AN ALTERNATIVE SIMPLIFIED VERSION OF THE VECEA POTENTIAL NATURAL VEGETATION MAP FOR EASTERN AFRICA

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SUMMARY

This document provides a short description of the methodology used to create a harmonized natural vegetation map for eastern Africa. The map was derived from the potential natural vegetation map for eastern Africa developed by the VECEA (Vegetation and Climate change in East Africa) project. This map offers the hitherto most detailed description of the potential natural vegetation of this region, but it suffers from some inconsistencies in how vegetation types are classified across the different countries. The version presented in this manuscript provides a more harmonized classification of vegetation types across the region. The objective was to facilitate the modelling of vegetation types, e.g., for use in assessments of effects of climate change on future vegetation distribution patterns, and to provide a better base for analyses that require the classification of unique types, e.g., in conservation gap analysis.

INTRODUCTION

This short document presents an adapted version of the potential natural vegetation map [1] for eastern Africa developed by the VECEA (Vegetation and Climate change in East Africa) project. The original potential natural vegetation map for eastern Africa is based on historical vegetation maps, developed during the 50s to 70s of the twenties' century, during the so-called "golden age of reconnaissance surveys" [2] and complemented by land use and soil maps. The map, available on http://www.vegetationmap4africa.org, offers a unique source of information collected at a time that land use changes and fragmentation of natural vegetation was much less advanced. Information which was used to estimate the distribution of the potential natural vegetation (PNV), which is defined here as the vegetation that would persist under the current environmental conditions, including those created by man, if it was already there [3].The map is described in Lillesø et al. [4] and includes information about the main associate woody species for each vegetation type, including all known useful tree species (Kindt et al. [5–9]). As data on individual species or biodiversity is scarce in this region, information provided by this map on the potential distribution of vegetation types and their species assemblage offers an alternative source of information that can be used to infer the suitability distribution of indigenous plant species at a scale so far not possible [10].

The PNV maps follow a similar classification framework as provided by White [11]. However, it retains more of the details on the original mapping units. The reclassification of the vegetation units of the original maps to the PNVs was based on the documentation of the original maps, literature resources and expert-knowledge of vegetation scientists from each of the six countries. For some limited areas for which no vegetation maps were available, probability distribution models, based on the distribution of the PNVs in the rest of the region, were used to fill in the blank areas. More details are provided in van Breugel et al. [12]. The final map recognizes 79 unique and compound potential natural vegetation types (PNVs), which are listed in Table 1. We will refer to this map as the VECEA PNV map.

One potential problem with the use of this map is that a number of the types are mapped in one country only, while mapped as part of a more aggregated vegetation type in other countries. This was done to maintain the maximum level of information available. However, this may be sub-optimal for regional level assessments. Another disadvantage of the VECEA PNV map is that a number of vegetation types are mapped both individually and as part of compound vegetation types. The latter was done when documentation and other available sources were not conclusive as to the exact nature of the potential vegetation in an area.

For modelling of the vegetation types (e.g., for use in assessments of effects of climate change on future vegetation distribution patterns) and for the use of coverage and representativeness statistics (e.g., in gap analysis), a map is required that has a regionally harmonized classification and in which each raster cell is assigned a unique vegetation type. The objective of the work presented here was to provide such a map, while maintaining as much as possible the information of the original VECEA map.

METHODS

Adaptation for a more consistent regional classification

For the PNVs that were mapped as a unique type in one country (or region), but as part of a more aggregated vegetation unit in other countries or regions, we used the lowest common denominator. I.e., they were aggregated into their more aggregated vegetation types. These changes are indicated in Table 1 in the column 'reclass' with the new PNV code.

PNVs that were only mapped for part of the countries in which it was documented to occur [5–9] and which could not be considered part of a more aggregated vegetation unit, were marked as ‘incomplete’ in Table 1, making it easier for the user to exclude these types in regional analysis or find other solutions.

Splitting based on the modelled PNV distribution

On the VECEA PNV map a number of vegetation types were both mapped individually and as part of compound vegetation types. We define here compound vegetation types as areas where we do not have conclusive evidence for one or another vegetation type to occur. They are assumed to occur in discrete and mutually exclusive areas.

