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Assessing habitat quality of the mountain nyala *Tragelaphus buxtoni* in the Bale Mountains, Ethiopia

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Abstract Populations of the endangered mountain nyala *Tragelaphus buxtoni* are significantly threatened by the loss of critical habitat. Population estimates are tentative, and information on the species' distribution and available habitat is required for formulating immediate management and conservation strategies. To support management decisions and conservation priorities, we integrated information from a number of small-scale observational studies, interviews and reports from multiple sources to define habitat parameters and create a habitat quality model for mountain nyala in the Bale Mountains. For our analysis, we used the FunConn model, an expertise-based model that considers spatial relationships (i.e., patch size, distance) between the species and vegetation type, topography and disturbance to create a habitat quality surface. The habitat quality model showed that approximately 18,610 km^2 (82.7% of our study area) is unsuitable or poor habitat for the mountain nyala, while 2,857 km^2 (12.7%) and 1,026 km^2 (4.6%) was ranked as good or optimal habitat, respectively. Our results not only reflected human induced habitat degradation, but also revealed an extensive area of intact habitat on the remote slopes of the Bale Mountain's southern and southeastern escarpments. This study provides an example of the roles that expert knowledge can still play in modern geospatial modeling of wildlife habitat. New geospatial tools, such as the FunConn model, are readily available to wildlife managers and allow them to perform spatial analyses with minimal software, data and training requirements. This approach may be especially useful for species that are obscure to science or when field surveys are not practical [*Current Zoology* 58 (4): 525–535, 2012].

Keywords Expert knowledge, FunConn model, Habitat mapping, Land cover, Mountain nyala, Wildlife conservation

Habitat loss, fragmentation, and degradation pose direct threats to wildlife species worldwide. Driven by human population growth, unsustainable consumption of natural resources, and policies that do not fully value biodiversity, habitat destruction is widely accepted as the leading cause of wildlife extinction rates in recent decades (Myers et al., 2000; Pimm and Raven, 2000; Hoekstra et al., 2005, Krauss et al., 2010). In many cases, the absence of adequate survey data to monitor wildlife populations and distributions prevents timely management and conservation decisions that could ultimately save a species or population. This is especially true with rare and endangered species in developing countries, where wildlife managers have limited resources and information to formulate effective conservation strategies. Given the urgency with many at-risk species, wildlife managers are increasingly looking for new approaches to assess a population's range and distribution, identify critical habitats, and guide conservation priorities (Menon et al., 2002; Sanderson et al., 2002; Thorbjarnarson et al., 2006).

These challenges associated with wildlife management and conservation may best be demonstrated in Ethiopia, where 83% of its 90 million people live in rural areas (CIA, 2011). Most Ethiopians have subsistence livelihoods relying on small-scale farming, livestock, and natural resources which have resulted in alarming reductions of both wildlife and habitat (Sillero-Zuberi and Macdonald, 1997; Stephens et al., 2001; FZS, 2007). Ethiopia's forests once covered 65% of the country and 90% of the highlands; today, forests cover only 2.2% of the country and 5.6% of the highlands (FAO, 2006). It should be noted that Ethiopia has unusually high incidence of endemism of flora and fauna, including at least 31 endemic mammals (Yalden and Largen, 1992). One species of particular concern is

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the mountain nyala *Tragelaphus buxtoni*, a spiral-horned antelope endemic to the southern highlands of Ethiopia. Currently listed as *Endangered* by the World Conservation Union (Sillero-Zubiri, 2008), the total population of the species and its full range remains undetermined. Recent work by Evangelista et al. (2008) provided strong evidence that the extent of suitable habitat and the potential range of the mountain nyala are significantly greater in the Bale Mountains than previously believed. Specifically, spatial models using regression analysis showed that unexplored regions on the southern and southwestern escarpments of the Bale Mountains had ideal environmental conditions for supporting large numbers of mountain nyala. Recent field surveys, interviews with local people, and published research conducted in some of these areas (e.g., Rira, Baluk, Fetcha Plain) confirmed that mountain nyala inhabited these areas and that much of the habitat remained intact (EWCD and ORLNRD, 2005[1]; Evangelista and Swartzinski, pers. observation 2006; Atickem et al., 2011).

Despite a new optimism for mountain nyala populations in the Bale Mounains, rapid loss of critical habitat due to increasing human land-use activities is a significant and immediate threat to the persistence of the species (Woldegebriel, 1996; Stephens et al., 2001; Evangelista et al., 2007; FZS, 2007). In 1986, Hillman (1986) estimated that 2,500 people lived or used resources within BMNP. By 2003, it was estimated that 40,000 people inhabited BMNP residing in more than 3,000 settlements (FZS, 2007). As human populations continue to grow at an alarming rate, so does the demand for agriculture, grazing lands, and natural resources (Evangelista et al., 2007; FZS 2007; Atickem et al., 2011). These trends pose direct threats to the mountain nyala and other wildlife species, primarily from habitat loss, fragmentation, and degradation. In the absence of adequate survey methods and data to determine mountain nyala populations and distributions, there is an increasing urgency to conserve and protect critical habitats to ensure the long-term survival of the species.

