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Predicting seasonal habitat suitability for the critically endangered African wild ass in the Danakil, Ethiopia

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Abstract

The African wild ass (*Equus africanus*) is the most endangered wild equid in the world and is listed as a Critically Endangered (CR) on the IUCN Red list. Today, only relict populations remain in Ethiopia and Eritrea. The current Ethiopian population persists in the Danakil Desert at a very low density. Wildlife managers need to identify the extent of the remaining suitable habitat and understand human–wildlife interactions for appropriate conservation strategies. This study employed the maximum entropy model (Maxent) to determine suitable habitat and seasonal distribution of African wild ass in the Danakil Desert of Ethiopia. Field surveys were conducted four times annually, twice during the wet season and twice during the dry season, for 2 years. Field data and predictor variables were separated into the dry and wet seasons, and models were generated for each season independently. Distance from water, distance from settlements, herbaceous cover and slope were the best predictors of suitable habitat for both dry and wet seasons. Evaluations of model performances were high with area under the curve (AUC) values of 0.94 and 0.95 for the dry and wet seasons, respectively. Our results will be critical for identifying the available suitable habitat that should be conserved to safeguard this species from extinction.

Key words: African wild ass, critically endangered, Danakil, Ethiopia, habitat modelling, ungulates

Résumé

L'âne sauvage africain (*Equus africanus*) est l'équidé sauvage le plus menacé du monde et il est classé En danger critique (CR) sur la Liste rouge de l'UICN. À ce jour, il n'en reste que des populations résiduelles en Éthiopie et en Érythrée. La population actuelle d'Éthiopie survit en très faible densité dans le désert du Danakil. Les gestionnaires de la faune sauvage doivent identifier l'étendue de l'habitat propice restant et bien comprendre les interactions hommes-faune sauvage pour mettre en place des stratégies de conservation appropriées. Cette étude utilise le modèle de l'entropie maximale (Maxent) pour déterminer quels sont l'habitat propice et la distribution saisonnière de l'âne sauvage d'Afrique dans le désert du Danakil en Éthiopie. Des études de terrain ont été réalisées pendant deux ans à raison de quatre fois par an, deux en saison des pluies et deux en saison sèche. Les données de terrain et les variables de prédiction ont été séparées entre saisons sèches et saisons des pluies, et les modèles ont été produits indépendamment pour chaque saison. La distance par rapport à l'eau, celle par rapport aux installations humaines, la couverture herbacée et la pente étaient les meilleurs facteurs de prédiction d'un habitat propice pour les deux types de saison. Les évaluations des performances du modèle furent élevées, avec des valeurs ASC de 0,94 et 0,95 respectivement pour les saisons sèches et les saisons des pluies. Nos résultats seront critiques pour identifier l'habitat propice disponible qu'il faudrait préserver pour sauver cette espèce de l'extinction.

Introduction

The African wild ass, *Equus africanus* Fitzinger 1857, is the most critically endangered wild equid in the world (Moehlman *et al.*, 2008). Historically, the African wild ass occurred throughout north-eastern Africa (Yalden, Largen & Kock, 1986; Fanuel, Moehlman & Lakew, 2007; Moehlman *et al.*, 2008; Kimura *et al.*, 2010). However,

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there have been dramatic reductions in its range, severe population declines and local extinctions primarily due to a number of anthropogenic factors (Moehlman, Fanuel & Hagos, 1998; Moehlman, 2002; Fanuel, Moehlman & Kifle, 2006; Fanuel, Moehlman & Lakew, 2007; Fanuel & Moehlman, 2008). The species is listed as Critically Endangered on the IUCN Red List and is listed on CITES Appendix I (Moehlman *et al.*, 2008). Although wildlife laws have protected the African wild ass in Ethiopia since 1972 (Negarit Gazeta, 1972), the species continues to be illegally hunted for food and traditional medicinal purposes (Klingel, 1972; Stephenson, 1976, 1978; Fanuel, 1994, 1995, 1999; Moehlman, 1994, 2002).

