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Modeling Cheetah *Acinonyx jubatus* Fundamental Niche in Kenya

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Abstract: The cheetah is currently recognized by IUCN as a threatened species. Kenya is one of country with significant cheetah population in the world though it fundamental niche is not well known. Wildlife can live in an area only if basic resources such as food, water, and cover are present and if the species is adapted in ways that allow them to cope with the climatic extremes, selection involves several levels of discrimination and spatial scales and a number of potentially interacting factors. This study was to model cheetah fundamental niche using suitable environmental predictors and evaluates suitability of current protected area coverage in its conservation. Two types of model input data used were cheetah occurrence locations and a suite of environmental variables thought to have a direct physiological role in limiting the ability of the species to survive. The species occurrence records and environmental variables were entered into a MaxEnt model which uses maximum entropy algorithm to identify environmental conditions that are associated with species occurrence. Ideal fundamental niche for cheetah were found to be localities within an elevation range of 1600-2100 meters above sea level, receiving mean annual precipitation of 800 mm, with the warmest quarter of the year receiving 250 mm, the wettest month receiving 120 mm, precipitation of coldest quarter 10 mm and temperature seasonality ranges of 150°. Cheetah fundamental niche run across protected areas and for effective conservation, Results could be used to direct conservation effort go beyond parks and reserves by encouraging community conservancies and development of ecological corridors. Protected area planning could benefit too from these results.

Keywords: Cheetah, Fundamental Niche, Protected Areas, Community Conservancies

1. Introduction

The fundamental niche of a species is the set of environmental conditions within which a species can survive and persist. The fundamental niche may be thought of as an ‘n-dimensional hyper-volume’, every point in which corresponds to a state of the environment that would permit the species to exist indefinitely (Hutchinson, 1957). The fundamental niche describes conditions suitable for survival of the species, and is thus of great importance for conservation. It is also referred to as potential or physiological niche, which denotes the full range of conditions under which the species actually does best hence potentially could be found. It can also be used to estimate the species’ ecological niche, for example by removing areas where the species is known to be absent because of con-specifics (Butler 1980), inter-specific competitors (Werner and Hall 1979), predators (Werner et al. 1983), human settlement or any other habitat destruction. Although a species’ realized distribution may exhibit some spatial correlation, the potential distribution does not, so considering spatial correlation is not necessarily desirable during species distribution modeling.

An animal’s habitat is, in the most general sense, the place where it lives. Wildlife can live in an area only if basic resources such as food, water, and cover are present and if the animals have adapted in ways that allow them to cope with the climatic extremes and the competitors and predators they encounter (Morison 2006). Habitat selection involves several levels of discrimination and spatial scales and a number of potentially interacting factors.

Ecological niche is realized or actual observed abundance distribution of a species. Usually will not include the full range of conditions under which the species could potentially be found and, in particular, may not include the physical conditions in which the species actually does best. The observed distribution of a species may differ from its fundamental niche if the species is excluded from the conditions in which it does best by competition, predation or human activities. Modeling of these factors with species presence data will result in a wealth of information about why and where we find a species. This is referred to as species distribution modeling (Guisan & Zimmermann 2000).

Species distribution models are empirical models relating field observations to environmental predictor variables based on statistically or theoretically derived response surfaces (Guisan & Zimmermann 2000). They estimate the relationship between species records at sites and the environmental and/or spatial characteristics of those sites (Franklin, 2009). Actual or potential geographic distribution of a species is estimated best by characterizing the environmental conditions that are suitable for the species, and to then identify where suitable environments are distributed in space. The environmental conditions that are suitable for a species may be characterized using either a mechanistic or a correlative approach. Mechanistic models aim to incorporate physiologically limiting mechanisms in a species' tolerance to environmental conditions. It require detailed understanding of the physiological response of species to environmental factors and are therefore difficult to develop for all but the most well understood species.

Correlative models aim to estimate the environmental conditions that are suitable for a species by associating known species' occurrence records with suites of environmental variables that can reasonably be expected to affect the species' physiology and probability of persistence. The central premise of this approach is that the observed distribution of a species provides useful information as to the environmental requirements of that species. Since spatially explicit occurrence records are available for a large number of species, the vast majority of species' distribution models are correlative, hence its use this research. Two types of model input data are needed: 1) known species' occurrence records; and 2) a suite of environmental variables thought to have a direct physiological role in limiting the ability of the species to survive.

The model can be used to predict species' occurrence in areas where the distribution is unknown. Thus, a set of environmental variables for the area of interest is input into the model and the suitability of conditions at a given locality is predicted. In many cases the model is used to 'fill the gaps' around known occurrences (e.g., Anderson et al., 2002a; Ferrier et al., 2002). In other cases, the model may be used to predict species' distributions in new regions (e.g. to study invasion potential, for review see Peterson 2003) or for a different time period (e.g. to estimate the potential impacts of future climate change, Pearson and Dawson, 2003).

Several recent studies comparing up to 16 of these approaches indicated that maximum entropy (MaxEnt) modeling performed as well or better than the other approaches (Elith, 2006, Hernandez, 2006 and Phillips 2006). As such, MaxEnt model was chosen to model and understand the suitable habitats for cheetah in Kenya.

Cheetah is a threatened species and to save it, one first needs to know where the species prefers to live, and what its requirements are for survival, i.e., its fundamental niche (Hutchinson, 1957). Studies in Serengeti, Tanzania shows cheetah inhabiting large, overlapping ranges averaging 833 km^2(Caro, 1994). This large area requirement frequently brings them into contact with humans as they may not be contained in national parks and reserves (Woodroffe & Ginsberg 2000). In Kenyan rangelands, predators including cheetah, may kill livestock and are therefore themselves killed by local pastoralists (Woodroffe, 2006). Gros, 1997 estimated total number of 793 cheetahs in protected areas of Kenya. Based on prey availability Masailand (Kajiado and Narok districts) and the dry northern Districts appear to offer the best prospects for cheetah conservation in Kenya based on relative prey availability (Gros,1997). Contrary to the prediction that prey biomass can be used as a predictor of cheetah numbers, a Serengeti study found that cheetahs frequently use areas with low prey density (Durant 1998). By selecting a variety of prey species the cheetah can survive in a range of conditions and can adapt to changes in the environment by changing hunting style (Frame and Frame 1977, Caro 1994). We aim to design a predictive cheetah distribution model, identify the set of most suitable environmental predictors of cheetah occurrences, analyze suitable areas for cheetah conservation in Kenya, and evaluate suitability of current protected area coverage in cheetah conservation.

2. Materials and Method

2.1. Study Area

The study was undertaken in Kenya, located in East Africa, which has a total area of 582,650 km^2. Kenya borders the Indian Ocean to the east, with a coastline of 536 kilometers, Somalia to the northeast, Ethiopia to the north, Southern Sudan to the northwest, Uganda to the west, and Tanzania to the south. It is located between latitudes 5°40' N and 4°4' S and between longitudes 33°50' and 41°45' E (Figure 1).

The country has a tropical climate, hot and humid at the coast, temperate inland and very dry in the north and northeast parts of the country. The long rains occur from April to June and short rains from October to December. The hottest period is from February to March and coldest in July to August. About 10% of Kenya area is set been set aside as either national or reserves for wildlife conservation, first national Nairobi national park having been established in 1946.