As with many developing countries, wildlife management and conservation activities in Ethiopia are constrained by limited personnel, equipment, software, funding and training. Access to new technologies and novel methods that are readily available to wildlife managers in western countries is often limited for managers in developing countries. To address some of these needs, there are a growing number of on-line tools, datasets and software that are freely available and designed to support wildlife management needs and strengthen capacity. A suite of spatial models and techniques are available and are popular among wildlife managers (Osborne et al., 2001; Yamada et al., 2003; Pearson et al., 2007). Spatial models are commonly used for predicting species occurrence (Evangelista et al., 2008), critical habitat (Turner et al., 2004), migratory patterns (Boone et al., 2006), and risk of disease (Pfeiffer and Hugh-Jones, 2002). Many of the new models and techniques are trained by presence and absence data (i.e., location coordinates) in conjunction with environmental data to statistically define a species' ecological niche within a landscape. For large wildlife species, such as the mountain nyala, these modeling approaches perform best at large spatial scales (Evangelista et al., 2008). At smaller spatial scales, these models may not be appropriate since presence and absence data are highly subjective due to the extensive ranges and migratory patterns of mobile species. Furthermore, the data required for empirically based models may not be available or may be difficult to acquire (Clevenger et al., 2002). In these cases, models that use qualitative information about wildlife species (i.e., expert knowledge) may be a better approach for spatially quantifying relationships between wildlife and their environment (Stroms et al., 1992; Yamada et al., 2003, Irvine et al., 2009). Known as expert-based modeling, the methodology has been practiced by wildlife managers for decades and continues to be a valuable tool today (Drew et al., 2011; Theobald et al., 2011). Expertise on a species may be provided by wildlife managers, researchers, hunters, local and indigenous people or scientific literature. This important knowledge base, coupled with modern geospatial tools and information, has strengthened both the application and performance of modern expert-based models.

We tested this model approach on mountain nyala using a synthesis of observations, geographic information systems (GIS) and the Functional Conductivity model (FunConn v1; Theobald et al., 2006) to define habitat quality in the Bale Mountains. Our immediate goal was to identify critical mountain nyala habitat to support management and conservation priorities. A secondary goal was to test the application of free on-line

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[1] Ethiopian Wildlife Conservation Department and Oromia Rural Land, Natural Resource Department (EWCD and ORLNRD), 2005. Assessment of the wildlife resource in Hurufa–Soma proposed controlled hunting area, Oromia Region. Addis Ababa, ETH.

tools, datasets and software available for use by wildlife managers in Ethiopia and other developing countries. Expertise for this study was provided by small-scale studies presented in the literature (Brown, 1969a; 1969b; Stephens et al., 2001), reports from wildlife managers (EWCD and ORLNRD 2000; 2004; 2005), observations and interviews with a local-operating hunting safari company (Roussos, 2011), and our own observations (Evangelista et al., 2007; 2008). This knowledge base was used to define habitat parameters and develop a spatial model to identify critical mountain nyala habitat in the Bale Mountains.

1 Materials and Methods

1.1 Mountain nyala

Mountain nyala are known to inhabit three major mountain ranges that form a chain along the east side of the Rift Valley: the Chercher, Arussi and Bale Mountains. Populations in the Chercher and Arussi Mountains are highly fragmented and are confined to only a few high peaks. The majority of mountain nyala are found in the Bale Mountains, where most of the southern slopes are densely forested and only minimally impacted by human settlements and related land-use (Waltermire, 1975; Evangelista et al., 2007; Sillero-Zubiri, 2008). Recent mountain nyala population estimates range from 2,500 (Sillero-Zubiri, 2008) to 4,000 or more (Evangelista et al., 2007; Atickem et al., 2011). Since 2000, five new distinct populations have been documented by researchers and wildlife managers; four occur within the forests of the eastern and southern slopes of the Bale Mountains (EWCD and ORLNRD 2000[2]; 2004[3]; 2005; Evangelista et al., 2008). Mountain nyala can be found at elevations ranging from 1,600 m to 4,300 m, but they are generally concentrated within mesic habitats between 1,800 m and 4,000 m (Brown, 1969; Yalden and Largen, 1992). They are generally shy animals preferring steep slopes and dense forests for concealment, thermal cover, year-round forage and predator avoidance (Brown, 1969; Evangelista et al., 2007). Primarily browsers, mountain nyala are known to feed on a variety of trees, forbs, grasses and cultivars (Brown, 1969b; Hillman, 1985; Evangelista et al., 2007; Bussman et al., 2011).

1.2 Study site

Our study area was located in the southern highlands of Ethiopia, east of the Rift Valley. It included all of the Bale Mountains and encompassed an area of 22,495 km^2 bounded by UTM coordinates 478,000, 815,000 (upper left) and 660,000, 692,000 (lower right; World Geodetic System 1984, Zone 36). Recognized as a candidate World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Bale Mountains are ecologically unique for many reasons. Elevations range from 1,500 m to 4,377 m a.s.l. The elevation gradient and the abruptly rising peaks of the Bale Mountains create orographic precipitation that feeds over 40 streams, numerous springs and alpine lakes that support 12 million people throughout southern Ethiopia and Somalia (Hillman, 1988; Yalden and Largen, 1992; FZS, 2007).

