Where to Survey? Prioritization of Survey Areas for the Ethiopian Large Carnivores Survey Project

(December 2019)

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Introduction

Ethiopia is home to a rich mammal carnivore community, including members from the families; Mustelidea (five species), Canidae (eight species), Felidae (six species), Hyaenidae (two species) and Viveridae (11 species) (Yalden et. al., 1980). However, very little is known about the distribution and status of most Ethiopian carnivores, including some of the most charismatic species, such as the lion (*Panthera leo*), the leopard (*P. pardus*), the cheetah (*Acinonyx jubatus*), and the African wild dog (*Lycaon pictus*) which are the focus of this spatial analysis. The lack of such important baseline knowledge complicates effective planning, execution and monitoring of conservation efforts, as managers and conservationists need reliable estimates of distribution and population size of target species in order to make the right decisions. The Ethiopian Large Carnivores Survey project was designed to help provide baseline information to set up long-term monitoring plans for the remaining large carnivore populations in Ethiopia.

Surveying large carnivores at the landscape scale is challenging because they are rare and elusive, but more importantly because they range widely. In addition, no prior nationwide carnivore surveys were conducted for Ethiopia. As a result, prioritizing survey areas has been identified as a critical step to guide the carnivore survey process. I prioritized survey areas after conducting spatial modelling to identify suitable landscapes for the target species.

Methods

Species' occurrence points and environmental variables

I compiled occurrence records from various sources, including my own and colleagues' sightings, published literature, and online databases such as GBIF, VertNet, and iNaturalist. for south of the Sahara and ran the analysis at that level and clipped Ethiopia for calculating area proportions and mapping. The total number of presence records used were 1128 African wild dogs,1519 cheetahs, 2766 lions, and 1169 leopards for south of the Sahara, and 145 African wild dogs, 119 cheetahs, 361 lions, and 139 leopards for within Ethiopia. For the environmental variables I used the 19 global bioclim layers from WorldClim 1.4 (Hijmans et al. 2005), representing mean annual, seasonal, and extreme temperature and precipitation for 1950 to 2000, at a resolution of 2.5 arc minutes (~ 4.5 km). I removed highly correlated variables (≥ 0.7) from the full dataset of 19 bioclim variables using Pearson correlation, following Dormann et al. (2013). This reduced the environmental dataset to seven bioclim variables: annual mean temperature, mean diurnal range, isothermality, annual precipitation, precipitation of driest month, precipitation seasonality (coefficient of variation), and precipitation of coldest three months.

Ecological niche modeling of carnivore species

I used Maxent (v. 3.4.1), a maximum entropy algorithm in which environmental conditions associated with species' presences are contrasted with environmental conditions from background (pseudoabsences) locations across the training region to estimate the environmental suitability for the species (Phillips et al. 2004). For all four species, I trained the models at the extent of the study area around known presences and used the cross-validation approach, with five model replicates and 10% training presence threshold. Maxent produced models with relative probabilities of the carnivores' distribution, after evaluating the association between the carnivores and the environmental variables, by using known occurrences and pseudo-absences (location data extracted from the background pixel, in which the carnivore is known not to occur) (Elith et al. 2006, Phillips et al. 2006). To evaluate the models, I used the test occurrence data to calculate the area under the curve (AUC) of the receiver operating characteristic (ROC) plot. Its value ranges from 0.5 (random model) to 1 (perfect presence-absence discrimination) (Fielding and Bell 1997), and models with AUC >0.7 are considered reliable (Swets 1988). After checking the model AUC and test emission errors, I summed the five replicates in ArcMap to create a single model prediction for each species. Then I classified the resulting layer as a binary presence/absence map; pixels predicted as presence by three or more replicates were considered suitable for the species studied, and vice versa.

