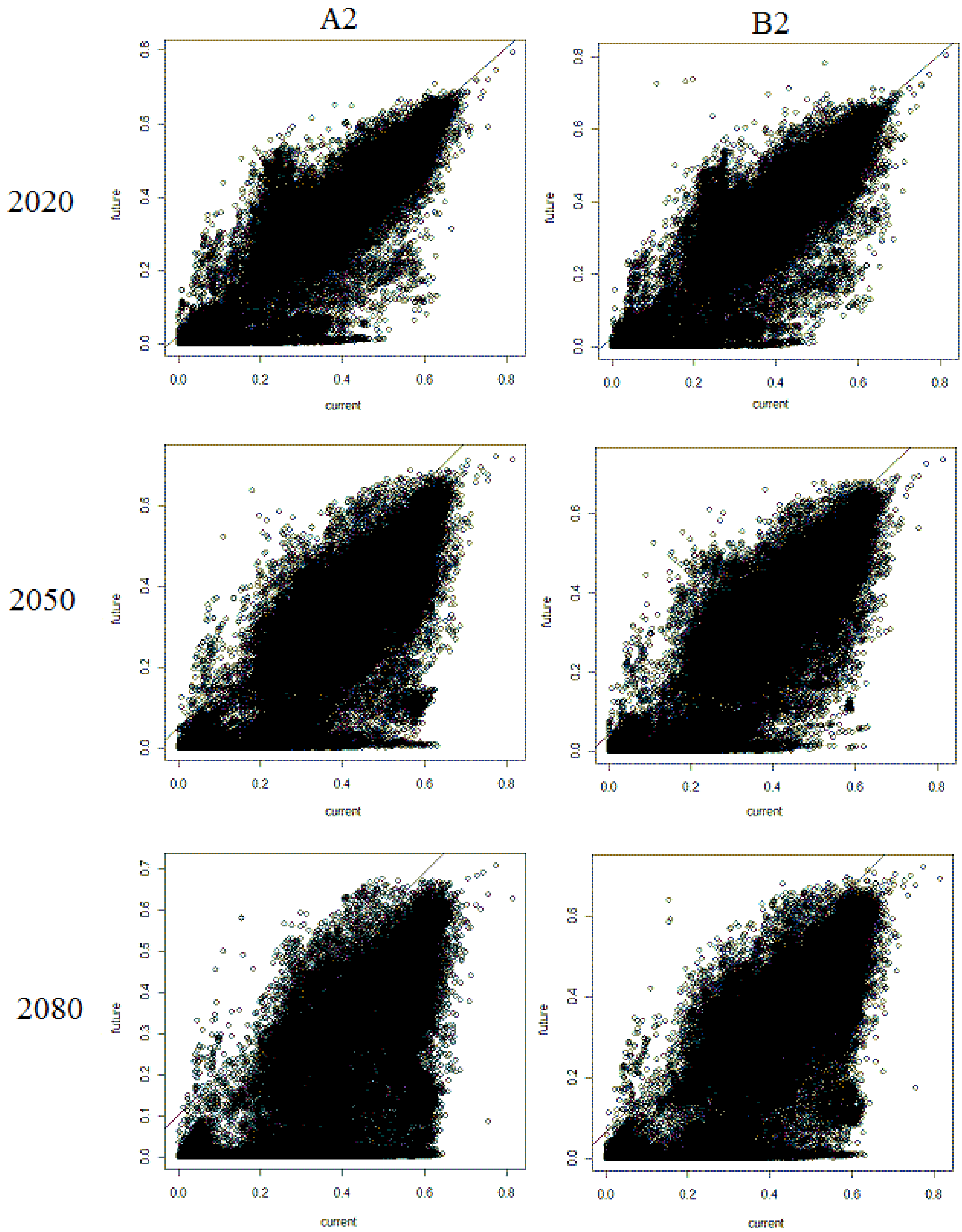
The response curves show the constraining values at which *R. unicornis* is likely to occur, for temperature (Bio1 – Bio11) in °C, precipitation (Bio12 – Bio19) in millimetres (mm) and altitude (alt) in metres (m). The graphs represent the environmentalmental variables used to model the species distribution based on its historic range.