In Ethiopia, the African wild ass was formerly found throughout the Danakil lowlands and as far south as Dire Dawa (Yalden, Largen & Kock, 1986). Between 1970 and 1971, aerial surveys covering approximately 16,000 km^2 in this area estimated that there were approximately 3000 wild asses or 18.8 African wild ass per 100 km^2 (Klingel, 1972). Yangudi-Rassa National Park supported the highest density with an estimated 30 African wild ass per 100 km^2. In 1976, Stephenson (1976) surveyed the Yangudi-Rassa area and estimated a density of 21 African wild asses per 100 km^2. In 1994, Moehlman and Fanuel did a ground survey of the Yangudi-Rassa National Park and Mille-Serdo Wild Ass Reserve and found less than one African wild ass per 100 km^2 (Fanuel, 1994, 1995; Fanuel & Solomon, 1994; Moehlman, 1994; Moehlman, Fanuel & Hagos, 1998). In 1995, an aerial survey conducted in Yangudi-Rassa National Park and adjacent areas revealed that sheep and goats were present at a density of 50 per km^2 (Thouless, 1995). During this aerial survey, no African wild ass was observed, likely due to the high densities of livestock. Thus, the African wild ass has been extirpated from most of its historical range and where it persists the density is low.

In the past 30 years, the Issa people have been moving north, pushing the rival Afar pastoralists west and north across the Awash River. The African wild ass is prized for food and medicinal purposes by both Afar and Issa pastoralists. However, poaching of the species by the Issa is believed to be considerable. Members of the Issa pastoral community openly admit that they will track and hunt African wild ass whenever the opportunity arises; they are also confident that they have exterminated the species from their territory (and from localities where they have displaced the Afar pastoralists). Thus, it is unlikely that the African wild ass occurs today in the Yangudi-Rassa National Park.

Pastoralism is the predominant lifestyle of the people living in the range of the African wild ass. The livelihood of these people in this harsh and remote area is dependent upon the survival of their livestock. As a result, it is in their best interest to maximize the size of their herds. Large numbers of domestic herbivores can have severe impacts on the environment, particularly on rangeland that also supports an array of wild herbivores. These impacts are magnified during periods of prolonged drought (Clark, 1983; Yalden, Largen & Kock, 1986; Duncan, 1992; Fanuel, 1994, 1999). When it rains, African wild asses are the first to arrive and take advantage of the lush grasses and new growth. The pastoralists and their herds arrive soon thereafter, and the African wild asses are pushed to areas that have poorer forage availability (Fanuel, 1999). Equids in an arid environment must drink regularly, and their range is limited by the availability of accessible water. African wild asses need to drink at least every other day, but lactating females with young foals need to drink every day during the dry season (Moehlman, 2005). Therefore, limited access to water is a significant threat to the survival of African wild asses and can negatively affect foal survival.

The greatest threat to the survival of the African wild ass is the presence of illegally armed people. Hunting with automatic weapons is much easier and more efficient than traditional methods. Currently, within the range of the African wild ass, most men from the Afar and Issa tribes over the age of 14 years carry automatic weapons (AK47) for the reoccurring intertribal conflicts, defending their livestock from thieves and wild predators, and illegal hunting of African wild ass and other wildlife.

The inhospitable habitat and the political instability in this area of Ethiopia create many challenges for the management and conservation of the African wild ass. In addition, the available information on the current range and the extent of suitable habitat for this critically endangered species in Ethiopia is inadequate. To effectively protect the species, it is essential for wildlife managers to know the current range of the African wild ass in Ethiopia, determine the extent of available suitable habitat and understand the factors that most influence the current distribution of African wild Ass.