In the Bale Mountains, vegetation communities are spatially situated within four altitudinal zones: the Afro-alpine (> 3,700 m a.s.l.), sub-alpine and ericaceous (3,200 m to 3,700 m a.s.l), upper Afro-montane forests (2,300 m to 3,250 m a.s.l.), and lower Afro-montane woodlands (1,500 m to 2,300 m a.s.l.; Bekele-Tesemma et al., 1993; Birnie and Tengnas, 1993). The plant assemblages and diversity associated with the four altitudinal zones have been described in great detail in the scientific literature (Hedberg, 1951; Weinert and Mazurek, 1984; Uhlig, 1988; Nigatu and Tedesse, 1989; Miehe and Miehe, 1994; Bussman 1997; Wesche et al., 2000). The importance of each zone to the mountain nyala has been described by Brown (1969b) and Evangelista et al. (2007).

To date, over 1,300 species of flowering plants have been documented in the Bale Mountains, including 163 species endemic to Ethiopia and 400 species with medicinal value to the people (FZS, 2007). The Bale Mountains are also home to more than 77 mammals and 170 bird species (26% and 57% are endemic to Ethiopia, respectively) and support the largest populations of mountain nyala and Ethiopian wolves *Canis simensis* in the world (Hillman, 1986; Williams, 2002; FZS, 2007).

In 1970, BMNP was created to protect the area's biological diversity and endemic species. The park encompasses 2,200 km^2, including most of the Sanetti

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[2] Ethiopian Wildlife Conservation Department and Oromia Rural Land and Natural Resource Department (EWCD & ORLNRD). 2000. Wildlife assessment of the Besmenna–Udu Bulu proposed Controlled Hunting Area. Oromia Region. Addis Ababa, ETH.

[3] Ethiopian Wildlife Conservation Department and Oromia Rural Land and Natural Resource Department (EWCD & ORLNRD). (2004) Report on wildlife census in Abasheba Demero Controlled Hunting Area, Oromia Region. Addis Ababa, ETH.

Plateau and a significant portion of the Harenna Forest (Waltermire, 1975; Hillman, 1986). The Mena Angetu National Forest Priority area, which covers nearly 1,900 km^2, borders the park to the southwest. The Adaba-Dodolla Integrated Forest Management Program, a community forestry project initiated in the late 1980s, is located to the northwest of the park along the foothills of the northwestern slopes of the Bale Massif. There are five Controlled Hunting Areas in the Bale Mountains that were primarily established for limited hunting of mountain nyala (one to the north, one to the south, and three to the east of the park). The Controlled Hunting Areas are intensively managed by the Ethiopian Wildlife Conservation Authority and the safari companies that hold the hunting leases to minimize habitat loss, exploitation of natural resources and poaching. Other tourism activities (e.g., bird watching, trekking) are increasingly becoming popular in BMNP. As previously mentioned, the number of human inhabitants in the region has escalated in recent decades. We should also note that at the time of this writing, construction of a paved road is underway that will run through the northern part of BMNP. Once completed, another sharp increase in human population and vehicle traffic is anticipated along the northern border of the park.

1.3 Mapping land cover

Land cover maps that depict vegetation and land-use types are essential for mapping and modeling wildlife habitat quality (Osborne, 2001; Turner et al., 2004). There are currently no concise, fine-scale land cover maps for the Bale Mountains. For our habitat quality analyses, we produced a land cover map of the Bale Mountains at 30 m^2 using classification tree analysis, a commonly used approach for mapping land cover (Lees and Ritman, 1991; Parmenter et al., 2003). All spatial analyses for the land cover map were conducted using ArcGIS 9.2 mapping software (ESRI, 2006). Our analyses used 29 independent variables including spectral data from four Landsat 7 ETM+ satellites; two scenes acquired in November 2000 and two in February 2001 were processed as a single mosaic. We extracted values from bands 1, 2, 3, 4, 5 and 7 to be analyzed individually and calculated Normalized Difference Vegetation Index (NDVI) using the formula [*(NIR-red) / (NIR+red)*], where *NIR* is band 2 (near infrared) and *red* is band 1 (Sellers, 1985; Myneni et al., 1995). In addition to the six bands and NDVI data, we generated three tassel cap transformations representing wetness, greenness and brightness (Kauth and Thomas, 1976[4]). We also included in the analyses monthly mean precipitation from WorldClim (Nix, 1986; WorldClim, 2006), slope in degrees, a digital elevation model (DEM), soil wetness index (see Moore et al., 1991) and solar insolation (see Kumar et al., 1997). From the DEM, we calculated elevation ratios, differences and standard deviation using methods described by Jenness (2006). When necessary, we re-sampled large-scale geospatial data to a 30-m^2 resolution to match those of the satellite data.

To train our land cover analysis, we used 1,669 reference points collected by the authors between 2004 and 2008. Reference points included 1,066 calibration field plots and an additional 603 points representing water and agriculture (*n*=1669). The calibration plot is a simple circular plot with a diameter of 7.2 m that is based on the Forest Inventory and Analysis Program of the U.S. Forest Service (Huang et al., 2001[5]). For each plot, we estimated the percent cover of vegetation by species as well as percent cover of soil, rock and water. The total percent cover for each plot equaled 100% and was recorded in a top-down manner (beginning with the canopy and ending at the ground's surface) that best represented the spectral reflectance captured by satellite sensors. Plot locations were generated using stratified random sampling within smaller geographic areas. Because our calibration plots targeted natural vegetation features, we generated additional water and agriculture points (*n* = 603) in ArcGIS from Landsat 7 ETM+ band 8 (panchromatic).