I further refined the binary suitability maps using the gridded human population of the world v. 4 (CIESIN 2016) for the year 2015 at a resolution of 1 km, and a global land cover layer for 2015 (ESA 2017) at a resolution of 300 meters. To this end, I created binary maps of human population density and land cover using common thresholds from the literature to separate suitable and unsuitable conditions (population density; land cover) for the species. Specifically, Woodroffe (2000) and Riggio et al. (2013) were used for deciding the human population density thresholds: 6.3 people/km^2 for African wild dogs, 16.5 people/km^2 for cheetahs, 958 people/km^2 for leopards, and 26 people/km^2 for lions. I relied on multiple sources to reclassify the land cover map to suitable and unsuitable categories for each species (Supplementary Material I). I overlapped, sequentially, the binary suitability maps based on climate (4.5 km resolution) for each species with human population density and land cover maps, preserving the finer resolution of the land cover. As a result, the final potential suitability maps for the four carnivore species studied has a spatial resolution of 300 m.

Results

The climate based Maxent ecological niche model replicates had high accuracy and good predictive capability, as measured with AUC (> 0.8) and testing omission error (<0.20) metrics. The potential distributions based on Maxent climate models were reduced in extent by as much as 34 % (for African wild dog) and as little as 17% (for leopard) when refined with human population density and land cover layers (Table 1).

Table 1: Proportion of areas in Ethiopia with carnivores predicted present by the climatic model (Maxent) and when refined by human population density and suitable land cover

Species	% Predicted present by climate models (Maxent)	% Refined (Maxent output refined by human population density and land cover)	% Refined overlapping with Pas
African wild dog	35.93	2.18	0.34
Cheetah	53.44	10.27	1.23
Leopard	66.41	49.35	3.90
Lion	66.08	20.37	2.87

Most of the present predicted area by the Maxent climate models for African wild dog and cheetah was in the central and eastern parts of the country, while for leopards and lions the western part of the country was also climatically suitable. For all four carnivores, the southeastern tip of the country, which borders with Somalia, is predicted to be climatically unsuitable (Fig. 1)

