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Predicting habitat suitability for the endemic mountain nyala (*Tragelaphus buxtoni*) in Ethiopia

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Abstract. The use of statistical models to predict species distributions and suitable habitat has become an essential tool for wildlife management and conservation planning. Models have been especially useful with rare and endangered wildlife species. One such species is the mountain nyala (*Tragelaphus buxtoni*), a spiral-horned antelope endemic to the Ethiopian highlands. The full range of the species has never been adequately defined and recent discoveries of new populations suggest that others may exist undetected. To identify potential mountain nyala occurrences, we used classification tree analysis to predict suitable habitat using 76 climatic, topographical and vegetative variables. Three model evaluation methods showed a strong performance of the final model with an overall accuracy of 90%, Cohen's maximised κ of 0.80 and area under the receiver operating characteristic curve (AUC) value of 0.89. Minimum temperature and maximum precipitation generally had the greatest predictive contributions to suitable mountain nyala habitat. The predicted habitat covered an area of 39 378 km^2, with the majority occurring in remote forests on the southern escarpment of the Bale Mountains. Other areas within the predicted range may be too impacted by human and livestock populations to support mountain nyala; however, the model will be useful in directing future surveys for new populations while offering clues to the species historical range.

Additional keywords: classification tree, ecological niche model, habitat suitability, WorldClim.

Introduction

Tragelaphus buxtoni (mountain nyala) is a large spiral-horned antelope endemic to Ethiopia's highlands. First identified by the scientific community in 1908 (Lydekker 1910, 1911), very little is known about the biology, range and population of the species. Mountain nyala are believed to inhabit only the southern highlands east of the Rift Valley. Remnant populations exist in the Chercher and Arussi mountains; however, most inhabit the Bale Mountains (Fig. 1; Brown 1969*a*; Yalden and Largen 1992; Evangelista 2006*b*; Sillero-Zubiri 2007). Mountain nyala are generally found between 1800 and 4000 m, but have been observed at elevations as low as 1500 m (K. Wakijira, pers. comm.). Generally, the species prefers dense highland forests for concealment, thermal regulation and the availability of seasonal forage. In particular, mountain nyala prefer the upper and lower Afro-montane zones, which are dominated by *Hagenia abyssincia*, *Hypericum revolutum*, *Juniperus procera* and *Sinarundinaria alpina* (Bekele-Tesemma *et al*. 1993; Miehe and Miehe 1994; Bussman 1997). Historic records suggest that the ericaceous belt (sub-alpine zone dominated by *Erica trimera* and *E. arborea*) was at one time prime mountain nyala habitat; however, much of this habitat type has been converted for agriculture and livestock grazing (Brown 1969*a*, 1969*b*; Malcolm and Evangelista 2005; Evangelista *et al*. 2007). At night, mountain nyala have been observed congregating in open spaces, such as cultivated fields, grasslands, wet meadows, fens and the Afro-alpine habitats to feed and drink (Evangelista 2006*b*).

Habitat loss and land degradation are the most significant threats to mountain nyala and the majority of Ethiopia's wildlife. Ethiopia's forests once covered 65% of the country and 90% of the highlands. Today, Ethiopia's forests cover only 2.2% of the country and 5.6% of the highlands (FAO 2006). As forest habitats are reduced by the growing human population and need for natural resources (e.g. agriculture, livestock grazing, fuel-wood), mountain nyala populations are becoming fragmented and increasingly confined to small areas (Evangelista 2006*b*). Although it is evident that habitat loss is reducing the known range of mountain nyala, the full distribution of the species has never been adequately determined. As a result, total population estimates remain inconclusive, hindering effective management strategies and skewing conservation policy (East 1999; Refera and Bekele 2004; Evangelista 2006*b*; Evangelista *et al*. 2007; Sillero-Zubiri 2007). For the Ethiopian Wildlife Conservation Department (EWCD), identifying the full range and total population of mountain nyala is a high priority and a requirement for implementing effective management plans, facilitating conservation strategies and formulating wildlife policy (T. Hailu, pers. comm.).