This does not include the transitional zones and ecotones, which we consider important vegetation zones by themselves, such as the PVNs T/g, E/Fc, F/gm (with the F representing Fa, Fb and possibly Fd), Wk/g, Wn/g, Wmd/Bd, and Wmd/Wn (see Table 1 for the corresponding PNV names). We also left the coastal mosaic as separate vegetation zone. On the one hand information on the distribution of the different PNVs within this zone is largely missing. On the other hand, it is characterized by a unique set of environmental conditions. This would render estimations of the distribution of the different PNVs based on extrapolated model results (following the method detailed below) highly uncertain.

The other compound vegetation types were split into their individual PNVs by modelling the probability distribution of these PNVs. These were subsequently used to extrapolate the distribution of the PNV into other areas that are not or non-conclusively classified as a unique PNV, as schematically explained in Figure 1.

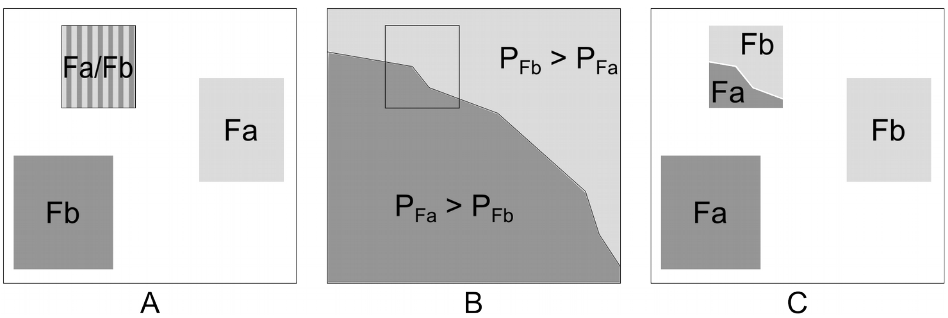

Figure 1: Splitting compound vegetation types based on modelled distribution of the PNVs. A) Mapped distribution of Fa and Fb, including an area where the two are mapped as a compound vegetation type. B) Presence/absence maps based on the probability distribution models of Fa and Fb, whereby each raster cell is classified as the PNV with the highest probability value. C) Results of B are used to classify the areas within the compound vegetation type as Fa or Fb.

We used maximum entropy (Maxent) suitability distribution modelling [13,14], widely used for species distribution modelling, to create probability distribution maps of the individual PNVs. The underlying assumption was that like for species the distribution of each PVN is driven by a specific and unique combination of environmental variables.

As input for the modelling we used the PNVs distribution as mapped on the VECEA PNV map. A training data set was created by randomly sampling 0.2% of the raster cells within the mapped distribution areas of the PNV. As background data we used a random sample of 0.2% of the region. For each point we recorded the values of 24 climatic, edaphic and topographic variables (Table 2). To run the model, we used the default settings of the Maxent program.

For evaluation of the model we used all presence and absence raster cells in the target region and calculated the area under the curve (AUC) of the receiver operator characteristic (ROC). We repeated this but limiting the region from which to sample absence and presence points to a 50 km buffer zone around the boundaries of the mapped distribution of the PNVs (represented by D^1 in Figure 2). We repeated this using a buffer zone of 25 and 10 km. To carry out these evaluations we created the r.edm.eval addon for GRASS GIS, which is available from https://svn.osgeo.org/grass/grass-addons/grass7/raster/r.edm.eval/.

The projected probability distribution layers of the PNVs were used to reclassify the raster cells classified as compound vegetation types on the original VECEA PNV map (marked with double asterisk in Table 1 and marked red in Figure 3). Within each compound vegetation type, we compared the modelled probability values for the PNVs making up that compound and each raster cell was classified as the PNV with the highest probability value.