Classification tree analyses were conducted using S-Plus 3 statistical software (Insightful, 2000). Twenty percent of the calibration plots were randomly selected and withheld from the training analyses for accuracy evaluations. Two processes were required in order to map land cover to a high degree of detail. The first

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[4] Kauth RJ, Thomas GS, 1976. The tasseled cap – a graphical description of the spectral–temporal development of agricultural crops as seen by Landsat. Proceedings of the Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Indiana, pp. 4B41–4B51.

[5] Huang C, Yang L, Homer C, Coan M, Rykhus et al., 2001. Synergistic use of FIA plot data and LANDSAT 7 ETM+ images for large area forest mapping, In: Thirty–fifth Annual Midwest Forest Mensurationists Meeting and the Third Annual Forest Inventory and Analysis Symposium, October 17–19, 2001, Traverse City, MI.

process used classification tree analysis to partition the data into seven land cover classes. Some of the land cover classes from the first map remained as final classifications (e.g., water, *Erica* sp.), while others were further partitioned independently in a second process for greater detail (e.g., deciduous forest and coniferous forest). Classification trees were pruned using tenfold cross-validation (Breiman et al., 1984). Following each stage of the classification tree analyses, we overlaid the withheld validation plots to assess specificity and sensitivity and overall accuracy (see Fielding and Bell, 1997).

1.4 Functional connectivity modeling

To map habitat quality for the mountain nyala, we used the *Habitat Modeling* toolset available within the Functional Connectivity model (FunConn) that is freely available on the World Wide Web (http://www.nrel.colostate.edu/projects/starmap/funconn_index.htm). The FunConn model was created specifically to identify critical habitat, movement patterns and landscape connectivity related to large mammal conservation (Theobald et al., 2006; Theobald et al., 2011). The model operates with ArcGIS software and is based on a complex structure that relies on user-defined attribute weighting and cost analyses. In addition to understanding some fundamental habitat preferences of the species of interest, only land cover data is required for developing a model. The flexibility of FunConn also allows the user to integrate other spatial data (e.g., disturbance, slope) that may be significant to habitat quality for a particular species.

The *Habitat Modeling* feature creates a habitat quality surface based on three factors: (1) resource quality, (2) patch structure and (3) distance from disturbance. A resource quality surface is generated by defining habitat parameters within a land cover surface. Each land cover class is indexed from 0 to 100 (unsuitable habitat to optimal habitat, respectively) based on habitat preferences of the target species (i.e., mountain nyala). Patch structure is defined as a species' response to edge and core habitats. The values are ranked between 0 and 100 (unsuitable habitat to optimal habitat, respectively) and correlated to increasing distances from edge habitat within and outside of core habitats (Fig. 1; Theobald et al., 2006). A distance from disturbance table is generated by integrating known disturbances (e.g., roads, towns) with the land cover data. By creating a disturbance re-class table using the two data sets, the model is able to capture degrees of disturbance effects in unique cover types and at varying distances. Once these attribute tables are defined and new surfaces created, the model generates a surface of the study area ranking habitat quality from 0 to 100 (unsuitable habitat to optimal habitat, respectively). Finally, minimum patch size needs to be determined by the smallest biologically relevant patch size (measured in hectares) for the species of interest. This value may be best estimated from a population's known smallest home range. Further details on the operation of the FunConn model can be found in Theobald et al. (2006).

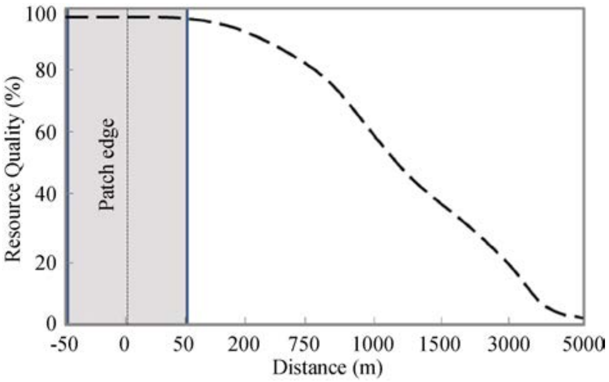

Fig. 1 Parameters of patch structure for the mountain nyala that reflect anticipated changes of habitat quality over increasing distance

In our analyses for the mountain nyala, we defined the resource quality values based on a suite of field observations related to habitat preference and locations at which the species has been observed (Evangelista et al,. 2007; 2008). The resource quality parameters are defined in Table 1 and are based on observed preference of habitat structure (Evangelista et al., 2007) and availability of forage (Appendix 1). The parameters for patch structure were also determined by field observations and represent the mountain nyala's preference for forested and edge habitats and avoidance of exposed areas with little cover (Fig. 1; Evangelista et al., 2007; 2008). We used road and town surfaces to represent disturbances for the Bale Mountains. Towns were divided into three categories (major towns, small towns and villages) to represent different populations and varying degrees of disturbance. Agriculture was not included in the disturbance parameters because it was represented in the resource quality values (i.e., land cover data). Our data did not include information on the locale of small homesteads or livestock grazing areas. Since settlements and grazing are assumed to decrease as distance from a road or town increases, we were able to partially account for these impacts when defining disturbance parameters (Fig. 2). Lastly, we defined the minimum patch size for the mountain nyala as 5 km^2. This estimate was determined from population observations made near BMNP headquarters, the smallest known concentration of mountain nyala (Refera and Bekele, 2004), and followed recommendations used for the North American elk (*Cervis elaphus*; using methods from Jetz et al., 2004).