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In recent years, several populations of mountain nyala have been documented for the first time (Evangelista 2006*a*, 2006*b*). In 2000 and 2001, the species was found to be widespread throughout the eastern slopes of the Bale Mountains (Evangelista 2006*b*; Evangelista *et al*. 2007). In response to apparent land degradation and poaching activities, the EWCD established three controlled hunting areas (CHA) in the Bale Mountains to intensively manage the species through limited trophy hunting. In 2005, the EWCD discovered two additional populations: the first was located in the south-western region of the Bale Mountains and the second on the north-eastern slope of the Arussi Mountains (Fig. 1). Populations in these two areas have been surveyed by the EWCD and are currently under review for management through controlled hunting. Collectively, the five new CHAs are estimated to have between 1750 and 2000 mountain nyala based on line-transect surveys conducted by the EWCD (Evangelista 2006*b*). In 2006, mountain nyala were found to be prevalent in the higher elevations of the Harenna Forest, a cloud forest that covers the southern escarpment of the Bale Mountains (P. Evangelista, pers. obs. 2006–2007; Evangelista *et al*. 2007). Population surveys have not yet been conducted for the area, but the presence of mountain nyala has been confirmed in four regions inside and outside of the Bale Mountains National Park by EWCD and the authors. These recent discoveries and other undocumented reports suggest that additional populations of mountain nyala are likely to exist and add to knowledge of the species' habitat requirements. However, the Ethiopian highlands are vast and often inaccessible, creating many logistical challenges in the search for new populations.

Fortunately, advancements in computer technology and software are allowing ecologists to integrate field observations, remotely sensed data, geographical information systems (GIS) and digital image processing to define species distributions and identify undiscovered populations. Specifically, probability models are employed by ecologists to predict species occurrence (Corsi *et al*.1999; Pearson *et al*. 2007), migratory patterns (Boone *et al*. 2006), critical habitats (Hatten and Paradzick 2003; Turner *et al*. 2004), risk of diseases (Broadfoot *et al*. 2001; Pfeiffer and Hugh-Jones 2002), invasion of non-native species (Ficetola *et al*. 2007; Evangelista *et al.* in press) and management priorities (Clevenger *et al*. 2002; Felix *et al*. 2004). One of the most widely used model applications is classification and regression tree (CART) analysis. CART analysis is a commonly used non-parametric modelling technique that predicts the response of a dependent variable through a series of simple regression analyses (Breiman *et al*. 1984; Hansen *et al*. 1996; Lewis 2000). Unlike other regression approaches that conduct simultaneous analyses, CART models statistically partition the dependent data into two homogenous groups at a node, repeating the procedure for each group in a continuous process that forms a hierarchal tree. Classification trees are used when the dependent variables are categorical (i.e. presence, absence) and regression trees are used when the dependent variables are continuous (e.g. percent basal cover, species richness). Several characteristics of this modelling approach appeal to researchers