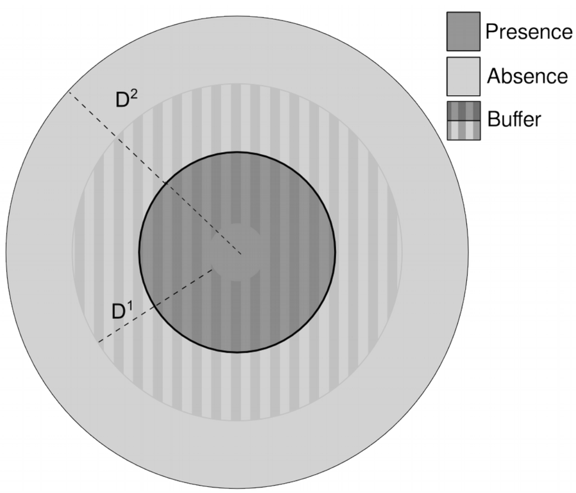

Figure 2. Sampling scheme of evaluation points for the computation of the AUC of Maxent models. The D^2 represents the radius of the whole study area, D^1 the radius of a buffer zone used to restrict the sampling of model evaluation points.

RESULTS & DISCUSSION

Aggregation of PNVs

Figure 3 shows the areas with PNVs that were changed. Most changes concerned the PNVs that were aggregated in more general vegetation types. The majority of these areas (88%) were 'edaphic grasslands and swamps' (g/X). Of these 58% was already classified as such on the original VECEA map, while 31% was classified as 'edaphic grasslands' and 10% as 'swamps'. The implicit assertion that edaphic grassland and swamps are vegetation sub-types of the more general vegetation type g/X is debatable; both have a distinct species ensemble [5]. However, the existing vegetation maps were often inconclusive on their respective distribution. Modeling their distribution was not an option as existing environmental data (including edaphic and hydrological data) is not of sufficient quality and resolution to identify the typical conditions under which the two different types occur.

Some PNVs like the 'Halophytic shoreline vegetation' were mapped in one country only (Tanzania). We could not reclassify these though as they do not form a sub-type of any of the other vegetation types mapped in the region. We therefore only highlighted these vegetation types as being mapped incompletely.

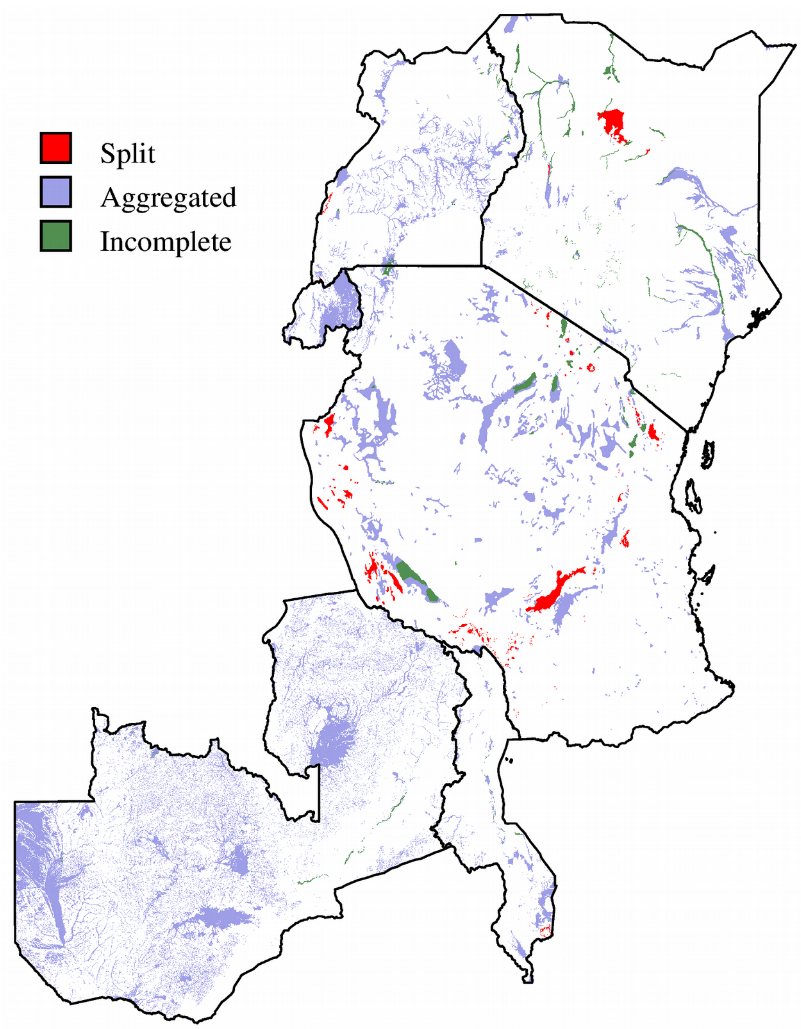

Figure 3. Split: areas that were classified as compound vegetation type on the VECEA PNV map and which were split in their individual PNVs using Maxent probability distribution maps of these PNVs. Aggregated: PNVs that were joined into aggregated PNV classes. Incomplete: PNVs that are known to occur in more areas than mapped.