The Maximum Entropy model (Maxent) has been widely used with many applications in conservation-and-management-related fields (Cowley *et al.*, 2000; Pearce & Ferrier, 2000; Stockwell & Peterson, 2002; Gibson *et al.*, 2004). In some cases, the Maxent model has been used to help wildlife managers identify previously unknown ranges of wildlife populations (Pearson *et al.*, 2007; Thorn *et al.*, 2009) and can guide the formulation of effective management and policy strategies (Baldwin, 2009; Braunisch, Patthey & Arlettaz, 2011). Generally, Maxent uses geo-statistical analyses to establish relationships between species occurrence (e.g. observations, scat and tracks) and environmental variables (e.g. elevation, slope, vegetation type, temperature and precipitation) to define the species' ecological niche and predict its distribution on the landscape (Elith *et al.*, 2006; Hirzel & Le Lay, 2008). The Maxent model relates presence-only data (usually geographic coordinates of species presence) to selected environmental variables to produce a probability model of a species' distribution (Phillips, Dudik & Schapire, 2004; Phillips, Anderson & Schapire, 2006). Several comparative studies on Maxent and other models have shown that Maxent performs better than other similar geospatial models and performs particularly well with limited data sets (Hernandez *et al.*, 2006; Evangelista *et al.*, 2008b; Kumar *et al.*, 2009). The main objective of this research was to use the Maxent model to determine suitable habitat and seasonal distribution for the critically endangered African wild ass in the Afar Region of Ethiopia and to apply this information for the determination of better management and conservation actions.

Methods

Study area

Our study area is in the Danakil lowlands, an arid landscape where the depression lies between 122 and 157 m below sea level in northern Ethiopia (Blower, 1968; Bosworth, Huchon & McClay, 2005). The Danakil spans the northern part of the African Rift Valley, which runs from north-east to south dividing Ethiopia into three distinct regions: the Western Highlands, the Eastern Highlands and the Rift Valley Lowlands. The depression consists of a vast desert of lava ridges (Stephenson, 1978) and is the hottest place year-round on the African continent and one of the hottest places on earth. The climate is arid and the mean seasonal temperature ranges from 25–30 °C, but diurnal temperatures can range from 11–48 °C. The hottest season of the year is between May and August when the daytime temperature reaches 48 °C. The coolest season of the year occurs between November and January when night-time temperatures drop to 11 °C. Annual rainfall ranges from 96 to 300 mm with most of the rain occurring during July and August (Daniel, 1977).

In 1969, the Yangudi-Rassa National Park (4731 km^2) and the Mille-Serdo Wild Ass Reserve (8766 km^2) (Fig. 1) were established by the Ethiopian government mainly for the conservation of the African wild ass (Hillman, 1993). These two areas were selected based on the UNESCO mission wildlife survey conducted in 1963 (Huxley *et al.*, 1963; UNESCO, 1964; Blower, 1968; Hillman, 1993), which identified these viable sites for African wild ass conservation.

From 1994 to 2007, surveys in the species historical range documented that African wild ass distribution had been significantly reduced and remnant populations were only found near Lake Afdera (unprotected area) and in the Mille-Serdo Wild Ass Reserve (Fanuel, Moehlman & Lakew, 2007). The study area was determined based on these field surveys and is located between 40°58′ and 41°47′E and between 11°29′ and 13°3′N and covers an area of 12,300 km^2 (Fig. 2). The landscape is dominated by lava rocks, however, across the flat sandy plains; the wind piles the sand to form large sand dunes. Elevation of the area ranges from *c.* 100 m below sea level in the Danakil depression up to 900 m above sea level in the southern portion.

Ethiopia's second longest river, the Awash River, forms the southern boundary of the study area (Fig. 2). Along the river and particularly to the north of the river, land is irrigated for approximately 2–3 km for the cultivation of crops, cottons, fruits and recently sugar cane. This agricultural activity restricts wildlife access to the river. Apart from the Awash River, Lake Gamary, Lake Afambo, Aila Manda, Edgilo and Andeley are some of the permanent water sources that can be used by African wild ass throughout the year (Fig. 2). Seasonal water sources occur during the rainy season, but only persist for a few months after the rains end.