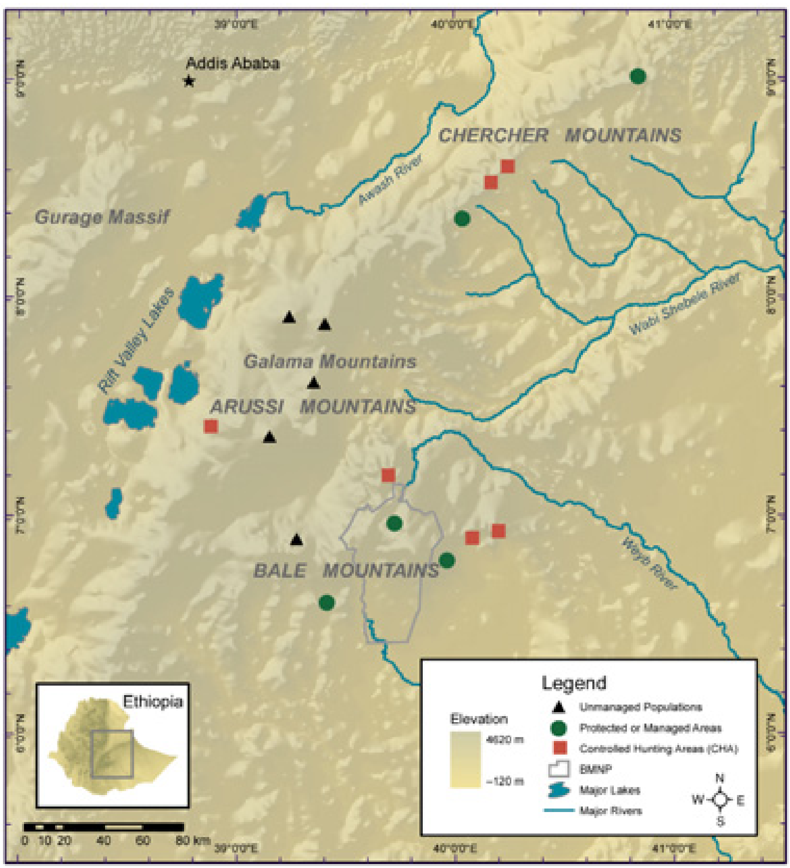

Fig. 1. Map of Ethiopia's southern highlands and known populations of mountain nyala.

and resource managers. First, the analyses explicitly allow for non-linear relationships between the dependent and independent variables. These methods make no *a priori* assumptions about the distribution of the data, the relationships among independent variables or relationships between the dependent and independent variables. Second, they are well suited to handle non-homogenous datasets (i.e. unbalanced sample sizes, high variability). Finally, the results are easily interpreted and the predictive strength of each independent variable is explicitly reported in the results (Michaelsen *et al*. 1994; Andersen *et al*. 2000; Evangelista *et al*. 2004).

The aim of our study is to use classification tree analyses at landscape and regional scales to identify areas suitable for mountain nyala and to direct future survey efforts that may lead to the discovery of undocumented populations. We rely on known distribution information with a suite of environmental variables to relate species occurrence and absence to geographical and topographical features. In addition, to model evaluations that are built into classification tree analyses (i.e. predictive strength of independent variables, number of partitions and terminal nodes), we evaluate model performances with three proven statistical tests.

Methods

Study area

Although mountain nyala are believed to inhabit only a small portion of Ethiopia's southern highlands, the extent of our initial analyses included the entire county, which encompasses 1.12 million km^2 (MoWR 2001). Ethiopia is located in East Africa and often described as the 'roof of Africa' because of its rugged mountain topography, which has the largest expanse of Afro-alpine habitats on the continent (Gamachu 1988; Uhlig and Uhlig 1991). Over 50% of Africa's land mass above 2000 m and over 80% of the land mass above 3000 m is found in Ethiopia (McClanahan and Young 1996). The Ethiopian highlands are divided by the Rift Valley into two dominant massifs: the Bale Mountains in the south-eastern block and the Simien Mountains in the north-western block. Elevation in Ethiopia ranges from 120 m below sea level to 4620 m above sea level. The contrasting topography and Ethiopia's situation within the Intertropical Convergence Zone result in varying climates across the country. Temperatures in the arid regions of the country may be as high as 37°C, and temperatures at higher elevations are known to dip as low as –15°C (MoWR 2001).

Annual precipitation also fluctuates across Ethiopia's landscape, occurring in two distinct seasons: the *Bega*, a dry season from October to May, and the *Kiremt*, a long rainy season from June to September. A small rainy season called the *Belg* occurs in April and May at the end of the *Bega.* Mean annual precipitation ranges from 2000 mm in areas of the south-west to less than 200 mm over the Afar lowlands (MoWR 2001). Based on Koppen's climate classification system, 10 climate zones define the Ethiopian landscape (Gonfa 1996). These climate types harbour many unique and diverse ecosystems that include desert, savanna grasslands, shrubland, savanna woodlands (*Acacia* sp.), tropical forests, montane forests, bamboo (*Yushane alpine* and *Oxytenanthera abyssinica*), heathlands (*Erica* sp.) and Afro-alpine (Logan 1946; Von Breitenbach 1961; Egziabher 1988; Miehe and Miehe 1994; Bussman 1997; Carr 1998; Embaye 2000).