Model results

The results in Table 3 show high AUC values for the evaluation over the whole study area, providing confidence in the ability of the models to predict the distribution of their respective PNVs well enough to be able to use it for extrapolation.

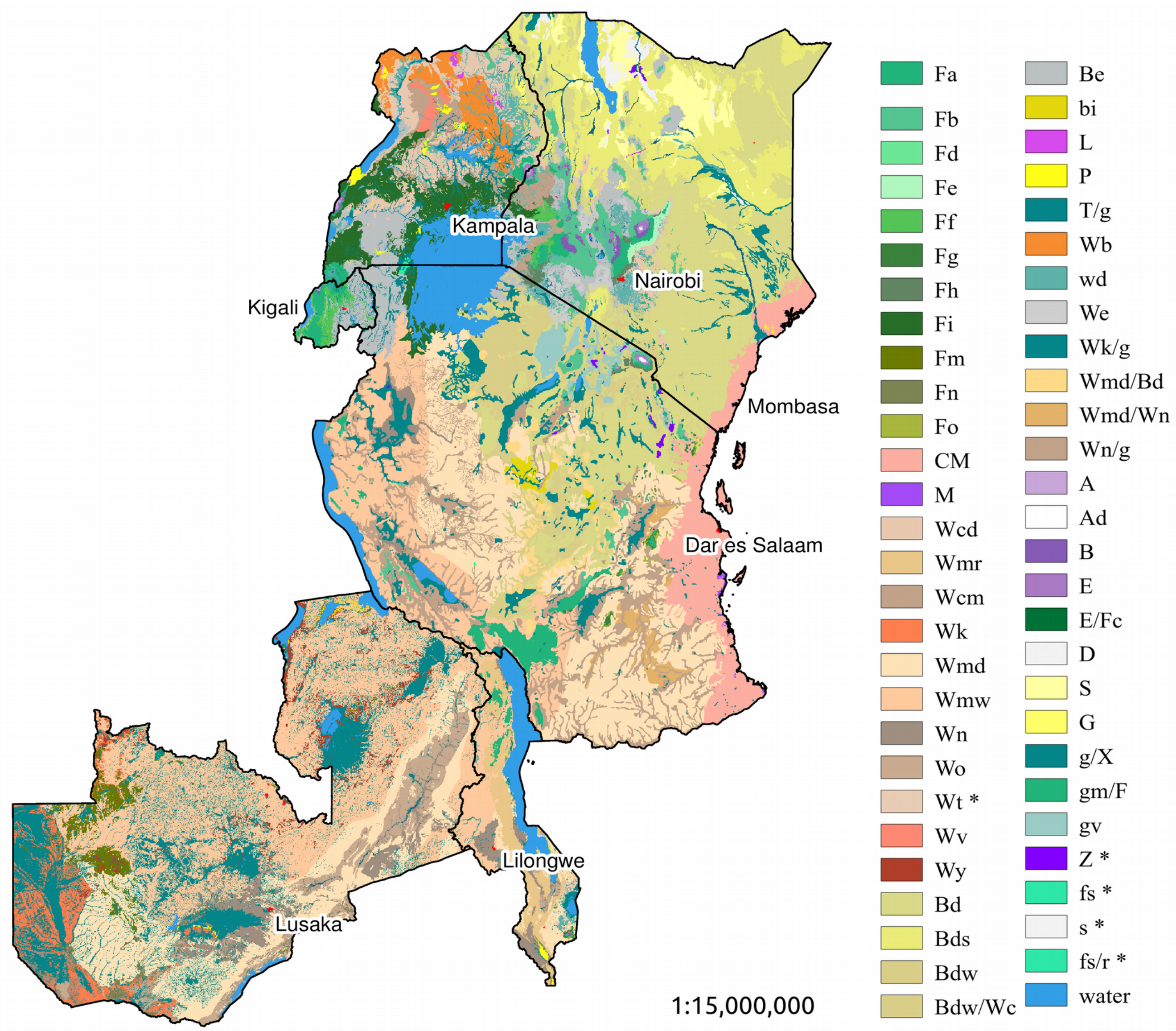

Figure 4. The potential natural vegetation map of eastern Africa (PNV map) based on the VECEA PNV map by van Breugel et al. [1]. The full names of the potential natural vegetation types, corresponding to the codes in the legend, are provided in Table 1. The codes marked with an asterisk are vegetation types that were not used in our analysis.

However, results also show that model performances decrease when only considering predictions within a buffer zone around the vegetation boundaries. This suggest that even though the PNV models capture the general distribution patterns of this vegetation types well, one should be more careful when interpreting the modelled distribution in more detail, especially when considering model predictions at distances of much less than 25 km from the vegetation boundaries.

The final map is shown in Figure 4. It consists of the 50 PNVs including 11 types of forest, 13 types of open forest and woodland, 15 types of bushlands, thickets and wooded grasslands, 5 types of highland vegetation, 2 types of arid zones and 4 types of grassland and herbaceous vegetation, as listed in Table 1.

TABLES

Table 1. List with the potential natural vegetation types mapped by the VECEA potential natural vegetation map. The column 'reclass' marks the PNVs which distribution is incompletely mapped (*), the compound PNVs split using modeling (**), and PNVs aggregated into larger mapping units (PNV code).