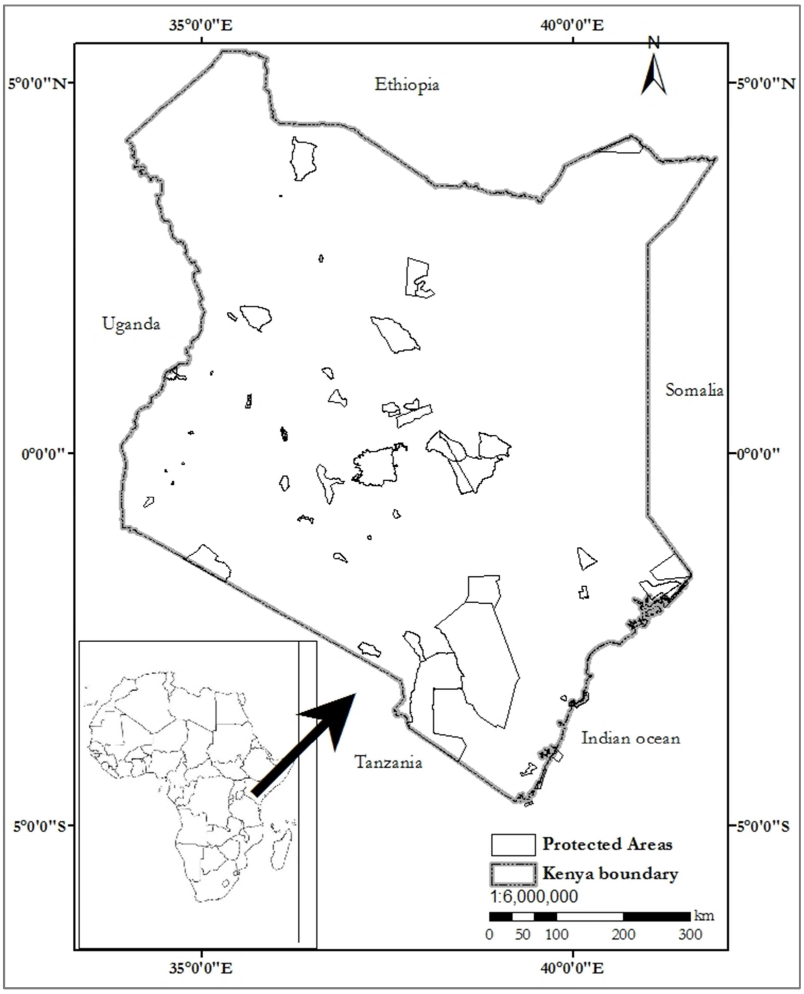

Figure 1. *A map showing the study area.*

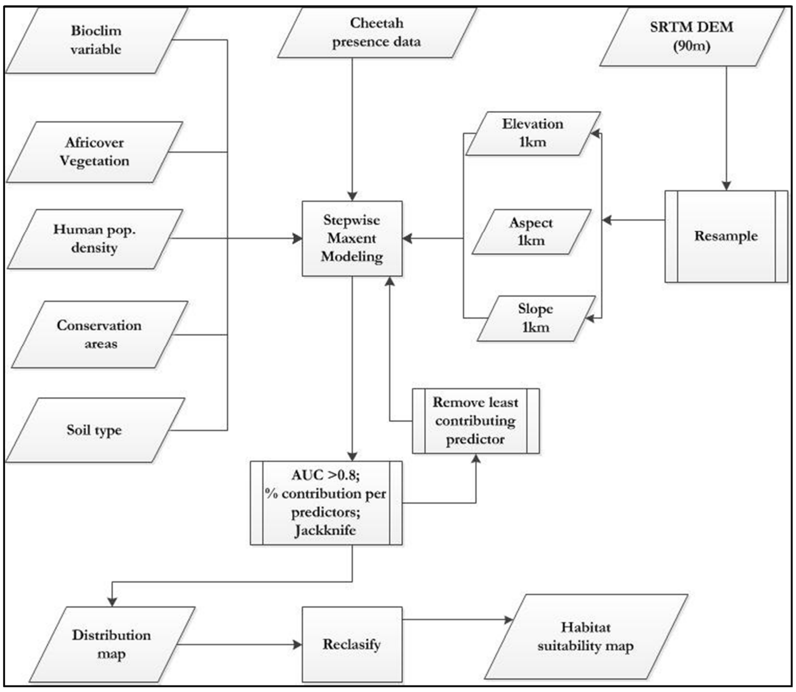

Figure 2. *Flowchart of the modeling process using MaxEnt Model.*

2.2. Research Work Flow

MaxEnt model require two types of data input: biological data species geo-referenced locations, describing the species' distribution, and environmental data, a suite of environmental variables of Vegetation cover types, Soil type, Bioclimatic data, slope, elevation, Conservation areas and human population density, describing the landscape in which the species is found (Figure 2).

2.3. The Target Species

Cheetah (*Acinonyx jubatus*) is a medium-large cat, with females weighing an average of 35.9 kg and males 41.4 kg (Caro 1994). Genetic analysis suggests that cheetah cats have diversified in three main lineages, with the cheetah (*Acinonyx jubatus*) occupying the pantherine lineage together with lions, tigers and lynxes (Caro 1994). With the exception of a small population in Iran (Jackson 1998) there is scant evidence of cheetahs outside Africa. The main remaining populations exist in southern and eastern Africa (Caro 1994).

Cheetahs are diurnal and hunt during the day (Caro 1994). Various strategies are employed including stalking, approaching prey in full view and flushing hidden prey from long vegetation (Caro 1994), all utilizing the cheetah's exceptionally high running speed. Preferred food of cheetahs varies with location. For example, on the Serengeti plains, Thomson's gazelles are the preferred prey, whilst impala are favoured in South Africa and puku in Zambia (Caro 1994) although most preferred species weigh less than 40 kg (Schaller 1972a).