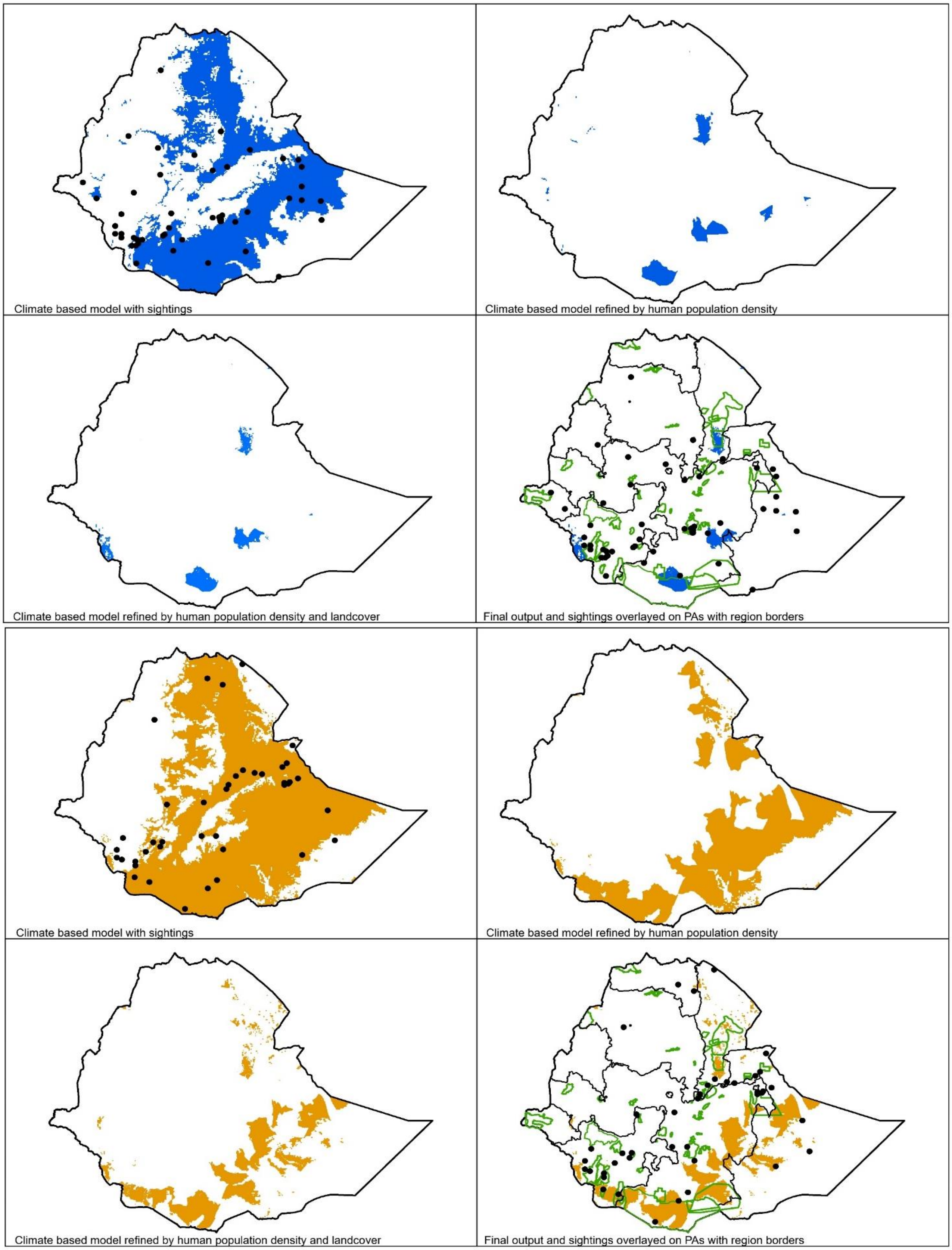

Fig. 1. Maps showing the climate based Maxent prediction (top left corner), refined areas by human population density (top right), refined by human density and land cover (lower left), and the overlap with protected areas per region (bottom right) by species (African wild dog in blue and cheetah in yellow, respectively)