Code	Name	Reclass
A	Afroalpine vegetation	
Ad	Afromontane desert	
B	Afromontane bamboo	
E	Montane Ericaceous belt	
E/Fc	Montane Ericaceous belt + Single-dominant *Widdringtonia whytei* forest	
Fa	Afromontane rain forest	
Fa/Fb	Afromontane rain forest + Afromontane undifferentiated forest	**
Fb	Afromontane undifferentiated forest	
Fd	Single-dominant *Hagenia abyssinica* forest	
Fd/B	Single-dominant *Hagenia abyssinica* forest and afromontane bamboo	**
Fe	Afromontane moist transitional forest	
Ff	Lake Victoria transitional rain forest	
Fg	Zanzibar-Inhambane transitional rain forest	
Fh	Afromontane dry transitional forest	
Fi	Lake Victoria drier peripheral semi-evergreen Guineo-Congolian rain forest	
Fm	Zambezian dry evergreen forest	
Fn	Zambezian dry deciduous forest and scrub forest	
Fo	Zanzibar-Inhambane lowland rain forest	
Fo/fs	Zanzibar-Inhambane lowland rainforest with swamp forest	Fo
fs	Swamp forest	*
fs/r	Swamp forest or riverine wooded vegetation	*
M	Mangrove	
CM	Coastal mosaic	
Wmr/Fg	Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane transitional rain forest	**
Wmr/Fo	Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane lowland rain forest	**
Wb	*Vitellaria* (synonym: *Butyrospermum* wooded grassland	
Wcd	Dry *Combretum* wooded grassland	
Wcm	Moist *Combretum* wooded grassland	
wd	Edaphic wooded grassland on drainage-impeded or seasonally flooded soils	
WdK	*Acacia tortilis* wooded grassland and woodland	Bd