Field data sources

Our first model relied on mountain nyala observations collected at regional levels from: (1) line-transect surveys conducted by the EWCD between 2002 and 2006 in nine CHAs (Evangelista 2006*b*); (2) population estimates from observations at Kuni-Muktar Wildlife Reserve and Galama Mountains Forest Priority Area (Malcolm and Evangelista 2005; F. Kebede, pers. comm.); (3) direct counts in the northern portion of Bale Mountains National Park (Refera and Bekele 2004); and (4) field observations using global positioning system (GPS) collected from the Senetti Plateau and the Harenna Forest in Bale Mountains National Park (P. Evangelista, pers. obs. 2002–2006). Most presence data did not include specific coordinates of observations. For these, we created boundary layers of management areas, CHAs and study sites in ArcGIS 9.2 (ESRI 2006) using GPS surveys, paper maps of CHAs provided by the EWCD (Evangelista 2006*b*), Refera and Bekele's (2004) map of their study site and Landsat7 TM satellite images (GLCF 2006). Within each boundary layer, we randomly generated *n* presence points based on the most current population estimate available for each defined area. All presence points were integrated into a single GIS shapefile and converted to a raster format with a pixel size of 1 km^2. When more than one presence point fell within a single raster pixel, that pixel would only represent a single occurrence for our analyses. This approach was necessary to avoid habitat bias of mountain nyala in areas with unnaturally high numbers (e.g. Kuni-Muktar; Evangelista *et al*. 2007) or areas where animals are easily or regularly observed (e.g. Gaysay; Refera and Bekele 2004). The total number of presence points summed from regional population estimates was 4766 and the total number of presence cells used in our first analyses was 1443. Additionally, we generated 4766 pseudo-absence points throughout Ethiopia with the criteria that each point had to be below 1500 m in elevation and it could not occur within the known mountain nyala populations (shapefiles previously described). We repeated the conversion from point data to raster cells leaving 4756 absence cells for our analyses.

For our second model, we generated 3000 random points within the predicted range of mountain nyala occurrence from the first model. Based on previous mountain nyala population field surveys and observations (Evangelista *et al*. 2007), we defined each random point as a presence or absence and omitted any points where occurrence was uncertain. Following this process, 471 points (181 presence and 290 absence) remained for the second analyses with 75% (144 presence and 233 absence points) used to train the model and 25% (37 presence and 57 absence points) withheld to validate the model.

Spatial data sources

To predict suitable habitat for mountain nyala, we used 76 independent spatial variables in our analyses that were derived from various remotely sensed data and GIS analyses. Data at coarse resolutions were re-sampled to 90 m and projected in the Universal Transverse Mercator system (WGS 84, Zone 37N). Continental and global datasets were reduced to the extent of Ethiopia. Using a 90 m Digital Elevation Model (DEM) from the National Aeronautics and Space Administration's (NASA) Shuttle Radar Topography Mission (SRTM; Jarvis *et al*. 2006; Farr 2007), we generated slope in degrees, aspect, surface roughness index, soil wetness index and solar insolation raster layers. Slope in degrees and aspect were generated in ArcGIS 9.2 Spatial Analyst (ESRI 2006). Soil wetness index was calculated using the formula [ln(A/tan β)], where ln(.) is the natural logarithm, A is the area drained per unit contour or specific area and tan β is the slope (Moore *et al*. 1991; Wolock 1993). The solar insolation grid was generated using the Shortwave program developed by Kumar *et al*. (1997).