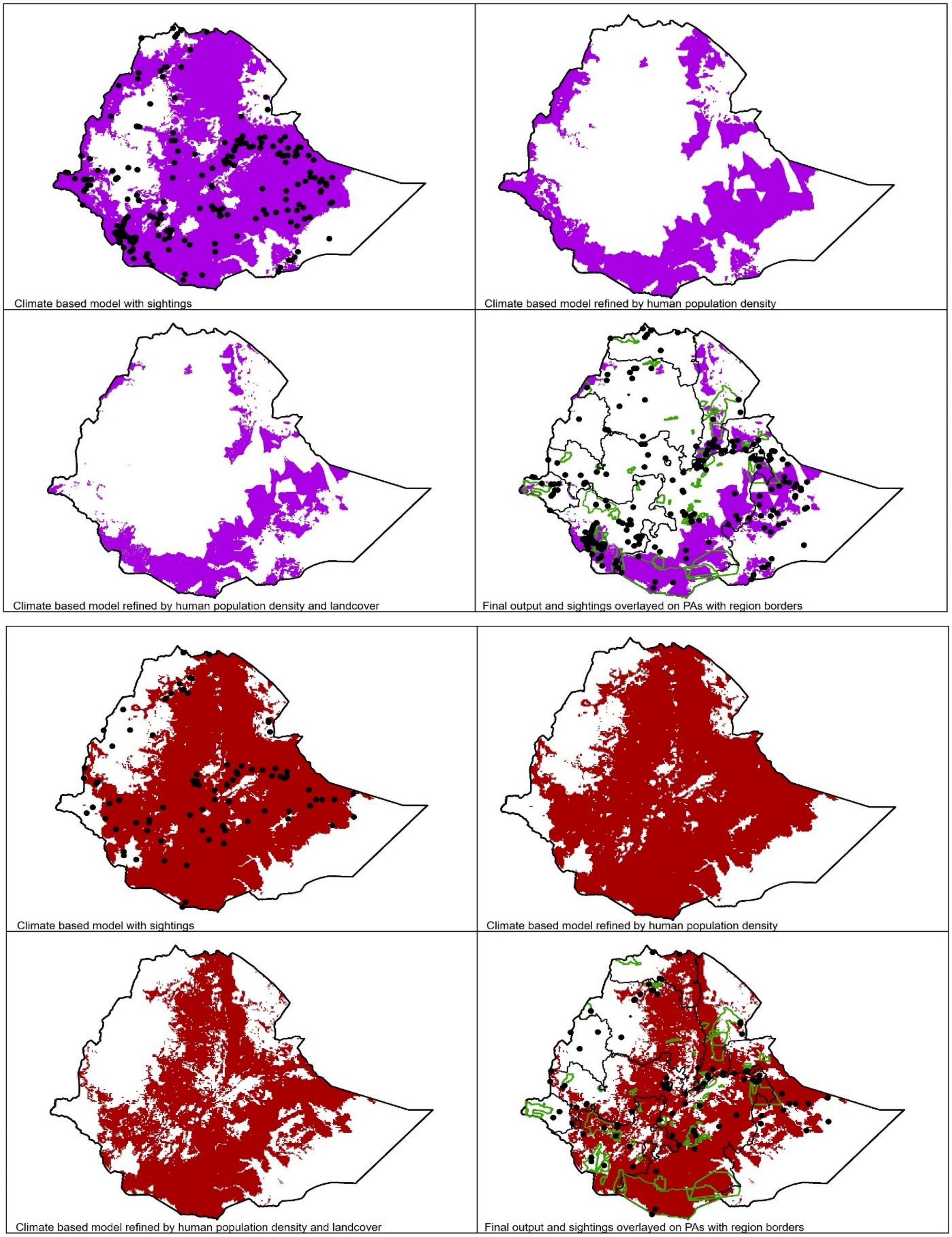

Fig. 2. Maps showing the climate based Maxent prediction (top left corner), refined areas by human population density (top right), refined by human density and land cover (lower left), and the overlap with protected areas per region (bottom right) by species (Lion (purple), and leopard (red) respectively).

Since climate, human population density, and land cover predicted that only 2.18% of the country is suitable for African wild dogs, the overlapping area between all four species is also a very small proportion of the country (Fig 3). Some of the areas that were predicted as suitable in the refined models, did not have known records (sightings) for the specific carnivores (Fig 4).