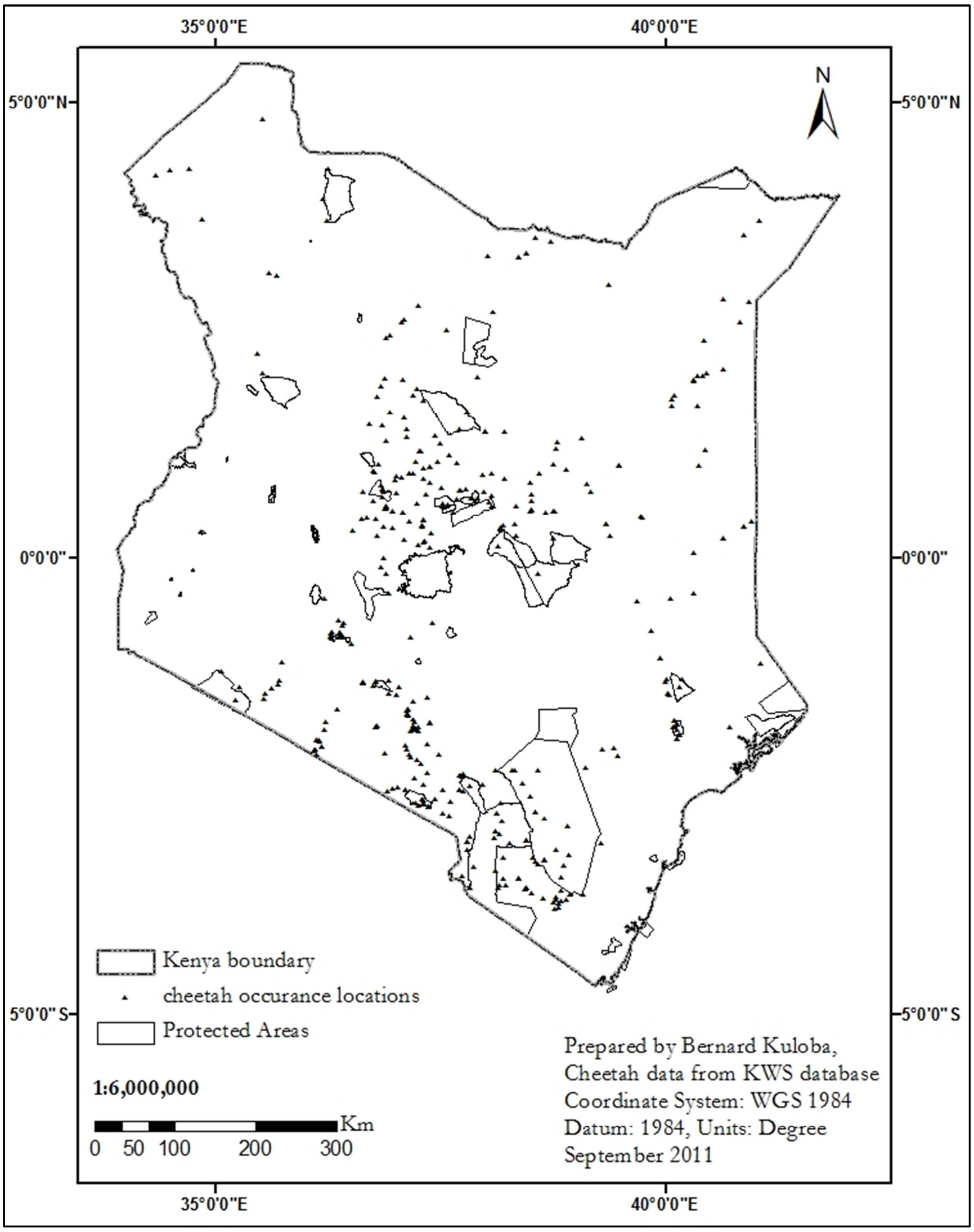

Figure 3. *Map showing spatial data on cheetah species known occurrence in Kenya (2004-2007).*

Cheetah is currently recognized by IUCN as a threatened species (IUCN 2010). The current conservation status of the cheetah (*Acinonyx jubatus*) in Kenya is a controversial issue. Because cheetahs are elusive and typically roam over large home ranges, it is difficult to discern whether the species is actually rare or merely rarely seen, let alone if it has recently become scarce, (Gros, 1997). Over the past 30 years, the fear that cheetah numbers could be declining in the country instigated several surveys of the cheetah's distribution and abundance, (Graham and Parker, 1965; Myers, 1975; Hamilton, 1986).

2.4. Species Observation Data

309 geo referenced cheetah presence data points in the entire cheetah range in Kenya were used in this research. The data was collected during a 2004- 2007 joint national survey by Action for Cheetah in Kenya, Cheetah Conservation Fund, East African Wildlife society and Kenya Wildlife Service. A field interview survey was used, where data were collected principally by means of detailed interviews. This was done by driving to villages, farms, ranger's outpost and protected areas throughout the country to make direct contacts with informants.

2.5. Environmental Predictors

Table 1 below provides a summary of the environmental variables used in the survey including the source of the environmental variable data.

Table 1. *Suite of potential environmental variables used in modeling.*

Environmental Variables	Units	Data type	Spatial	Source
Soil type	types	Categorical	Raster	www.africover.org
Vegetation cover	types	Categorical	Raster	www.africover.org
Bioclimatic data	°C and mm	Continuous	Raster	www.worldclim.org
Slope	Degree	Continuous	Raster	www.worldclim.org
Aspect	Degree	Continuous	Raster	www.worldclim.org
Elevation	M.a.s.l	Continuous	Raster	www.worldclim.org
Conservation areas	2 units	Categorical	Vector	www.kws.org
Human Pop.density	3 units	Categorical	Vector	www.wri.org

2.6. The Maxent Model

Modeling approach: Two types of data used were known cheetah species geo referenced occurrence locations and a suite of environmental variables of Vegetation cover types, Soil type, Bioclimatic data, slope, elevation Conservation areas and human population density. The occurrence points and environmental variables were entered into maximum entropy algorithm that aims to identify environmental conditions that are associated with species occurrence using MaxEnt software Version 3.3.3e, (Phillips et al. 2005). Fifty individual MaxEnt models were run in batch mode with the following settings: Auto features (feature types are automatically selected depending on the training sample size), perform jackknife tests, logistic output format, random test percentage = 30, regularization multiplier = 1, maximum iterations = 1000, convergence threshold = 0.0001, and maximum number of background points =10,000. This default setting was used because it has been validated in studies over a wide range of species and environmental conditions, and found to be robust to unknown prevalence, easier to interpret (Phillips, 2008).

Determining the most suitable environmental variable: While the model was being trained, track of environmental variable with highest gain when used in isolation to the model were noted. Each step of the MaxEnt algorithm increases the gain of the model by modifying the coefficient for a single feature; the program assigns the increase in the gain to the environmental variable(s) that the feature depends on. Jackknife test was used to assess the importance of each variable. Following this approach, the least important variable from the full model was determined and dropped from subsequent models. Then a new model was constructed with all predictor variables except the previously dropped variable. The weakest of the remaining variables was again determined using the jackknife test and was dropped from subsequent models. This procedure was continued until only minimum variables remained out of the initial 21 with at least AUC equal or more than 0.8. AUC ranges from 0.5 for models that are no better than random to 1.0 for models with perfect predictive ability. Phillips et al. (2006) demonstrated how the test can be applied using randomly selected 'pseudo-absence' records in lieu of observed absences. In this case, AUC tests whether the model classifies presence more accurately.

Model evaluation: The accuracy of this model was tested to determine its relevance, through receiver operating characteristic (ROC) plots, ROC plot is a plot of sensitivity and 1–specificity, with sensitivity representing how well the data correctly predicts presence, whereas specificity provides a measure of correctly predicted absences. Available data is partitioned into calibration and test datasets. The relative proportions of data included in each data set are somewhat arbitrary, and dependent on the total number of locality points available 70% for calibration and 30% for testing is common, (Huberty, 1994).

Mapping probability of presence: The point-wise mean image of the 50 output grids at 95 % confidence interval was generated from the MaxEnt model with probability of presence ranging from 0 to 1. The map represents probability of finding cheetah in any given location in the country, where 0 probability indicates absence while one 1 presence is certain given the prevailing environmental predictors. The image uses colours to indicate variation in predicted probability of presence. The map range from high probability of suitable conditions for the species, to typical conditions of those where the species is found and to shades indicating low predicted probability of suitable conditions.

Suitability of protected areas: The predicted conditions within protected areas were determined. The point wise image was reclassified into three classes, highly suitable where probability of presence is greater than 0.5, suitable where probability of presence is greater than 0.2 but less than 0.5 and not suitable habitat where probability of presence is less than 0.2. The country protected area coverage boundary was overlaid on the predicted probability map. The three classes within protected areas were determined. The effectiveness of protected area coverage was determined by estimating proportion of suitable areas within protected areas and how much of each class within protected areas. The suitable areas outside the protected areas were determined by subtracting areas within protected areas from total area generated by the model.