Most of the known range of the African wild ass is within areas with very low available forage and low densities of people and livestock. The vegetation in these areas is sparse with low cover (<20%) and low biomass productivity (*c.* 25 and 74 gm m^{-2} for dry and wet season, respectively; Fanuel & Almaz, 2005).

Data collection

The African wild ass inhabits remote and inhospitable parts of Ethiopia, which presents many logistical

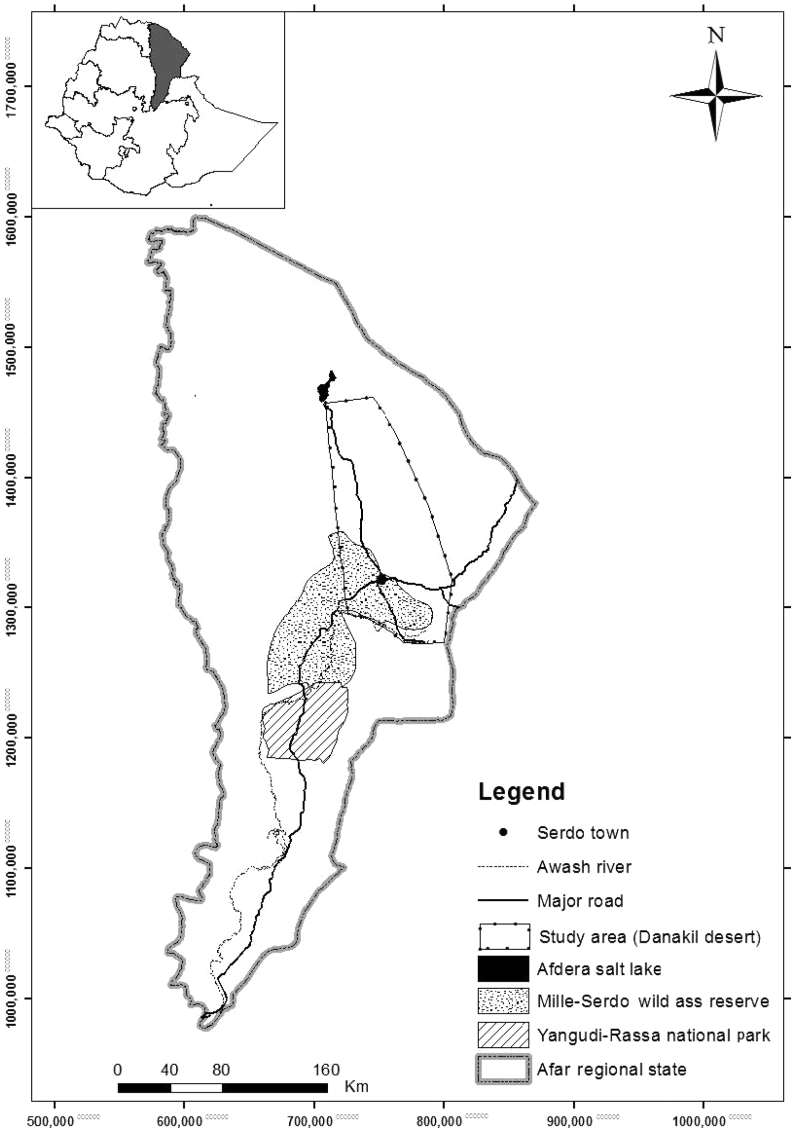

Fig 1 Location of the study area in relation to the Yangudi-Rasa National Park and the Mille-Serdo Wild Ass Reserve, Afar Region, Ethiopia (The representations of international boundaries on this map are not authoritative)

challenges. As the terrain is very undulating and covered with lava rubble, some areas were inaccessible by vehicles. In these areas, the fieldwork was performed on foot and with camels.