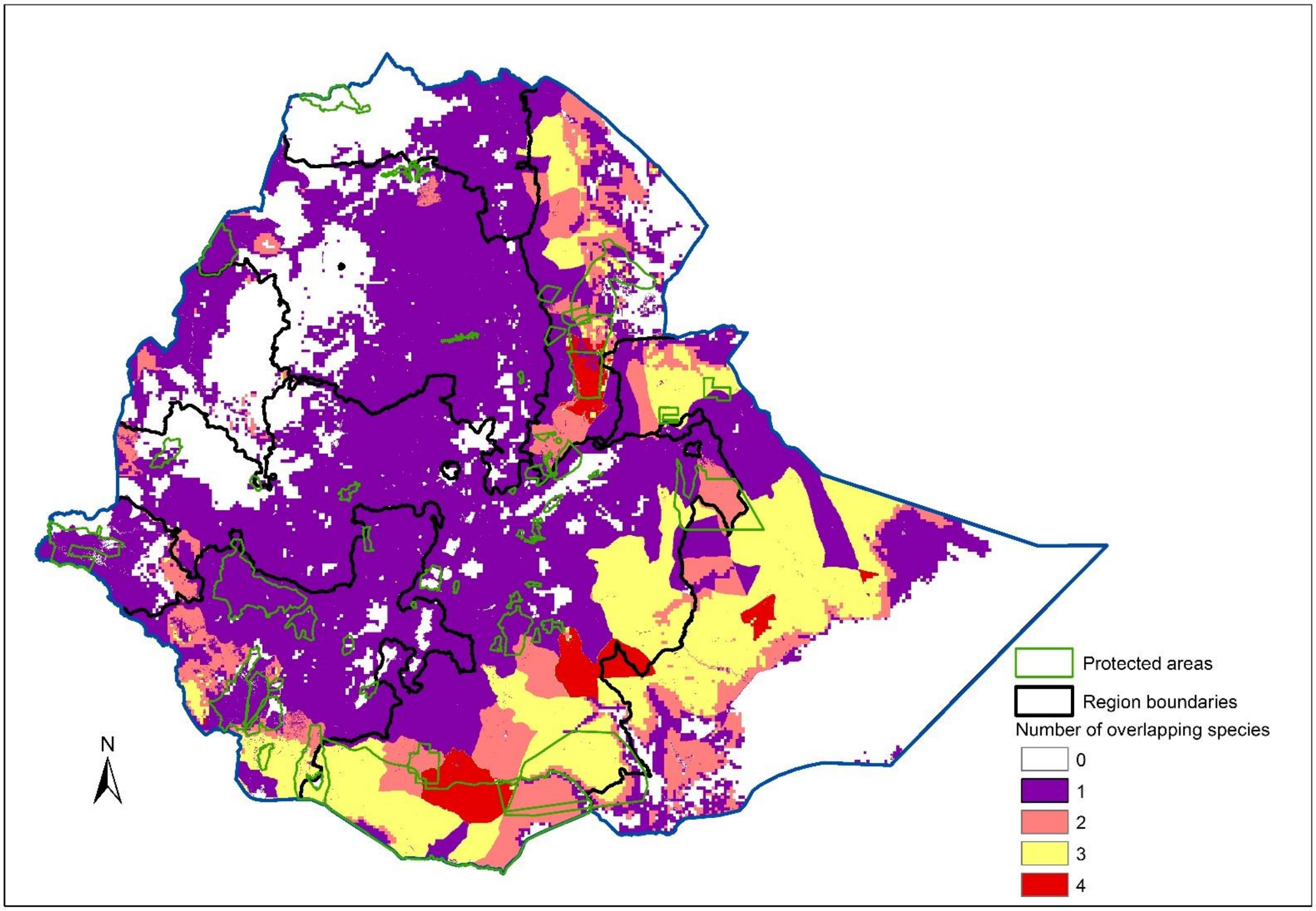

Fig 3. A map showing the number of species predicted to find a specific area suitable or unsuitable