Three global vegetation indices (GVI) and 12 normalised difference vegetation index (NDVI) scenes from moderate resolution imaging spectroradiometer (MODIS) instruments aboard NASA's Terra satellite were acquired from the Global Land Cover Facility (GLCF. 2006). GVIs included woody tree cover, herbaceous vegetation cover and bare ground cover at 500-m resolution. Collectively, these indices total 100% of ground cover and can be properly displayed in red, green and blue band combinations (Hansen *et al*. 2003*a*, 2003*b*). NDVI scenes were acquired for the 15th day of each month for 2003 at 250 m resolution (Kidwell 1990, 1991; Carrol *et al*. 2004). NDVI is calculated by [($NIR - red$) / ($NIR + red$)], where NIR is band 2 (near infrared) and red is band 1 (Sellers 1985; Myneni *et al*. 1995).

Nineteen bioclimatic parameters were acquired from the WorldClim (Hijmans *et al*. 2005; http://www.worldclim.org/). These fine resolution (~1 km) spatial data were interpolated from weather stations across the globe, with averages calculated from at least 10 years of data (Hijmans *et al*. 2005, 2006). The 19 BioClim variables are derived from mean monthly and quarterly climate estimates (e.g. minimum, maximum, mean temperature and precipitation) to approximate energy and water balances at a given location (Nix 1986; http://www.worldclim.org/bioclim.htm).

Statistical analyses and model evaluation

All statistical analyses were conducted using S-Plus 3 statistical software (Insightful 2000). We generated two classification tree models: the first to model suitable mountain nyala habitat for all of Ethiopia and the second to refine the predicted suitable habitat of the first. Classification trees were pruned using 10-fold cross-validation (Breiman *et al*. 1984). We used three methods to evaluate the performance of each model: (1) a confusion matrix that shows specificity and sensitivity and overall accuracy; (2) Cohen's maximised κ; and (3) area under the receiver operating characteristic curve (AUC) (Fielding and Bell 1997).

There are two possible errors that may occur in prediction models: false negatives (under prediction or under-fit models) and false positives (over predictions or over-fit models; Fielding and Bell 1997). Using the validation data, we presented the relative proportions of these errors in a confusion matrix. Specificity (the proportion of true-positive and false-positive absences) and sensitivity (the proportion of true-positives and false positive presences) are reported for the final model with overall accuracy reported as a percentage (Fielding and Bell 1997). Threshold dependent evaluation measure Cohen's maximised κ (Cohen 1960), was calculated using a cut-off threshold determined by plotting sensitivity against specificity (Fielding and Bell 1997). The κ statistic measures the proportion of correctly classified points (i.e. presence, absence) after accounting for the probability of chance agreement. κ statistic values range from –1 to +1, where +1 would be perfect agreement and any values less than 0 would indicate a performance no better than random (Cohen 1960; Allouche *et al*. 2006). Landis and Koch (1977) ranked analysis performances as poor when κ values are <0.40; good when the κ values range from 0.40 to 0.75; and excellent when κ values are >0.75

The AUC is calculated by generating a receiver operating characteristic (ROC) curve to plot the sensitivity to 1 – specificity for all possible thresholds (Pearce and Ferrier 2000). Commonly used in predictive models (Phillips *et al*. 2006; Russell *et al*. 2007; Evangelista *et al*. in press), the AUC is a measure of probability that a random positive point falls within the predicted range of occurrence and a random negative point falls outside (Pearce and Ferrier 2000). Strength of predictability ranges from weak to strong or 0 to 1.0 respectively. An AUC value of 0.5 represents complete random predictions, whereas a value of 1.0 shows perfect discriminatory ability (Pearce and Ferrier 2000).

Results

Our first model had nine terminal nodes with a residual mean deviance of 0.01 (Fig. 2). Of the 76 potential independent variables, seven predictors were selected in the model results with precipitation of the warmest quarter (BIO18) occurring twice in the tree. The probability of mountain nyala occurrence was greatest when precipitation of the warmest quarter (BIO8) was >270 mm (79% present, 21% absent), precipitation of the wettest month (BIO13) was <241 mm (88% present, 12% absent), minimum temperature of the coolest month (BIO6) was <10.1 C° (100% present, 0% absent) and temperature seasonality (BIO4) was <1279.6 (100% present, 0% absent). Other predictor variables of mountain nyala occurrence include maximum temperature of the warmest month (BIO5), precipitation seasonality (BIO15) and NDVI for the month of September (Fig. 2).