3. Results

3.1. The Full Model

Figure 4 below summarizes results of the full model. The jackknife test variable of importance, the environmental variable with highest gain when used in isolation was soils, which therefore appears to have the most useful information by itself. The environmental variable that decreased the gain most when it is omitted is precipitation of warmest quarter of the year (bio_180), which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over 50 replicate runs. Although soil predictive power was the best it was not used in the subsequent modeling because its resolution was low at 3km² compared to the rest of other environmental variables of 1 km². Re-sampling other variables to 3km would have lead to loss of details.

3.2. Model Selection

The environmental variable with highest gain when used in isolation was annual precipitation (bio_12), which therefore appears to have the most useful information by itself (Figure 5). The environmental variable that decreases the gain the most when it is omitted is elevation, which therefore appears to have the most information that isn't present in the other variables in this model.

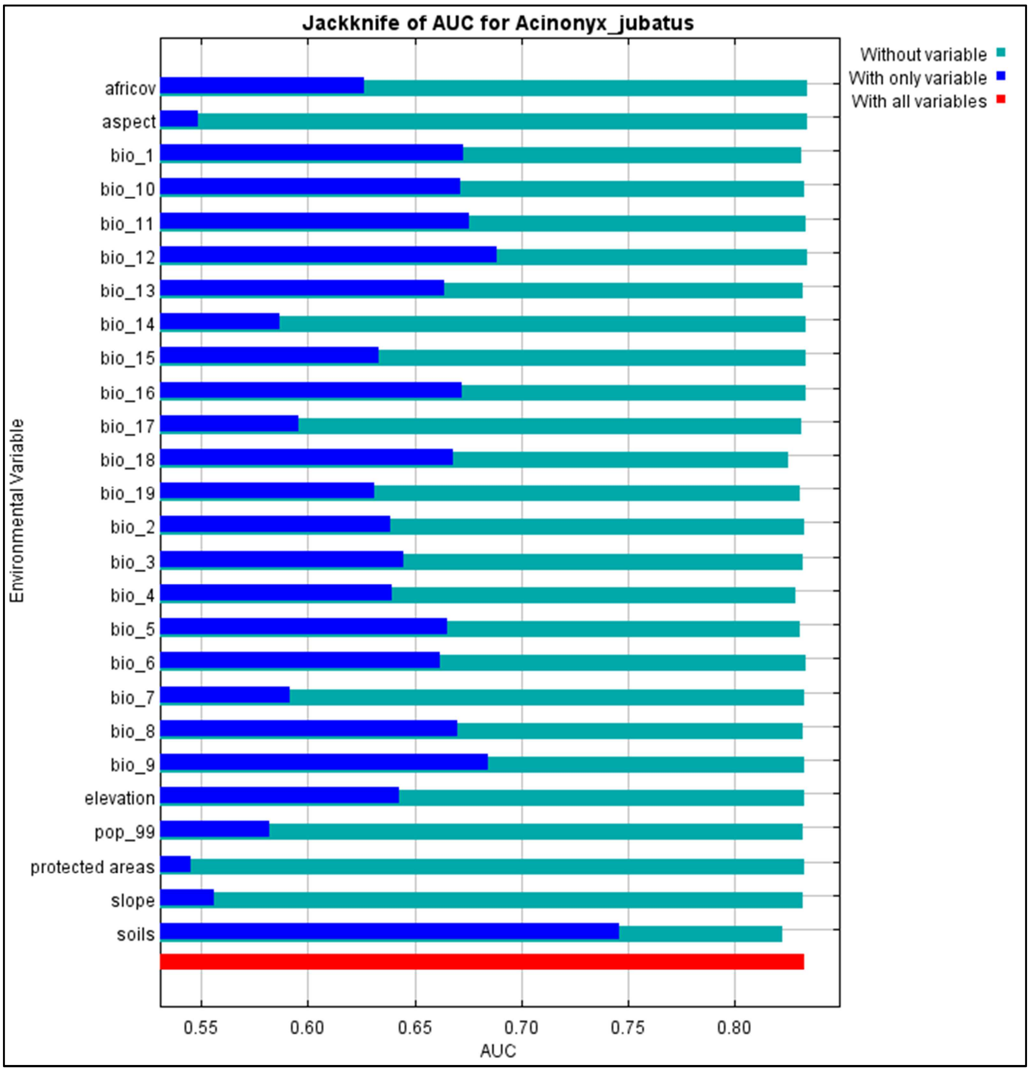

Figure 4. *Initial full model with all 26 potential environmental variables.*

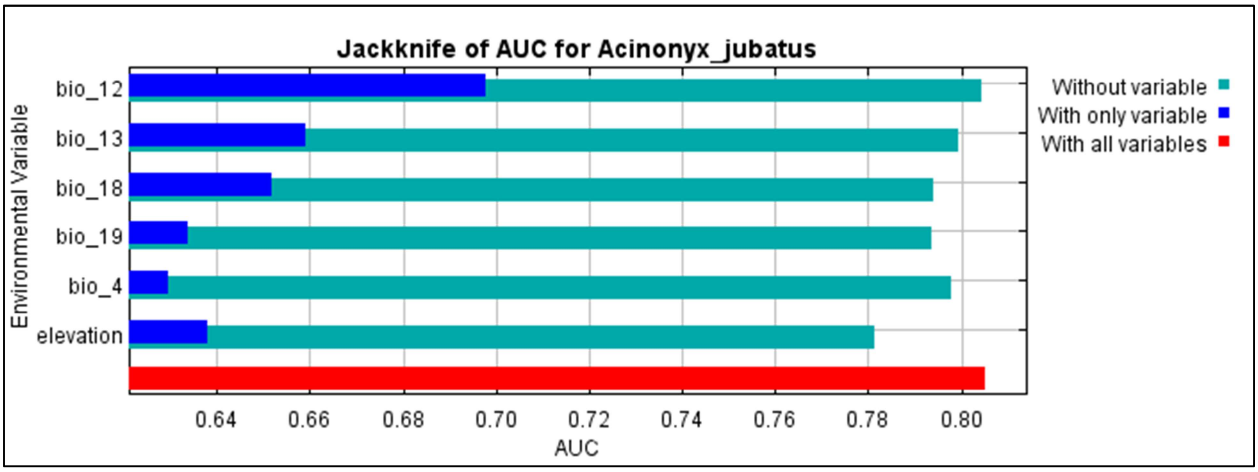

Figure 5. *Cheetah distribution predictive model using the most suitable environmental variables.*

Values shown are averages over 50 replicate runs. Other variable in the model were precipitation of the wettest month (Bio13), temperature seasonality (bio4) and precipitation of warmest month (bio18). Temperature seasonality appears to contribute little but when left out the model AUC fell under 0.8 indicating prediction was no better than random.

3.3. Analysis of Environmental Variable Contributions

Table 2 below gives estimate of relative contributions of each environmental variable to the model. Values shown are averages of 50 replicate runs. 70% of influence of the model was from precipitation, with precipitation during the warmest quarter of the year contributing about 28%. Elevations contributed 17% whereas temperature seasonality contributed below 10%. Relationship between precipitation and temperature were very important as seen from precipitation of warmest and coldest quarter contributing 50% of the total. In terms of permutation importance precipitation of the coldest quarter was the highest with about 40% followed by elevation. Precipitation of the wettest month of the year was the least.