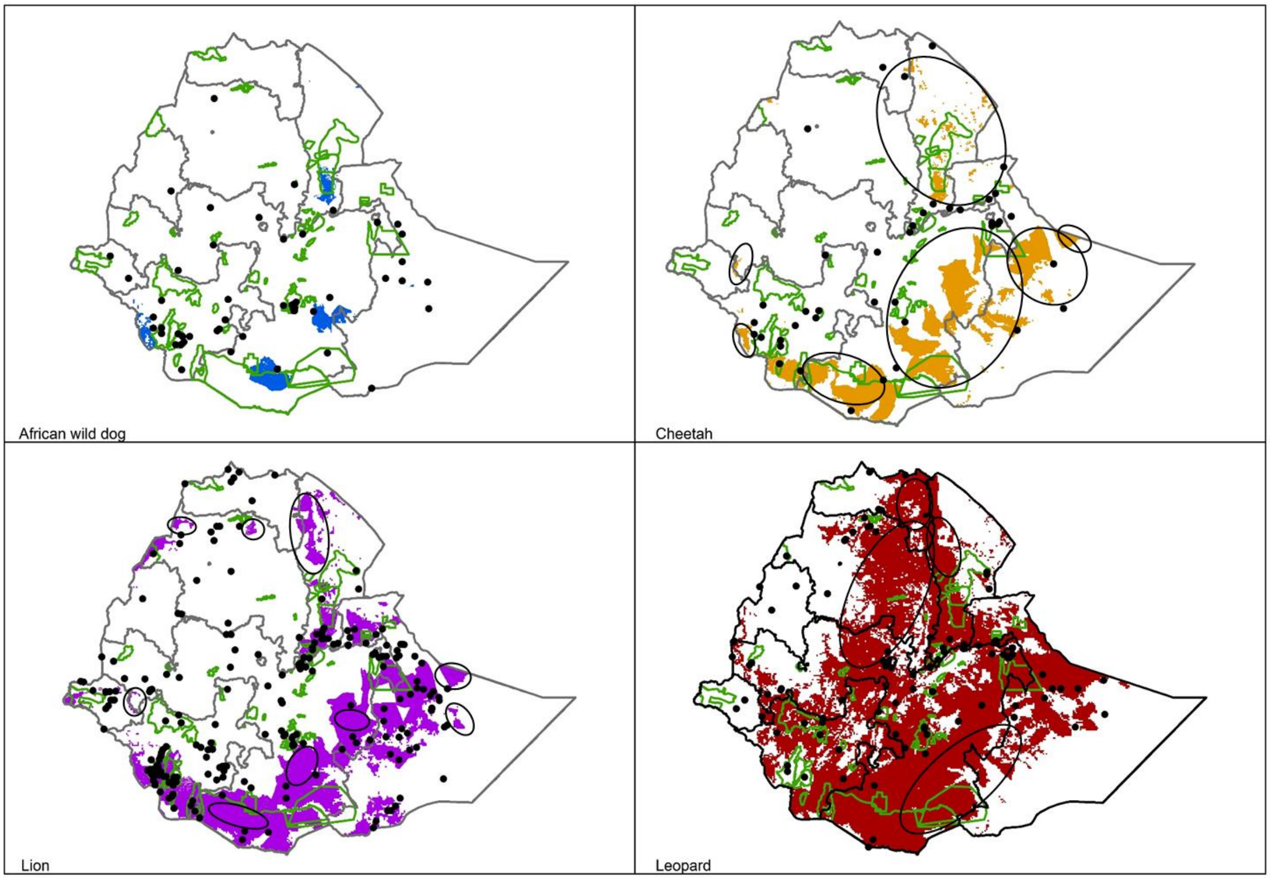

Fig 4. Areas predicted suitable but not associated with known records of the carnivores are highlighted by the black circles/oval shapes.

Limitations

1. Inherent limitations are common when using modelling approaches, and there could be potential errors too (Segurado and Araujo 2004, Marmion et al. 2009, Sequeira et al. 2018). Having different resolutions of input layers forced me to keep analyses to the smallest resolution. Approximations that are involved with different products (for example: land cover from European Space Agency (ESA) and human population density from Food and Agriculture Organization of the United Nations (FAO)) might also reduce the accuracy of the models. Classifications used at different stages of my analyses (for example: suitability classifications of land cover and human population density layers for refining ecological niche models) could also have introduced some bias, while maintaining simplicity of the outputs.

2. Majority of the sightings collated from Ethiopia are pre 2000. In the absence of a national database, collating sightings from individual researchers was challenging. As a result, due to lack of sightings, hyenas could not be included in the analysis despite the original plan to incorporate them.
3. Recent layers of human population density and land cover change do not exist for Africa, hence the use of slightly old data.

Despite the limitations, identifying potential suitable distributions via ecological niche modeling and further filtering the distributions using important factors is a cost-effective and reliable technique that can provide much-needed information to assist the management and conservation of Ethiopian large carnivores.