Table 1 User-defined resource quality parameters required for the FunConn model

Land cover type	Resource quality
Sparse vegetation	40
Heath (*Erica* spp.)	75
Coniferous	80
Deciduous	90
Woodland	60
Herbaceous	60
Bamboo *Sinaruninaria alpine*	95
Grasslands	50
Alpine shrub	55
Forest shrub	100
Water	0
Agriculture	40
Towns	n/a
Roads	n/a

The values represent a ranking of land cover types, from 0 (unsuitable) to 100 (optimal), for mountain nyala habitat quality.

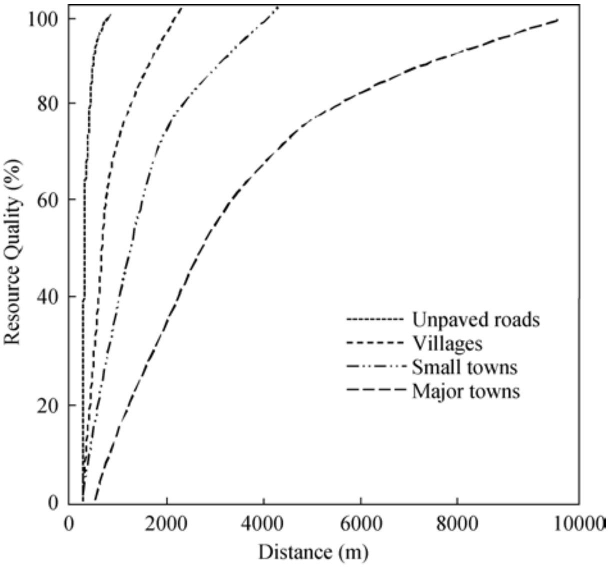

Fig. 2 Effects of distances from disturbances (i.e., roads, villages, small towns, major towns) on habitat quality for the mountain nyala

1.5 Model evaluation

To evaluate our model results, we used two independent datasets of mountain nyala observations and associated location coordinates. Both datasets were collected from the central and eastern regions of the Bale Mountains. The first dataset was recorded by the lead author (Evangelista, unpublished) between 2002 and 2009 and consisted of 209 observation points. Observations were made from a distance, and coordinates for observed animals were calculated using a GPS reading of the observer's location, a compass to record an azimuth bearing of the animal and rangefinder to determine the distance (m) between the observer and animal. The location coordinates (i.e., easting, northing) were then calculated using the following formulas [$E^{\text{mnyala}} = E^{\text{observ}} + (D + \cos Az)$] and [$N^{\text{mnyala}} = N^{\text{observ}} + (D + \sin Az)$], where E is easting, N is northing, D is distance in meters, and Az is azimuth.

The second independent dataset was recorded by a professional hunter (Roussos, personal communication) and operator of Ethiopian Rift Valley Safaris (ERVS). Since the establishment of two Controlled Hunting Areas in the Bale Mountains in the early 2000s (ORLNRD, 2000; 2004), ERVS has been the sole concession holder and maintains permanent camps, guards and game scouts. Mountain nyala is the main species hunted by ERVS clients, with 10 to 12 trophy licenses issued annually between the two hunting concessions. The data provided by the professional hunter were collected between 2000 and 2010 and consisted of 275 observation points. The location coordinates of observed animals were estimated from GPS readings and sightings recorded on paper maps (Roussos, personal communication). Both datasets were overlaid on the final model independently and habitat quality values were extracted. These were then graphed to see how well the habitat quality values matched the observation points of each expert dataset.

2 Results

Results from our first land cover map had an overall accuracy of 87%, and our final map had an overall accuracy of 83%. Our study area encompassed 22,494 km^2. Forb communities were dominant on the landscape, comprising 32% of the area (7,959 km^2); upland deciduous forest occupied 23% of the area (5,826 km^2); grasslands covered 16% (4,042 km^2); and agriculture covered 12% (2,927 km^2). The final land cover map is presented in Fig. 3. The lower accuracy percentage for our final land cover map was expected since the second analysis was restricted by the results of our initial land cover map (87% was the highest accuracy that could