Conventional sampling methods were not possible because African wild asses are few in number and scattered in small isolated groups in very rugged terrain. Flat areas were driven using line transects so as to systematically survey as much of this area as possible. In more rugged terrain, it was necessary to walk to high points and survey all of the valleys. Fieldwork was conducted for fifteen days four times a year, during each dry season (in May and November) and during each wet season (in March and September) in 2009 and 2010. As the African wild ass is entirely dependent on permanent water sources during the dry season, all permanent water points found in the study area were monitored and locations of African wild ass sightings and any sign of fresh tracks or droppings were recorded. A geographic positioning system (GPS) was used to record the coordinates of the species presence points, settlements and water points encountered during the wet- and dry-season fieldwork. A spotting scope was used to obtain demographic information to identify individuals and determine movement patterns. The total area surveyed was

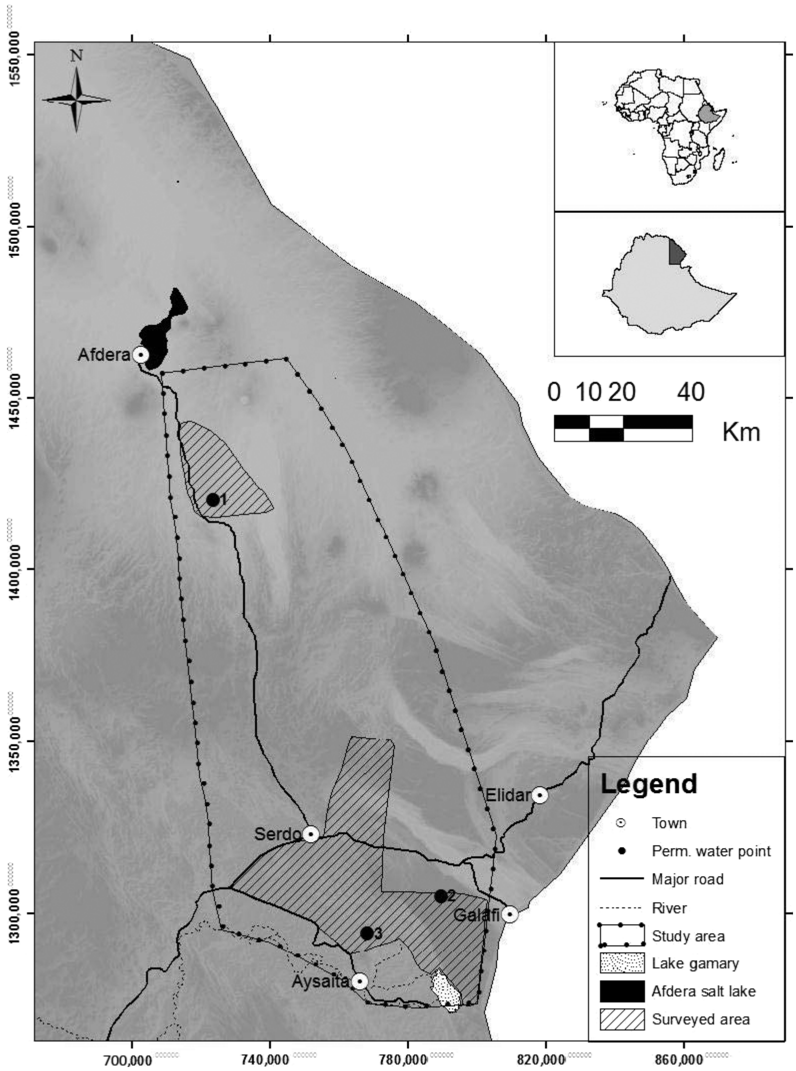

Fig 2 Survey areas with major landscape features, Afar Region, Ethiopia (Perm. water point = water spots which never get dry during the dry season and can be accessed over the year) (The representations of international boundaries on this map are not authoritative)

2130 km^2 representing approximately 17% of the entire study area (12,300 km^2). Visibility was good throughout the survey zone, and African wild asses could be spotted at a distance of 1000 m. Surveys were usually carried out when wild animals were most active, in the morning from 0600 to 1000 h and in the late afternoon from 1600 to 1800 h.