The final model, analysed within the boundaries of our first model, had 10 terminal nodes with a residual mean deviance of 0.1008 (Fig. 3). Of the potential independent variables, nine were significant in the model results with surface roughness index occurring twice in the tree. The probability of mountain nyala occurrence was greatest when minimum temperature of the coolest month (BIO18) was <3.3 C° (92% present, 8% absent) and precipitation of the warmest quarter (BIO18) was >281 mm (98% presence, 2% absent). Other significant variables in the model include surface roughness, precipitation of the wettest quarter (BIO16), minimum temperature for December, mean temperature for March, precipitation of the coldest quarter (BIO19) and herbaceous cover (Fig. 3). The predicted suitable habitat had an area of 39 378 km^2, with ~97% of the predicted area in the Chercher, Arussi and Bale mountains and nearly 2% of the predicted area in the Gurage Massif on the west side of the Rift Valley (Fig. 4).

Evaluation methods showed that the final model's performance was strong for training and validation datasets. The training model had an AUC of 0.93 and κ value of 0.88. The confusion matrix showed the training model to have an overall

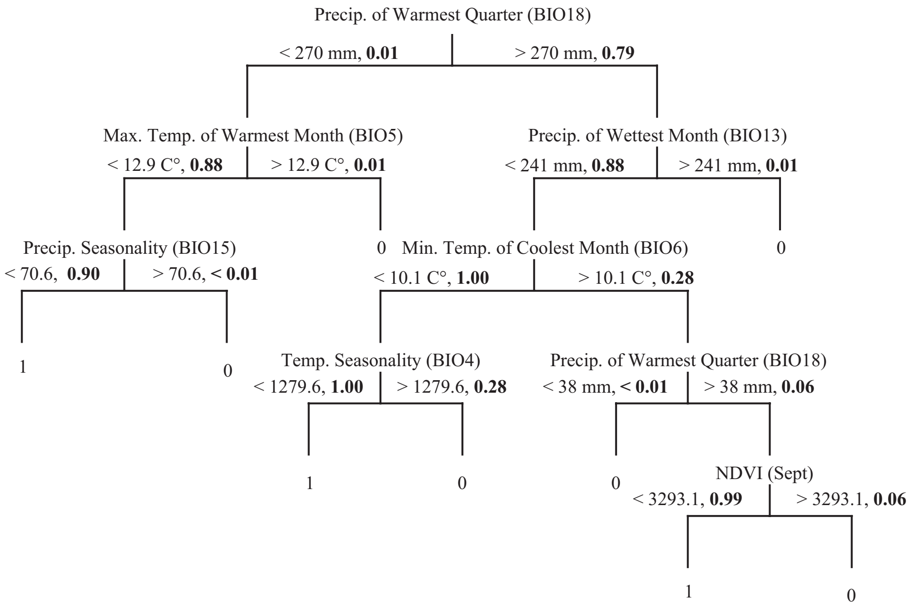

Fig. 2. Classification tree analysis of suitable mountain nyala habitat for Ethiopia. Bold numbers represent the percentage of presence points that fell within the given criteria of significant independent variables.

accuracy of 94% with specificity at 99% and sensitivity at 87%. The validation data had an AUC value of 0.89 and κ value of 0.80. Overall accuracy of the validation model was 90% with specificity at 95% and sensitivity at 84%.

Discussion

The results of our analyses support earlier assessments of the habitat specialist characteristics of the mountain nyala and its limited range within the Ethiopian highlands. At the landscape scale, mountain nyala habitat is heavily reliant on precipitation and temperature, which are known to have direct influences on vegetation structure and diversity (Bekele-Tesemma *et al*. 1993). These environmental variables also played significant roles at a regional scale in addition to topographical and vegetation variables. Although the species' range presented by the final model is highly restricted, it is substantially larger than the speculated range reported in the literature (Malcolm and Evangelista 2005; Evangelista 2006*b*; Sillero-Zubiri 2007). Suitable habitat was predicted in areas that have not been explored during previous population research efforts. These areas are largely found in the south-western slopes of the Bale Mountains and coincide with Brown's surveys in the 1960s,