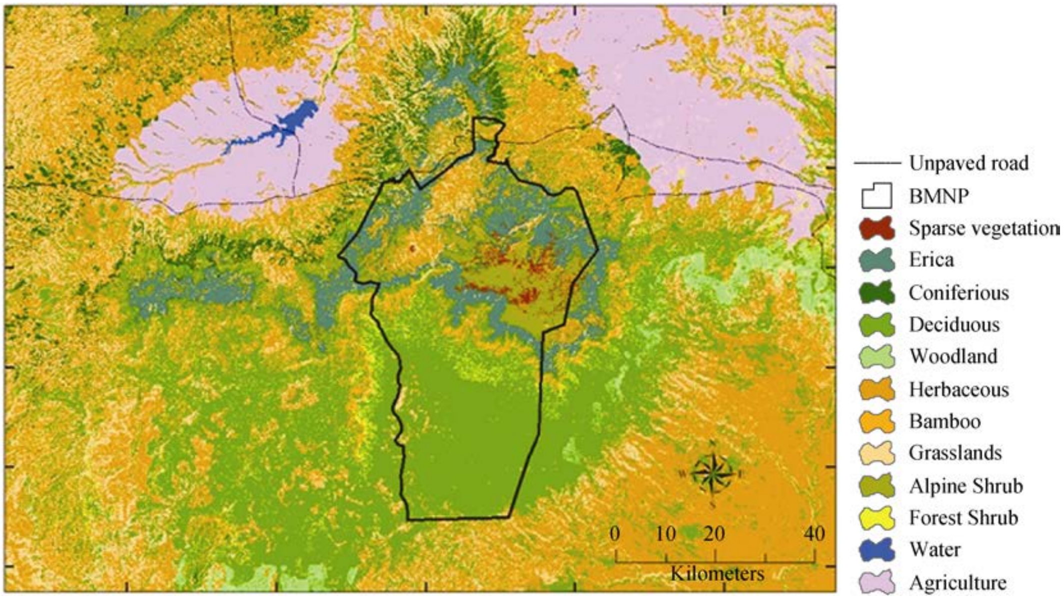

Fig. 3 Land cover types of the Bale Mountains using classification tree analyses

possibly be achieved by the second land cover map).

The results from the FunConn model indicated an extensive amount of high-quality habitat for the mountain nyala throughout the Bale Mountains (Fig. 4). The thresholds we defined for habitat quality considered 0–39 ranking as unsuitable habitat, 40–69 as poor habitat, 70–89 as good habitat and 90–100 as optimal habitat. Our results suggested that approximately 18,610 km^2 (82.7% of our study area) is unsuitable or poor habitat for the mountain nyala, while 2,857 km^2 (12.7%) and 1,026 km^2 (4.6%) was ranked as good or optimal habitat, respectively.

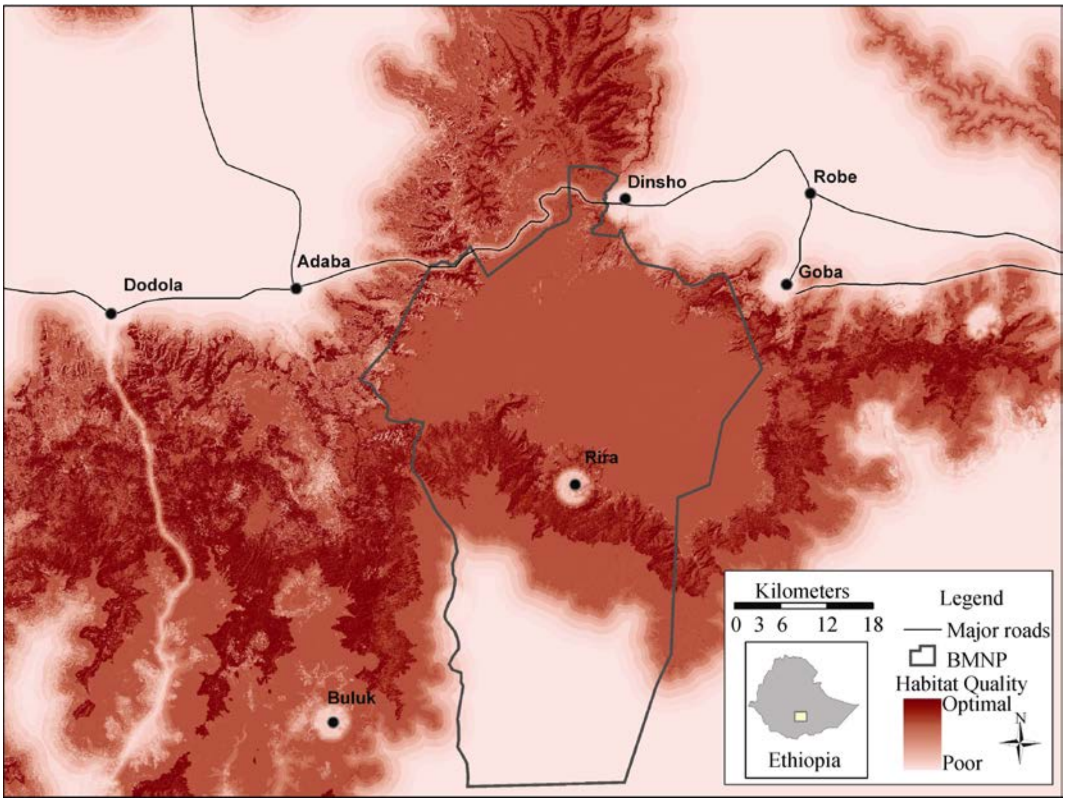

Fig. 4 Habitat quality model for the mountain nyala in the Bale Mountains

The results were generated with the FunConn model and a land-cover surface with user-defined habitat thresholds related human disturbance

Model evaluations using the two observation data sets suggest that the FunConn model performed well. Of the observations provided by ERVS and Evangelista, 70% and 73%, respectively, fell within areas ranked as good or optimal habitat (Fig. 5). Both data sets had 22% of the observations in areas ranked as poor habitat. Although these evaluations provide some measure of model performance, they need to be interpreted with some caution. Observation biases, animal movements and habitat degradation in some regions all factor into the data to some degree.