Predictor variables

Species distributions are limited in time and space due to certain environmental conditions (Barnard & Thuiller, 2008). The choice of environmental variables greatly influences the outcome of species distribution models. Careful selection of predictor variables was an important step. Predictor variables were selected based on the conditions that are either conducive to or limiting to African wild ass distribution in the Danakil. Nine main predictor variables were selected based on the available data set and the researcher's assumptions. These included elevation, slope, monthly minimum/maximum temperature and mean precipitation (from the WorldClim database, www.worldclim.org; Hijmans *et al.*, 2005), percent herbaceous and bare ground cover (from the Global Land Cover Facility, www.landcover.org), and user-generated distance from water and settlements. Monthly minimum and maximum temperature and mean precipitation were averaged for 2 months: the sampling month and the previous month. These months were selected because of their influence on forage production and on the distribution patterns of African wild ass during the sampling period. Slope, distance from water sources and distance from settlements were calculated using toolsets available in ArcGIS v. 9.2 (ESRI, 2007). All predictor variables were projected to WGS84 UTM zone 37N and clipped to the extent of the study area with a resolution of 90 m.

Spatial analysis

In this study, we chose to use the Maxent model (Phillips, Anderson & Schapire, 2006) because it requires presence-only data, can handle small data sets and generally performs better than the other modelling approaches (Elith *et al.*, 2006; Evangelista *et al.*, 2008a; Baldwin, 2009). If more than one presence points fell within the area of a single pixel of 90 m^2, then the duplicates were removed so that the pixel would represent a single occurrence or presence point for the model analysis. This reduced the number of presence points (i.e. observations and faecal piles) to 24 and 27 for the dry and wet seasons, respectively.

When running the Maxent model for the wet and dry seasons, we ran 25 replicate models randomly withholding 20% of the presence points (n = 4) each time. The final map outputs and evaluations were averaged from the 25 replicates for both dry and wet seasons. Three habitat suitability categories (unsuitable, suitable and optimum) were defined based on two threshold values generated by Maxent: (i) minimum training presence logistic threshold and (ii) maximum test sensitivity plus specificity logistic threshold. A habitat with values below the minimum threshold was considered unsuitable; a habitat that fell between minimum and maximum thresholds was considered suitable; and a habitat with values greater than the maximum threshold was considered optimum. Model results for the wet and dry seasons combined to produce a final map that represented the potential distribution of African wild ass in the Danakil lowlands throughout the year.

Model results were evaluated by two means that are automatically generated by Maxent: the area under the curve (AUC) and jackknife tests. AUC is the area under the receiver operating characteristics (ROC) curve. It is a standard and threshold-independent method mostly used to evaluate the model performance. AUC value ranges from 0 to 1 (Pearce & Ferrier, 2000; Phillips, Anderson & Schapire, 2006). An AUC value of 0.5 indicates a model that predicts no better than chance; higher AUC values, up to a maximum value of 1, indicate a much better model performance (Elith *et al.*, 2006; Peterson, Pares & Eaton, 2007). The second available means of evaluation is the jackknife test. This allows the estimation of the bias and standard error in the statistics and the test of variable importance.

Results

The Maxent model generated average AUC values of 0.937 and 0.948 for the dry and wet seasons, respectively. The minimum training presence logistic threshold and maximum test sensitivity plus specificity logistic threshold values were 0.027 and 0.248 for the dry season, and 0.044 and 0.457 for the wet season. The results of predicted ‘optimum’ suitable habitat indicated that there is a difference in habitat utilization during the dry and wet seasons of the year (Fig. 3). The results also indicated that the range of the African wild ass in the wet season (9498 km^2) is greater than the dry season (8858 km^2). However, dry-season ‘optimum’ habitat was greater (1819 km^2) than wet-season habitat (848 km^2). The predicted suitable habitat indicated that the species could occupy a range of up to 11,452 km^2 over the year.

Four variables, distance from water, distance from settlement, herbaceous cover and slope, were the most important predictors having the greatest contribution to the model results for both dry and wet seasons (Table 1). Jackknife tests showed the highest AUC gain for distance from water for both wet and dry seasons, indicating that it had the greatest predictive contribution of all the variables when considered independently. In contrast, minimum temperature during the dry season and bare cover during the wet season had the least AUC gain when tested independently (Figs 4 and 5).