Recommendations

I. I suggest combining the results of this analysis with expert and local knowledge from protected areas' staff and local people in potential survey areas.

II. I recommend the following areas be prioritized for surveying large carnivores in Ethiopia:

1. All refined areas for African wild dogs
2. Areas that are predicted suitable for more than one species (yellow and brown in Fig. 3)
3. Protected areas that are predicted suitable but with no prior known records. The following could be given priorities (Map of Ethiopia's Protected Areas is provided as Supplementary material II):

   3.1. Lion: Geralle National Park (NP), Borana NP, Chelbi Wildlife Reserve (WR), Shinile Meto Controlled Hunting Area (CHA), Gewane WR, Yangudi Rassa NP, Yabello Sanctuary, and Dembel Ayisha Adigala CHA

   3.2. Leopard: Gewane WR, Yangudi Rassa NP, Chifra CHA, Chelbi WR, Yabello Sanctuary, Jibat CHA, Murulle CHA, Babile Sanctuary, and Denkoro Chaka NP.

   3.3. Cheetah: Geralle NP, Yabello Sanctuary, Babile Sanctuary, Gewane WR, Yangudi Rassa NP, and Mille-Sardo WR

4. Unprotected areas predicted suitable but with no prior records (circled in Fig. 4).
5. Protected areas with known records and were predicted climatically suitable by Maxent (top left corners in Figs 1 & 2), but discarded during refinement by population density and land cover layers).

    5.1.African wild dog: Geralle NP

    5.2.Lion: Bale Mountains NP and Kafa Biosphere Reserve (BR)

    5.3.Cheetah: Awash NP, Belin CHA, and Mago NP.

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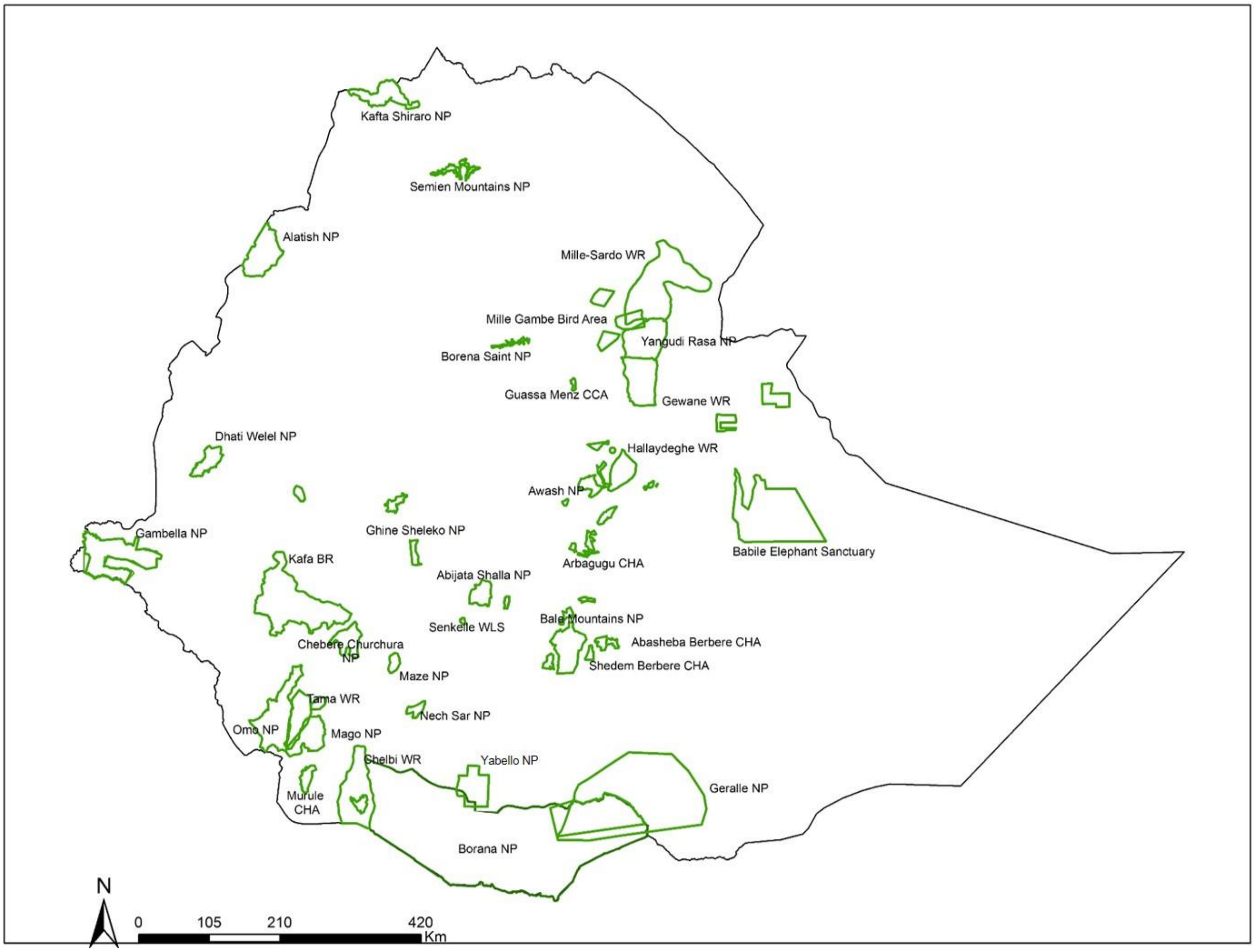
Supplementary Material I: Land cover/habitat suitability per large carnivore (Classes from ESA (2017)).