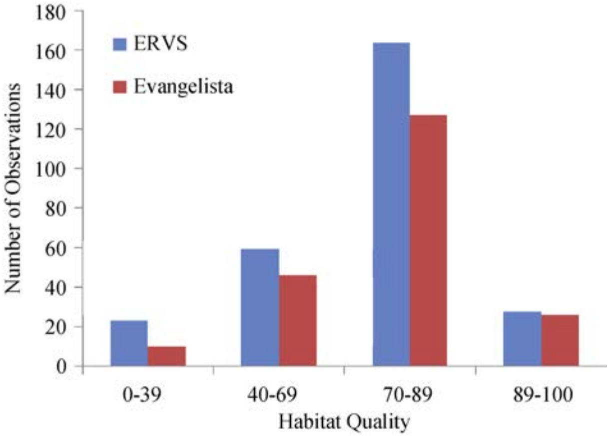

Fig. 5 Evaluation of habitat quality model for mountain nyala in the Bale Mountains using observations recorded by a safari company (ERVS) and the lead author (Evangelista)

3 Discussion

The results from this work have several important implications for wildlife managers, scientists, conservationists and policy makers. First, we have demonstrated that expert knowledge and small observational studies still play an important role in wildlife management and conservation. Because most statistical models rely on occurrence data, which may not always accurately reflect wildlife distributions or habitat preferences at regional scales (Stockwell and Peterson, 2002; Barry and Elith, 2006), expert knowledge is often overlooked in statistical modeling techniques. In this study, expertise was drawn from multiple small-scale studies presented in the literature, reports from regional and national wildlife managers, professional hunters, and our own observations to predict mountain nyala distributions based on habitat quality and human disturbance. Depending on the species of interest and its origin, additional sources of information may be available from local communities, non-governmental organizations, and on-line databases. Second, we successfully tested the application of the FunConn model, which is freely available to wildlife managers. The FunConn model only requires a land cover surface, where additional inputs and predictor variables (e.g., minimum patch size, resource quality threshold) are defined and weighted by the user. This reduces the need for large robust data sets (i.e., response and predictor variables) that may not be readily available to wildlife managers or for specific geographic regions. Because the model easily integrates multiple types of human disturbance (e.g., roads, towns, agriculture), and allows independent ranking of their impacts, the user may address anthropogenic impacts in model building with great detail. It would seem that the availability, simplicity and design of the FunConn model would be an attractive tool for wildlife managers that have limited resources and immediate management and conservation needs.

For the mountain nyala, our research provided valuable information for wildlife managers. Our model results not only support previous studies indicating that the extent of mountain nyala habitat is greater than previously reported (Evangelista et al., 2008; Atickem et al., 2011), but also suggest that a significant area of habitat remains intact. Human impacts are also apparent and the model indicates early stages of habitat fragmentation. We believe that our model of habitat quality for the mountain nyala can be improved by addressing several research needs. For example, better temporal data on movement patterns and seasonal ranges of individual animals would allow us to refine the model results. We speculate that movement is correlated with seasonal rain patterns and available forage. This is supported by local testimonies that mountain nyala migrated more extensively before Ethiopia's human and livestock populations were amplified (Kubsa, 1999[6]; Stephens et al., 2001). We also need to better understand the dietary requirements of the species. Our species list of important forage for the mountain nyala remains incomplete and did not reflect the nutritional importance of each species throughout the different seasons. Finally, there is a need to accurately identify the impacts of anthropogenic activities to mountain nyala distribution and habitat quality. There appears to be a wide range of both in

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[6] Kubsa A, 1999. Need Assessment and Recommendations for Active Community Involvement in the Conservation of Galama Controlled Hunting Area. Report on behalf of Advisory Assistance to the Forest Administration Project (GTZ).

the Bale Mountains and the human impacts and wildlife response may vary geographically (e.g., Gaysay Valley vs. Harenna Forest). Our analyses included several land-use features (i.e., towns, roads, and agriculture) but did not consider individual homesteads and livestock herds that are dispersed throughout the Bale Mountains. Some of this information is available (Atickem et al., 2011), but not in the detail required to be represented geospatially.

In conclusion, expert knowledge integrated with spatial models, such as Funconn, is proving to be a vital tool for addressing many wildlife issues. We have demonstrated how the importance of interdisciplinary studies integrated with new geospatial applications can be effective for scientific discovery. The FunConn model was well suited for the available data for the mountain nyala. It not only allowed us to analyze vegetation data with habitat preferences, but also considered the effects of topographical and disturbance data in a geospatial context. Habitat quality maps may prove to be useful for a number of wildlife species throughout Africa, especially for species inhabiting environments that are inaccessible due to landscape features, remoteness or conflict. The importance of identifying and preserving critical habitat for wildlife management and conservation is widely recognized. Future wildlife studies may consider our approach when targeting rare and endemic species that are obscure to science or where field surveys are not practical.