Discussion

The predicted seasonal (dry and wet) and year-round suitable habitat for African wild ass is critical information for identifying and implementing optimum conservation strategies. The study results also provide valuable guidance for further monitoring and surveying activities. AUC values for our models indicated that Maxent performed extremely well for predicting African wild ass habitat. Our analyses indicated that the African wild ass has a wider

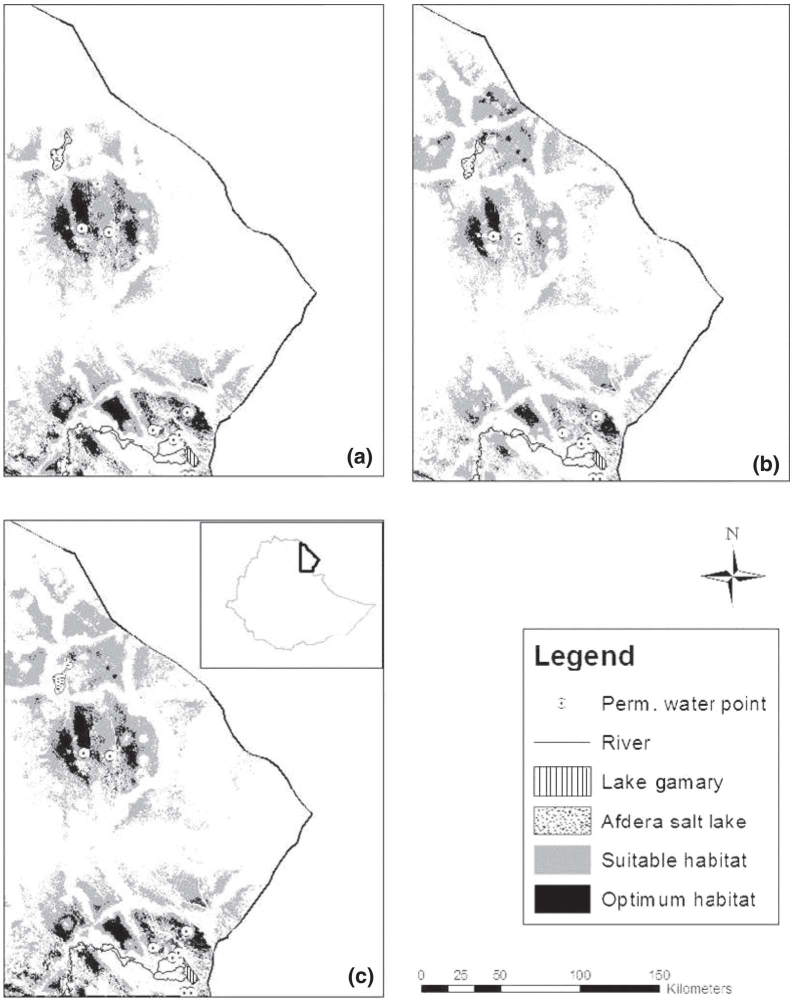

Fig 3 Estimated habitat suitability, during the dry season (a), wet season (b) and over the year (c), derived from the Maxent model using wildlife survey data from 2009 and 2010

Table 1 Relative contribution of predictor variables to the Maxent model for dry- and wet-season habitat analysis of average results of 25 replicates

	Percent contribution	
Predictor variable	Dry season	Wet season
Distance from water	46.7	33.4
Distance from settlement	15.3	17.7
Herbaceous cover	12.7	11.7
Slope	10.5	13.8
Minimum temperature	4.6	0.1
Maximum temperature	4.3	8.5
Elevation	3.9	7.2
Precipitation	2	7.7
Bare cover	0	0

distribution range during wet seasons compared with dry seasons. This is likely due to direct response to spatially increased water and forage availability. In the northern range of the study area (Afdera area), livestock densities and human settlements were very low. In the southern range of the study area (Serdo), the livestock population was approximately three times more dense (Central Statistics Agency, 2008). In the northern area, the African wild ass was not constrained by human/livestock presence therefore could move freely away from permanent water sources during the wet season. However, the southern area of their range has a higher density of people and livestock that rely on the Awash River. During the wet season, these people and livestock disperse throughout the southern areas and this may restrict free movement by the African wild ass. The African wild asses are