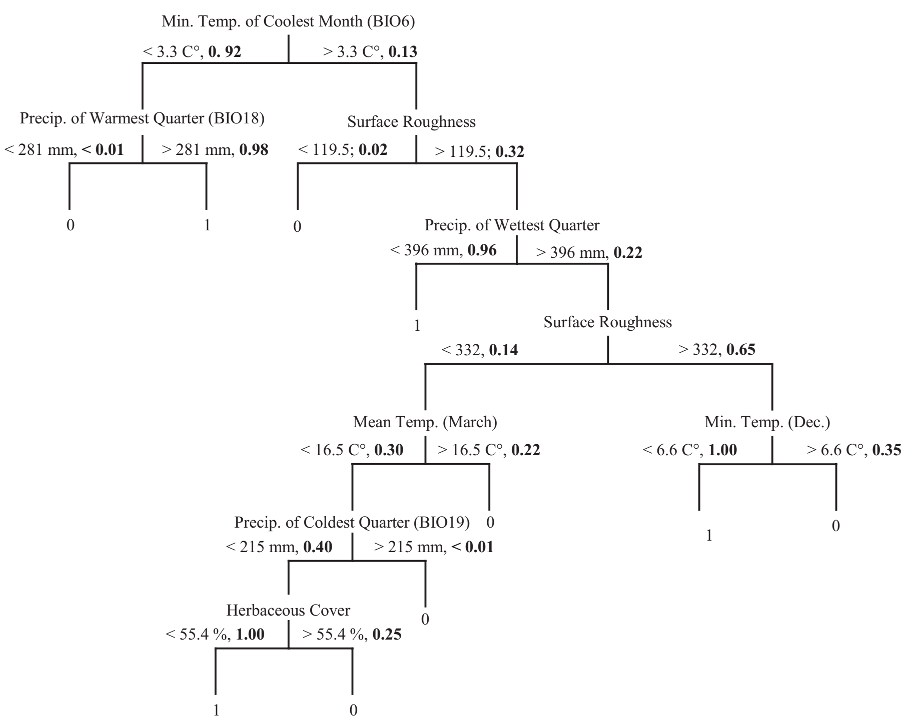

Fig. 3. Classification tree analysis of suitable mountain nyala habitat within the predicted range of the first model (Fig. 2). Bold numbers represent the percentage of presence points that fell within the given criteria of significant independent variables.