The six final environmental variable used are shown in figure 6 below with their ranges, indicating Kenya to have varied environmental conditions. Annual precipitation range from 172-2625mm, precipitation of the wettest month of the year 42-697, precipitation of warmest quarter 23-1011, precipitation of coldest quarter 0-617,elevation -1-4725masl and temperature seasonality 48-172°.

Table 2. *Contribution and permutation importance of each variable in the model.*

Environmental variable	Percent contribution %	Permutation importance %
Precipitation of warmest quarter(bio_18)	26.8	14.4
Precipitation of coldest quarter (bio_19)	23.7	39.3
Elevation	17.4	21
Annual rainfall (bio_12)	12.3	2.9
Temperature seasonality (bio_4)	10.4	11.9
Precipitation of wettest month (bio_13)	9.4	10.6

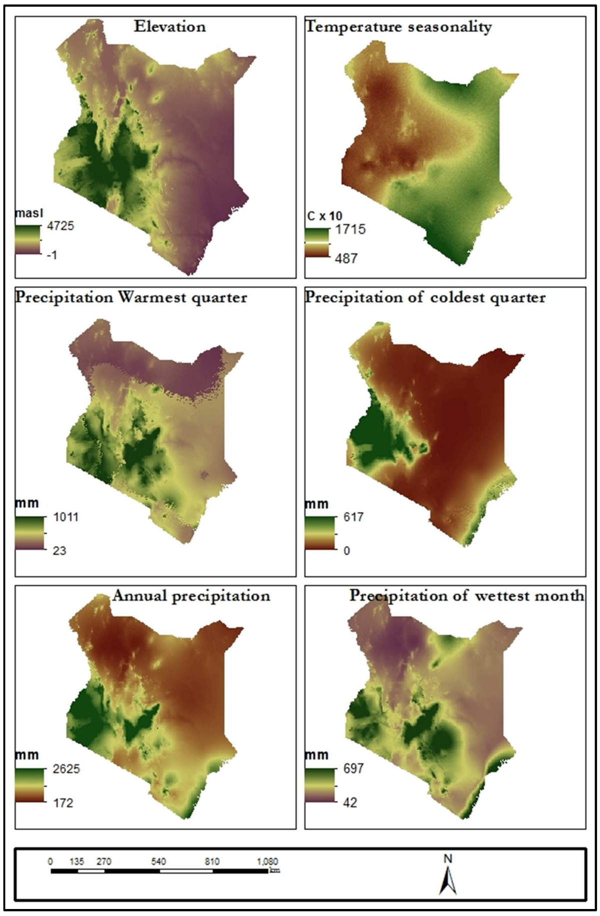

Figure 6. *Environmental variables with highest influence on cheetah distribution.*

3.4. Model Evaluation

Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate 50 runs. The omission rate is close to the predicted omission, because of the definition of the cumulative threshold. The omission rate is very close to the predicted omission hence the model is good (Figure 7).

Figure 8 below shows receiver operating characteristic (ROC) curve of the model for the same data, averaged over the 50 replicate runs. The specificity is defined using predicted area, rather than true commission. The model was also evaluated using the receiver operating characteristic (ROC) curve, averaged over the 50 replicate runs. Specificity was defined using predicted area, rather than true commission. The average test AUC for the 50 replicate runs is 0.803, and the standard deviation is 0.015, which was above 0.8. AUC range is 0.5-1.0, with values between 0.5-0.7 indicating low discriminate ability, values between 0.7-0.9 indicating moderate discriminate ability, and values > 0.9 indicating high discriminate ability (Pearce and Ferrier 2000, Manel *et al.*, 2001). The AUC value of 0.8 is an indication that the model is good.

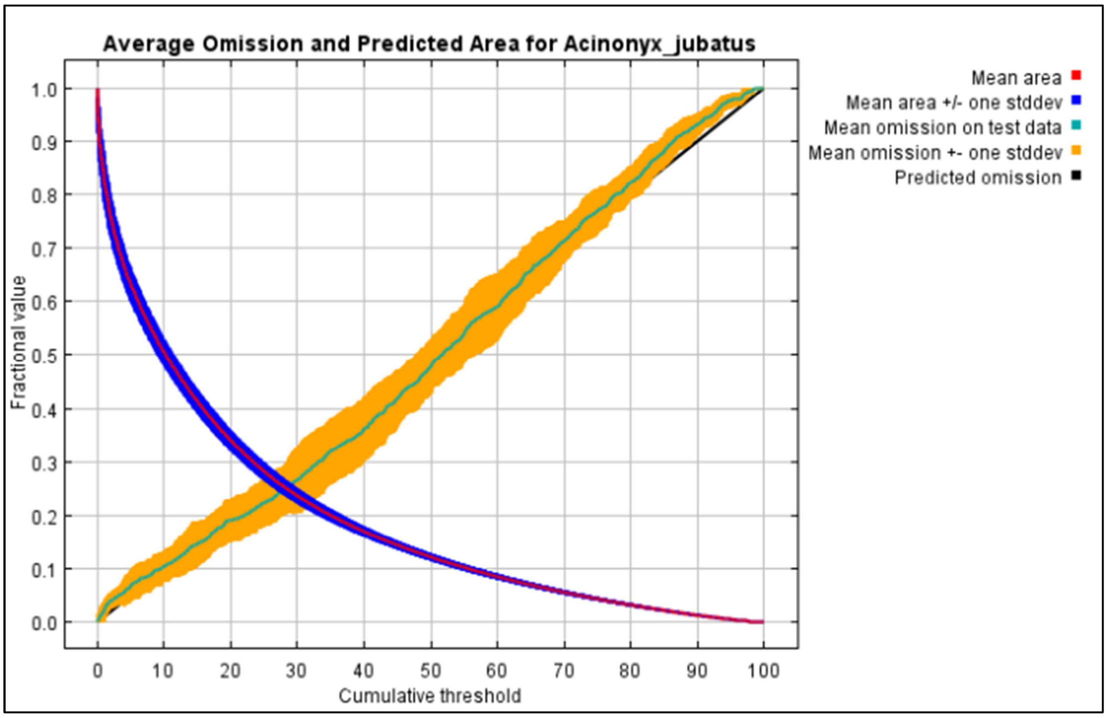

Figure 7. *Test omission rate and predicted area as a function of the cumulative threshold.*