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Appendix S1 Important vegetation species for the dietary requirements of the mountain nyala

Family	Species	Growth type	References	Altitundinal vegetation zones
Acanthaceae	*Acanthus eminens*	herb	5	lower and upper Afro-montane
Acanthaceae	*Acanthus sennii*	herb	5	lower and upper Afro-montane
Acanthaceae	*Asystasia gangetica*	herb	5	lower and upper Afro-montane
Acanthaceae	*Hypoestes aristata*	herb	3, 4, 5	lower and upper Afro-montane
Acanthaceae	*Hypoestes triflora*	herb	1, 4, 5	lower and upper Afro-montane
Amaranthaceae	*Achryanthes aspera*	herb	5	lower and upper Afro-montane
Apocynaceae	*Carisa edulis*	shrub	5	lower and upper Afro-montane
Asphodelaceae	*Kniphofia foliosa*	herb	1, 4, 5	lower and upper Afro-montane
Asteraceae	*Artemisia afra*	shrub	2, 3, 4, 5	lower and upper Afro-montane
Asteraceae	*Bothriocline schimperi*	herb	3, 4, 5	lower and upper Afro-montane
Asteraceae	*Carduus ellenbeckii*	herb	5	lower and upper Afro-montane
Asteraceae	*Carduus nyassanus*	herb	1, 2, 5	lower and upper Afro-montane
Asteraceae	*Cirsium dender*	herb	4, 5	lower and upper Afro-montane
Asteraceae	*Echinops* spp.	herb	1, 5	lower and upper Afro-montane
Asteraceae	*Helichrysum splendidum*	herb	5	upper Afro-montane & sub-alpine
Asteraceae	*Senecio* spp.	herb	5	lower and upper Afro-montane
Balsaminaceae	*Impatiens* spp.	herb	5	lower and upper Afro-montane
Campanulaceae	*Canarina eminii*	vine (woody)	5	lower and upper Afro-montane
Celastraceae	*Maytenus undata*	tree	5	lower and upper Afro-montane
Convolvulaceae	*Convolvulus kilimandshari*	vine (woody)	5	lower and upper Afro-montane
Cupressaceae	*Juniperus procera*	tree	1, 5	upper Afro-montane & sub-alpine
Ericaceae	*Erica arborea*	shrub	4, 5	upper Afro-montane & sub-alpine
Fabaceae	*Erythrina brucei*	tree	5	lower and upper Afro-montane
Fabaceae	*Parochetus communis*	herb	5	lower and upper Afro-montane
Fabaceae	*Trifolium* spp.	herb	5	lower and upper Afro-montane
Hypericaceae	*Hypericum revolutum*	tree	5	upper Afro-montane & sub-alpine
Lamiaceae	*Thymus schimperi*	herb	5	lower and upper Afro-montane
Lemnaceae	*Lemna minor*	herb (aquatic)	5	lower and upper Afro-montane
Lobelliaceae	*Lobelia inconspicua*	herb	1, 4, 5	lower and upper Afro-montane
Malvaceae	*Abutilon grandflorum*	vine (woody)	5	lower and upper Afro-montane
Oleaceae	*Jasminum abyssinicum*	vine (woody)	5	lower and upper Afro-montane
Poaceae	*Agrostis* spp.	grass	1, 4, 5	lower and upper Afro-montane
Poaceae	*Bromus leptoclados*	grass	5	lower and upper Afro-montane
Poaceae	*Hordeum vulgare*	grass (cultivar)	5	lower and upper Afro-montane
Poaceae	*Koeleria* spp.	grass	5	lower and upper Afro-montane
Poaceae	*Oplismenus compositus*	grass	1,5	lower and upper Afro-montane
Poaceae	*Pennisetum* spp.	grass	5	lower and upper Afro-montane
Poaceae	*Poa* spp.	grass	1, 5	lower and upper Afro-montane
Poaceae	*Streblochaete longiarista*	grass	5	lower and upper Afro-montane
Poaceae	*Triticum* spp.	Grass (cultivar)	5	lower and upper Afro-montane
Ranunculaceae	*Clematis hirsuta*	vine (woody)	5	lower and upper Afro-montane
Rosaceae	*Alchemilla abyssinica*	herb	1, 5	lower and upper Afro-montane
Rosaceae	*Alchemilla rothii*	herb	3, 4, 5	lower and upper Afro-montane
Rosaceae	*Hagenia abyssinica*	tree	3, 5	upper Afro-montane & sub-alpine
Rosaceae	*Potentilla* spp.	herb	4, 5	lower and upper Afro-montane
Rosaceae	*Rosa abyssinica*	shrub	5	lower and upper Afro-montane
Rosaceae	*Rubus apetalus*	shrub	1, 5	lower and upper Afro-montane
Rosaceae	*Rubus steudneri*	shrub	1, 5	lower and upper Afro-montane
Scrophulariaceae	*Hebenstretia dentata*	herb	2, 4, 5	upper Afro-montane & sub-alpine
Urticaceae	*Urera hypelondendron*	shrub	5	lower and upper Afro-montane
Verbenaceae	*Premna schimperi*	tree	5	lower and upper Afro-montane

References are coded as follows: [1]Brown, 1966a; [2]Hillman, 1985; [3]Hillman and Hillman, 1987; [4]Refera and Bekele, 2004; [5]Evangelista and Swartzinski, personal observation, 2001–2006.