Appendix C

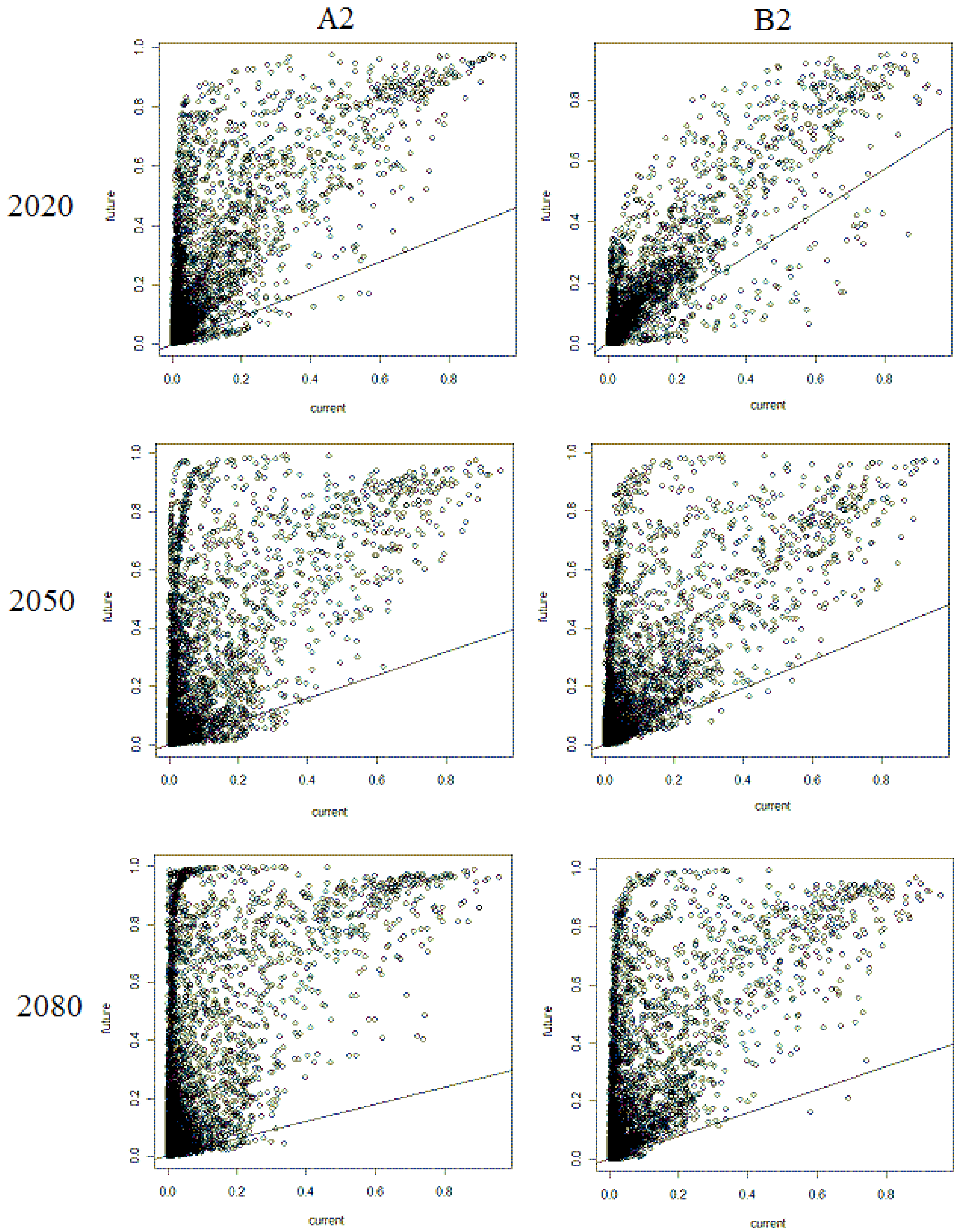
Correlation Graphs for the protected range of *D. b. Michaeli*



Correlation graphs for the Historic Range of *D. b. michaeli*



Correlation Graphs of the protected range of *R. unicornis*



Correlation graphs for the historic range of *R. unicornis*