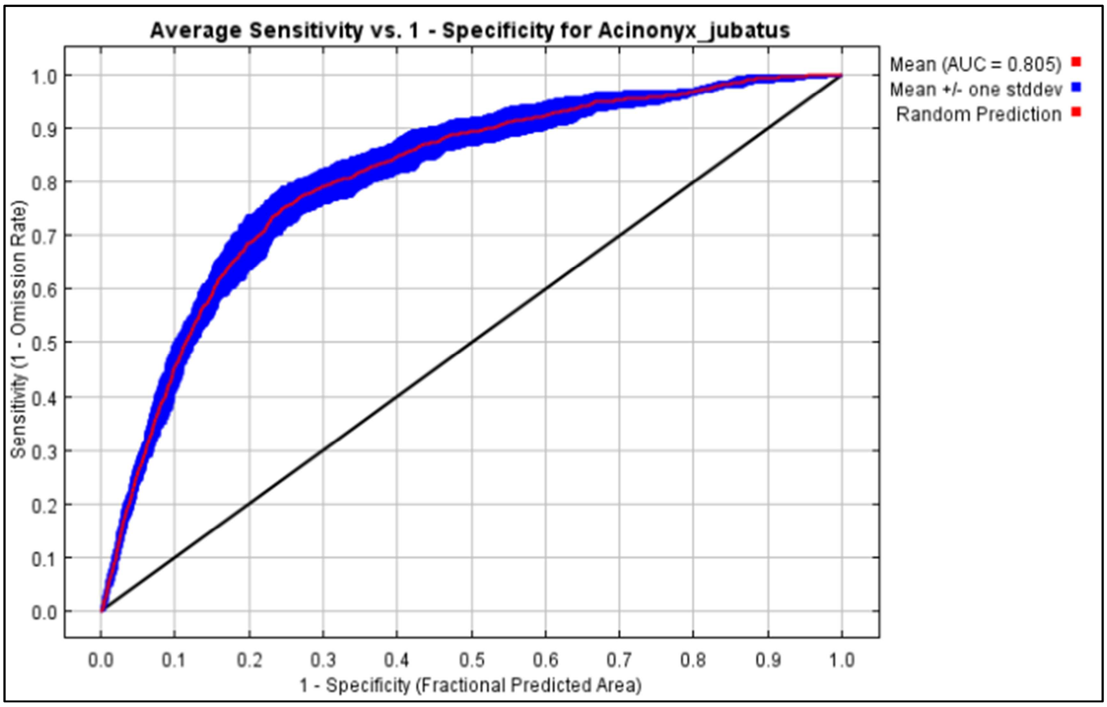

Figure 8. *The receiver operating characteristics (ROC) of the model.*

3.5. Suitable Environmental Conditions

Table 3. Optimum performance level of each variable in the model.

Variable	Kenya	Fundamental niche
Precipitation of Coldest Quarter (Bio_19)	0 – 600mm	10- 110 mm
Precipitation of the Warmest Quarter (Bio_18)	20 – 700mm	160- 320mm
Precipitation of Wettest Month (Bio_13)	40 - 500mm	120mm
Annual Precipitation (Bio_12)	200 – 2600mm	650-800mm
Temperature Seasonality (Bio_4)	50 - 170	70-90, 130-150°
Elevation	0 – 4000m.a.s.l	0-2100m.a.s.l

Cheetah distribution is predicted to occurs at localities of an elevation ranging from 0-2100m above sea level, with climatic condition of mean annual precipitation of 650-800mm, where precipitation of the warmest quarter is between 160-320mm, precipitation of the wettest month is 150mm, precipitation of coldest quarter is 10-110mm and temperature seasonality ranges of 70°-90° or 130°-150° (Table 3).

3.6. Suitable Areas for Cheetah Observations

Figure 9 below shows areas where the probability of sighting cheetah in Kenya is high. The open savannah ecosystems are the main locations where the probability of sighting cheetah is high.

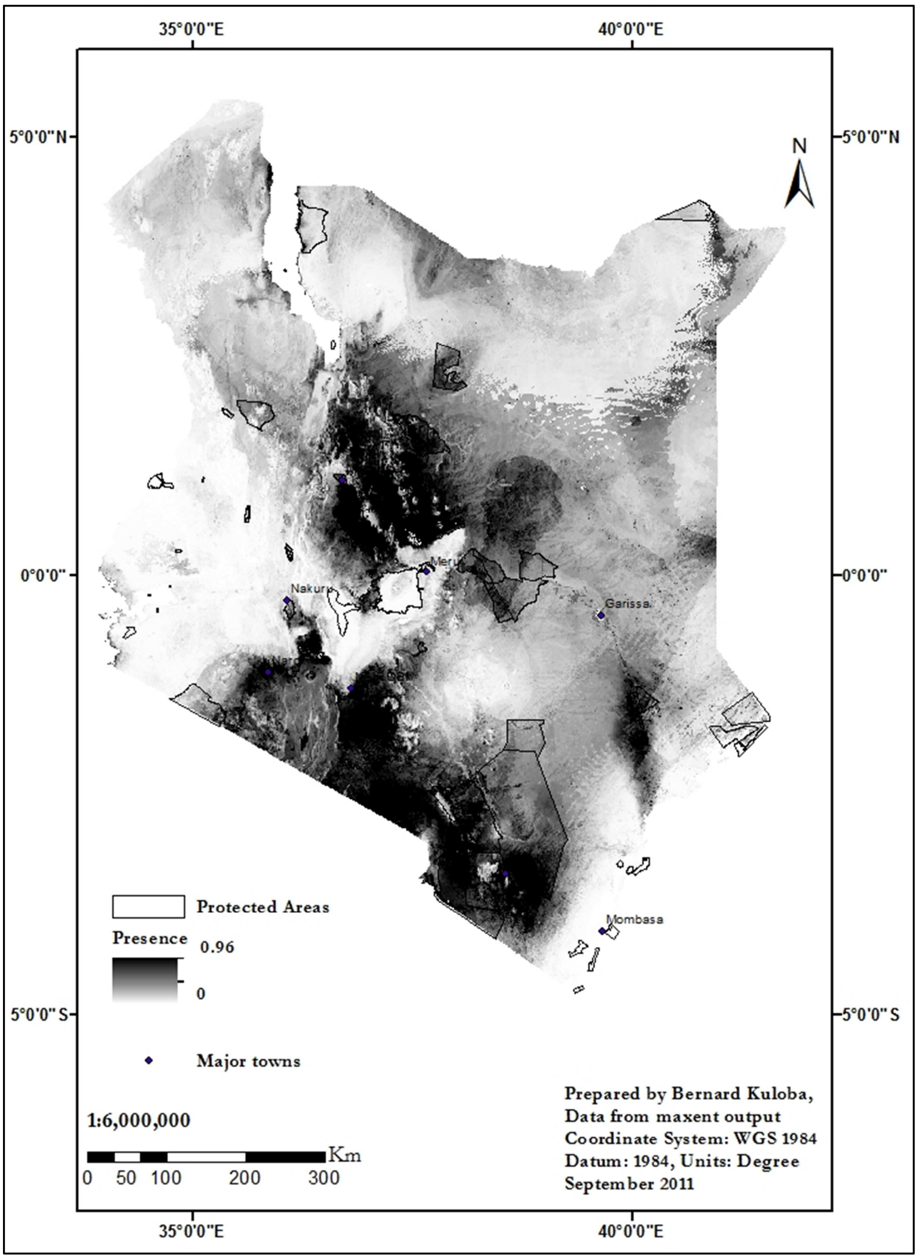

Figure 9. *Spatial distribution of areas where there is high probability of sighting cheetahs in Kenya.*