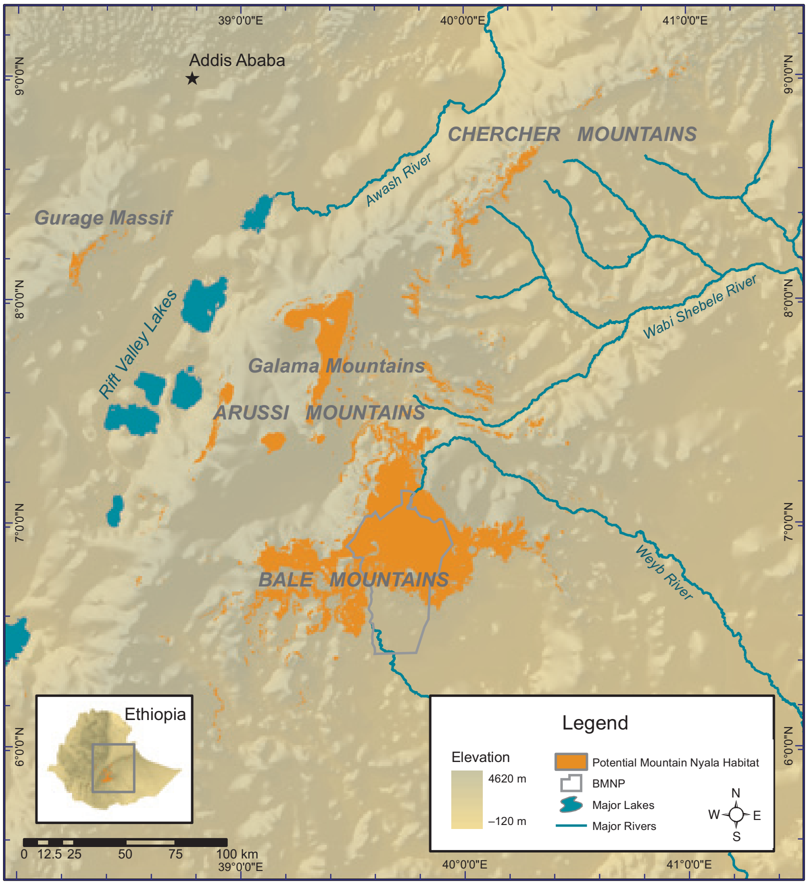

Fig. 4. Map of suitable mountain nyala habitat based on the second classification tree analysis.

occurrences reported by Yalden and Largen (1992) and several recent discoveries we previously reported. In 2006, two of the authors attempted to explore this region's interior but found the terrain difficult to navigate and traverse (Evangelista *et al*. 2007). The survey team was able to confirm the presence of mountain nyala in much of the area, and local people that were interviewed consistently reported that significant populations were common throughout the large expanses of forest (Evangelista 2006*b*; Evangelista *et al*. 2007).

The final model also predicts that several regions outside the Bale Mountains may have suitable habitat for mountain nyala. Of particular interest are the tributaries and headwaters of the Wabe Shebele River located east of the Arussi Mountains (Fig. 1). Although we have never adequately explored these regions from the ground, several aerial surveys revealed pockets of intact forests with steep topography that is prohibitive to human settlement and livestock grazing. Additionally, we have received reports from local people that mountain nyala are found in these areas. The northern tributaries of the Wabe Shebele River, which flow from the Arussi and Chercher mountains, are currently managed for mountain nyala and include one of the recently discovered populations in 2005 (Evangelista 2006*b*). A second area of interest is the Gurage Massif located on the west side of the Rift Valley. Although mountain nyala have never been documented beyond the southern highlands and east side of the Rift Valley, it is possible that the species may have historically occurred there. Aerial surveys of the Gurage Massif reveal only remnant forested areas remain with large expanses of heathlands densely populated with settlements and livestock (P. Evangelista, pers. obs. 2007). Mountain nyala are known to persist in areas heavily impacted by land-use activities (e.g. Galama Mountains, Gaysay Valley); however, we find it unlikely that the species can presently be found there. Future field surveys and in-depth interviews with the local people are warranted, and could reveal significant information on the present and historical status of the mountain nyala throughout the Gurage Massif.

Our models were fitted with environmental variables that included climate, topography and vegetation indices, but lack data on human and livestock populations, land-use and vegetation types. We believe that model performances could be improved if such data were available and integrated into our analyses. Similarly, we have compiled numerous reports from local people regarding mountain nyala sightings, but we elected to exclude this information from the analyses because it either has not been adequately confirmed or the locations were sometimes vague. Although the results from the models suggest that the distribution of mountain nyala and suitable habitat are significantly greater than previously thought, it should be noted that human population densities, agriculture, livestock grazing and deforestation will greatly reduce the actual area of occupancy (Evangelista *et al*. 2007; Sillero-Zubiri 2007).

Despite the caveats, the models have significant value in identifying suitable habitat for mountain nyala and adding to the scientific knowledge of this endemic species. Specifically, our results provide the first map of probable range of the mountain nyala based on field observations since Brown (1969*a*). Our analyses also demonstrate the strong correlation between the species' range and specific climate and topographic conditions. This information not only provides wildlife managers with important geo-spatial data to support management and conservation decisions, but can also guide future surveys to new areas where the mountain nyala may likely persist. Finally, our results offer clues to the of mountain nyala's historic range, which may have once included areas west of the Rift Valley. The current known distribution of the mountain nyala and our model results support the belief that the species' range has always been isolated to the Ethiopian highlands.

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