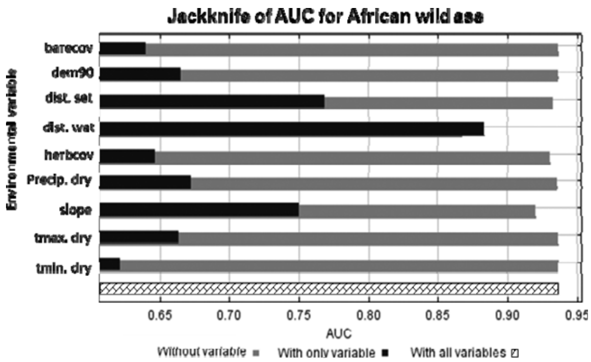

Fig 4 Jackknife of area under the curve (AUC) (area under the receiver operating curve) for African wild ass, showing average AUC gains for each variable calculated from 25 subset models carried out for the dry season habitat suitability analysis. (barecov = bare cover, dem90 = elevation, dist. set = distance from settlement, dist. wat = distance from water, herbcov = herb cover, precip. dry = precipitation of the dry season, tmax. dry = maximum temperature of the dry season, tmin. dry = minimum temperature of the dry season)

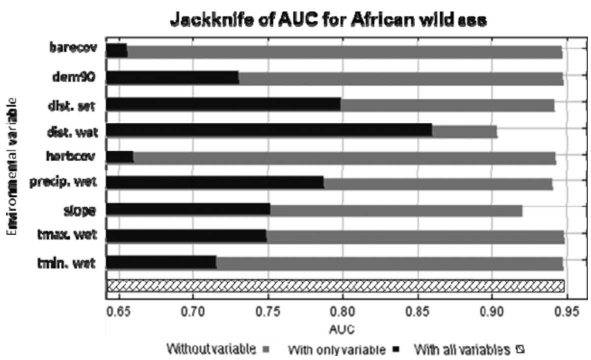

Fig 5 Jackknife of area under the curve (AUC) for African wild ass, showing average AUC gains for each variable calculated from 25 subset models carried out for the wet season habitat suitability analysis. (precip. wet = precipitation of the wet season, tmax. wet = maximum temperature of the wet season, tmin. wet = minimum temperature of the wet season, for other definitions see Fig. 4)

water-dependent, and during the dry season, they are normally observed in a radius of 10–25 km from permanent water sources. However, the larger size of optimum habitat during the dry season indicates that low availability of forage may force the African wild ass to traverse a larger area to fulfil nutritional requirements. In the southern study site, African wild asses were observed 25 km away from permanent water source during the dry season. This was the farthest distance recorded.

The contributions of all predictor variables used in the models differed in their values between the dry and wet seasons. Four predictor variables were the most significant for both seasonal analyses. For both seasons, the distance from water was the strongest predictor, which should not be surprising given that African wild ass are water-dependent. The distance from human settlements was the second strongest predictor for both seasons. As African wild asses are hunted by local people for food and medicinal purposes, they have good reasons to avoid people and livestock. The African wild ass is often found in remote areas away from human habitation and closer to permanent water sources.

We believe that our results will be beneficial to wildlife managers allowing them to make more accurate decisions for safeguarding this critically endangered species. Further research and data collection could potentially improve the modelling results, especially concerning the impacts of people and livestock on African wild ass movement patterns, breeding habits and juvenile survivorship. The results from the Maxent models are the first maps produced of African wild ass distribution and optimum habitats. We anticipate that our results will be used to define areas that need specific planning and management interventions for the conservation of this critically endangered species.

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