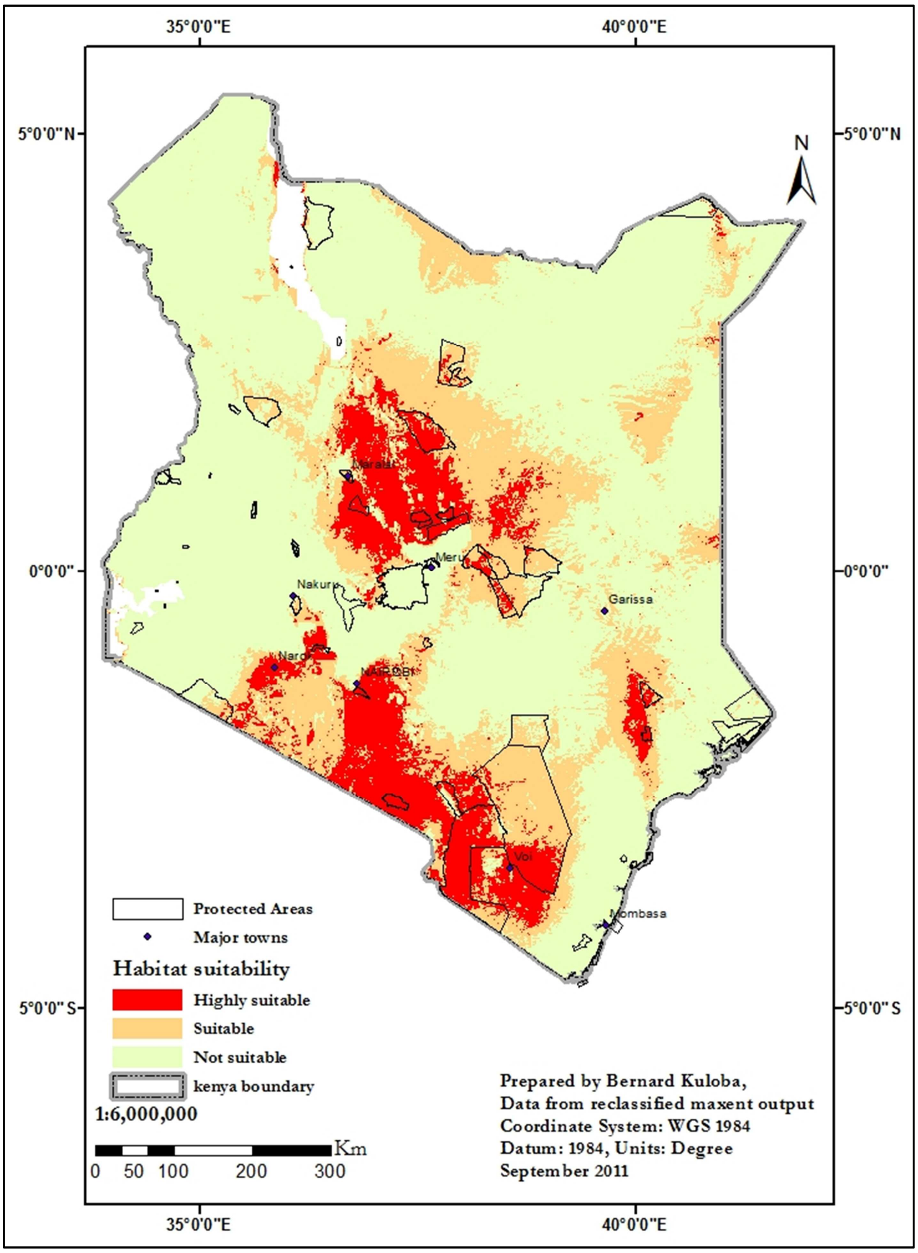

Figure 10. *Suitable habitats for cheetah in Kenya.*

The suitable areas for cheetah are located in two areas in the country, central part around Laikipia-Samburu-Isiolo and in southern part along Kenya-Tanzania border, which include the Masai Mara ecosystem, Amboseli ecosystem, and the Tsavo Conservation areas (Figure 10).

Three areas are identified as key from the distribution map, Masai Mara-Amboseli-Machakos-Tsavo, Samburu-laikipia-Isiolo and TanaRiver. Much of the highly suitable habitats are outside protected area coverage though in close proximity. Amboseli and Tsavo west are predicted to have best environment for cheetah conservation.

3.7. Suitability of Cheetah Conservationin Current Protected and None Protected Areas in Kenya

11.6% of Kenya is highly suitable for cheetah conservation, while 22.8% is categorized as suitable (Table 4). In total 40% of Kenya has suitable environment for cheetah conservation, in contrast about 10% of the country has been set aside as parks or reserves. For area under parks and reserves 31.4% is considered highly suitable whereas 43% is suitable. A quarter of protected areas are not suitable for cheetah conservation (Table 4; Table 5).

Table 4. *Suitable cheetah habitat distribution in Kenya.*

Habitat category	Country (%)	Protected areas (%)	None protected areas (%)
Not suitable	65.48	25.60	69.64
Suitable	22.88	43.00	21.12
Highly suitable	11.64	31.40	9.24
Area %	100.00	100.00	100.00

Table 5. *Proportion of land in Kenya showing the amount which is under parks and reserves.*

Habitat category	Country (%)	Protected areas (%)	None protected areas (%)
Not suitable	380,142.55	11,843.88	367,719.46
Suitable	132,845.04	19,853.86	111,527.61
Highly suitable	67,548.61	14,510.37	48,762.72
Area size	580,536.21	46,208.11	528,009.79

4. Discussion

4.1. Cheetah Distribution

Cheetah distribution could be classified as found in Mara conservation, Meru, Samburu-Isiolo-Marsabit and Tsavo conservation areas (Figure 11). The distribution spread across the protected areas. The study used both intrinsic or natural ecological variables such as climate and landform and extrinsic variables related to human like population densities and land conservation status. Extrinsic variables like population and conservation status did not explain the model well. Protected areas are found in different parts of the country at different elevation hence some were not suitable either because of the amount of precipitation, temperature seasonality or elevation. Important environmental features that are expected to influence the presence of cheetahs include vegetation cover; the presence of predators and the availability of water and prey (Caro, 1994; Bissett & Bernard, 2007), in this model presence of other predators and prey base were not use but used primary environmental variables. In Narok district the highly suitable areas were found outside Masai Mara national reserve. Gros 1997 explained high cheetah density on community ranches compared to the Masai Mara National Reserve in terms of predation of cheetah cubs by large predators within the reserve. The density in the reserve was found to be half that occurring on adjacent rangelands, result from this study could explain in environmental suitability unlike the disparity in terms of lower large predator numbers control by pastoralists.