Agriculture	Forest	Grassland	Wetland	Shrubland	Sparse vegetation	Others

ID	Class	AWD	Cheetah	Lion	Leopard
10	Rainfed crops	NO	NO	NO	LOW
11	Herbaceous cover	LOW	LOW	LOW	MEDIUM
12	Tree or shrub cover	YES	MEDIUM	YES	YES
20	Irrigated or post-flooding cropland	NO	NO	LOW	LOW
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	NO	LOW	LOW	YES
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	LOW	LOW	MEDIUM	YES
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	YES	LOW	YES	YES
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	YES	LOW	YES	YES
61	Tree cover, broadleaved, deciduous, closed (>40%)	YES	LOW	YES	YES
62	Tree cover, broadleaved, deciduous, open (15-40%)	YES	LOW	YES	YES
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	YES	LOW	YES	YES
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	YES	LOW	YES	YES
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	YES	LOW	YES	YES
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	YES	LOW	YES	YES
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	YES	MEDIUM	YES	YES
120	Shrubland	YES	YES	YES	YES
122	Deciduous shrubland	YES	YES	YES	YES
130	Grassland	YES	YES	YES	YES
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	YES	YES	YES	YES
151	Sparse tree (<15%)	YES	YES	YES	YES
152	Sparse shrub (<15%)	YES	YES	YES	YES
153	Sparse herbaceous cover (<15%)	YES	YES	YES	YES
160	Tree cover, flooded, fresh or brackish water	LOW	LOW	MEDIUM	MEDIUM
170	Tree cover, flooded, saline water	LOW	LOW	MEDIUM	MEDIUM
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water	NO	NO	YES	YES
190	Urban areas	NO	NO	NO	NO
200	Bare areas	LOW	LOW	LOW	YES
201	Consolidated bare areas	LOW	LOW	LOW	MEDIUM
202	Unconsolidated bare areas	LOW	LOW	YES	YES
210	Water bodies	NO	NO	NO	NO

Supplementary Material II: Map of Ethiopia's Protected Areas.



Supplementary Material III: Geographical boundaries and names of Ethiopia’s regions