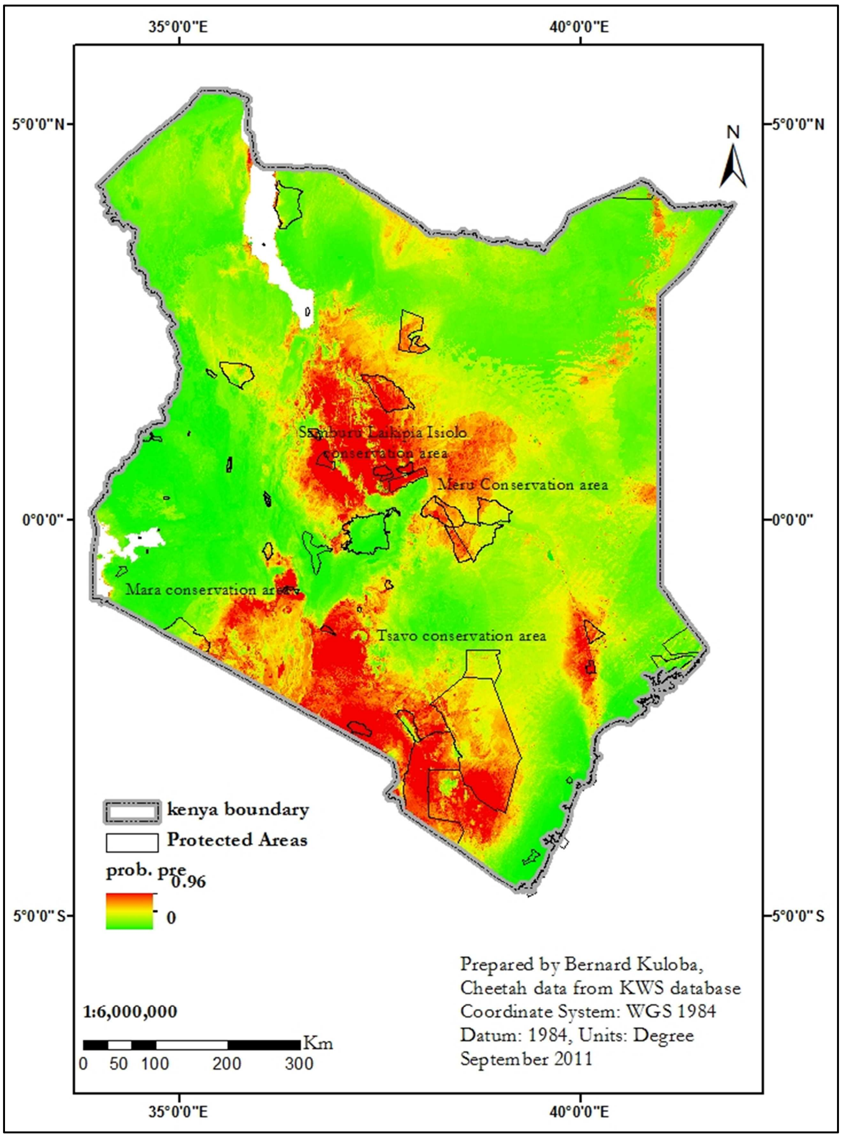

Figure 11. *The distribution of cheetah in Kenya.*

4.2. Predictive Model

The predicted model was statistically robust given the AUC of 0.805. AUC range is 0.5-1.0, with values between 0.5-0.7 indicating low discriminate ability, values between 0.7-0.9 indicating moderate discriminate ability, and values > 0.9 indicating high discriminate ability (Pearce and Ferrier 2000, Manel *et al.*, 2001). The distribution of cheetah could not be detected on basis of whether areas is protected or not protected as the difference was not significant. Species distribution model works well when presence data cover geographic and ecological extent of the species. The extent of data used here compares well with past surveys which covered the same districts of the country (Gros 1997). MaxEnt uses background environmental data for the entire study area. It focuses on how the environment where the species is known to occur relates to the environment across the rest of the study area (background). One important factor with MaxEnt is the occurrence localities are also included as part of the background.

The model will be better if depending on degree to which the species is at 'equilibrium' with current environmental conditions. A species is at equilibrium with the physical environment if it occurs in all suitable areas, while being absent from all unsuitable areas. The degree of equilibrium depends both on biotic interactions, competitive exclusion from an area) and dispersal ability, cheetah with higher dispersal ability are expected to be closer to equilibrium than animals with lower dispersal ability (Araújo and Pearson, 2005).

The extent to which observed occurrence records provide a sample of the environmental space occupied by the species. In cases where very few occurrence records are available, perhaps due to limited survey effort (Anderson and Martinez-Meyer, 2004) or low probability of detection (Pearson et al., 2007), the available records are unlikely to provide a sufficient sample to enable the full range of environmental conditions occupied by the species to be identified. The study used 309 points compared to the minimum of 20 point for MaxEnt to work effectively (Philips, 2008).

4.3. Environment Condition Suitable for Cheetah

Cheetah distribution was predicted to occurs at localities of an elevation ranging from 0-2100m above sea level, with climatic condition of mean annual precipitation of 650-800mm, where precipitation of the warmest quarter is between 160-320mm, precipitation of the wettest month is 150mm, precipitation of coldest quarter is 10-110mm and temperature seasonality ranges of 70°-90° or 130°-150°. Snyman (2001) documented precipitation, temperature and elevation as primary factors influencing African vegetation or phytomass, with soil composition and precipitation accounting for 66% of the variation in phytomass. Gastone *et al.* (2009) while studying lion demography in different protected area across Africa showed that climatic parameters explained 62% of overall variance, whereas landscape features explained 32%; climatic parameters were fairly balanced between the effects of temperature (34%) and rainfall (28%).

This model relied more on intrinsic or natural ecological factors such as climate and landform. However, extrinsic factors related to human interference [trophy hunting, poaching (Whitman et al., 2007; Frank *et al.*, 2006), agricultural and urban development (Bourn & Blench, 1999; Herrmann, 2004), habitat conversion, civil conflicts (Siefert, 2005) severely impact on cheetah.

4.4. Management Implications

Communication Tool: The distribution maps can be used as a tool to equip conservationists with a powerful communication tool in their negotiations with land and livestock owners. Suitable areas range will be related well with farms hence local people will appreciate why they need to tolerate and conserve cheetah on their farms. This might be important to the long-term survival of cheetahs if they are to occupy much of their fundamental niche, which is outside the protected areas. Resources for wildlife survey is very limiting, using this distribution map, available resources can be directed to high potential. This will focus the surveys and might yield a better result. Contrary to the prediction that prey biomass can be used as a predictor of cheetah numbers, a Serengeti study found that cheetahs frequently use areas with low prey density (Durant 1998). By selecting a variety of prey species the cheetah can survive in a range of conditions and can adapt to changes in the environment by changing hunting style (Frame and Frame 1977, Caro 1994).

Protected Area planning framework: Conservation of wildlife in Kenya is tourism based, this has allowed infrastructure and tourism facilities development within parks and reserves. To ensure balance between conservation and tourism activities cheetah distribution map should be one of a guiding tool in location of these facilities. Parks could be zoned, where developed is prohibited in highly suitable areas. Over 80% of the predicted suitable areas are found outside protected areas, this means that conservation activities outside protected areas are absolutely critical to ensure that these habitats. This result could be used to guide in setting up of community conservancies. This could be done by mobilizing communities whose land is suitable for conservation. KWS cheetah conservation strategy recognizes the need to establish carnivore conservation zones outside protected areas (KWS, 2007).

Ecological corridors: Three core areas were identified in this study for cheetah conservation, Narok-Kajiado areas, Tsavos and Laikipia- Samburu-Isiolo. These areas could be connected through ecological corridors. Such initiative will allow cheetah movements. Studies in Serengeti have shown, cheetah inhabiting large, overlapping ranges of an average 833km² (Caro 1994). The distribution maps could be used by relevant authorities to support identification and prioritization of corridor and dispersal areas for improved connectivity of cheetah movement.

5. Conclusion

Suitable areas for cheetah conservation were established by means of predictive habitat modeling using MaxEnt. Ideal fundamental niche for cheetah were localities within an elevation range of 1600-2100 meters above sea level, receiving mean annual precipitation of 800 mm, with the warmest quarter of the year receiving 250 mm, the wettest month receiving 120 mm, precipitation of coldest quarter 10 mm and temperature seasonality ranges of 150°. Comparison of protected areas versus non protected areas could not reveal any difference in cheetah distribution because cheetah niche cut across the protected areas boundaries. Cheetah fundamental niche run across protected areas and for effective conservation, results could be used to direct conservation effort go beyond parks and reserves by encouraging community conservancies and development of ecological corridors. Protected area planning could benefit too from these results.

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