Code	Name	Reclass
Wk	Zambezian Kalahari woodland	
Wmd	Drier miombo woodland	
Wmr	Miombo woodland on hills and rocky outcrops	
Wmw	Wetter miombo woodland	
Wn	North Zambezian undifferentiated woodland	
Wn/g	Catena of North Zambezian Undifferentiated woodland + edaphic grassland on drainage-impeded or seasonally flooded soils	
Wn/P	North Zambezian undifferentiated woodland + palm wooded grassland	P
Wo	Mopane woodland and scrub woodland	
Wt	*Terminalia sericea* woodland	*
Wv	*Vitex-Phyllanthus-Sapium-Terminalia* and *Terminalia glaucescens* woodland	
Wy	Zambezian chipya woodland	
Wcd/P	Dry Combretum wooded grassland + palm wooded grassland	P
Wmd/Bd	Transitional zone of drier miombo woodland/Somalia-Masai *Acacia*-Commiphora deciduous bushland and thicket	
Wmd/Wn	Transitional zone of drier miombo woodland + North Zambezian Undifferentiated woodland	
wd/P	Edaphic wooded grassland on drainage-impeded or seasonally flooded soils + palm wooded grassland	P
wd/r	Edaphic wooded grassland on drainage-impeded or seasonally flooded soils or riverine wooded vegetation	wd
We	Upland *Acacia* wooded grassland	
Bd	Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket	
Bds	*Acacia-Commiphora* stunted bushland	
Bdw	*Acacia-Commiphora* deciduous wooded grassland	
Be	Evergreen and semi-evergreen bushland and thicket	
bi	Itigi thicket	
Bd/g	Catena of Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket + edaphic grassland on drainage-impeded or seasonally flooded soils	Bd
Bd/Wcd	Transitional zone Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket and Dry *Combretum* wooded grassland	Wcd
Bds/S	Somalia-Masai *Acacia-Commiphora* shrubland + Somalia-Masai semi-desert grassland and shrubland	**
Bdw/Wc/g	Catena of *Acacia-Commiphora* deciduous wooded grassland, *Combretum* wooded grassland and edaphic grassland on drainage-impeded or seasonally flooded soils	
Be/fe/r	Evergreen and semi-evergreen bushland and thicket + Lake Victoria *Euphorbia dawei* scrub + riverine wooded vegetation	Be
Be/P	Evergreen and semi-evergreen bushland + thicket and palm wooded grassland	P
Be/r	Evergreen and semi-evergreen bushland and thicket + riverine wooded vegetation	Be
P	Palm wooded grassland	

Code	Name	Reclass
r	Riverine wooded vegetation	*
L	Lowland bamboo	
G	Climatic grasslands	
g	Edaphic grassland on drainage-impeded or seasonally flooded soils	g/X
g/P	Edaphic grassland on drainage-impeded or seasonally flooded soils and palm wooded grassland	P
g/T	Bush groups, typically around termitaria, within grassy drainage zones	
g/wd	Edaphic grassland on drainage-impeded + seasonally flooded soils and edaphic wooded grassland on drainage-impeded or seasonally flooded soils	wd
g/Wk	Edaphic grassland on drainage-impeded or seasonally flooded soils with groups of Zambezian Kalahari woodland	
g/X	Edaphic grassland on drainage-impeded or seasonally flooded soils + freshwater swamp	g
gv	Edaphic grassland on volcanic soils	
F/gm	Mosaic of montane grassland and afromontane forest	
X	Freshwater swamp	g/X
X/P	Freshwater swamp + palm wooded grassland	P
Z	Halophytic vegetation	*
Z/w	lakes with Halophytic shoreline vegetation	*
S	Somalia-Masai semi-desert grassland and shrubland	
s	Sand	*
D	Desert	

Table 2. *Environmental variables used to model potential natural vegetation types (PVNs). The bioclimatic variables were downloaded from http://www.worldclim.org. The aridity index layer was obtained from http://csi.cgiar.org/aridity/. The texture, lithology and drainage data layers were from the Harmonized World Soil Database (version 1.2) downloaded from http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/. The morphometric features data layer was computed using the r.param.scale module in GRASS GIS (version 7.0). The terrain wetness index was computed using the r.topidx module for GRASS GIS. Both were computed using the DEM (version 4) downloaded from http://srtm.csi.cgiar.org/Index.asp.*

Description
Bioclim 1 - Annual Mean Temperature
Bioclim 2 - Mean Diurnal Range (Mean of monthly (max temp - min temp))
Bioclim 3 - Isothermality (BIO2/BIO7) (* 100)
Bioclim 4 - Temperature Seasonality (standard deviation *100)
Bioclim 5 - Max Temperature of Warmest Month
Bioclim 6 - Min Temperature of Coldest Month
Bioclim 7 - Temperature Annual Range (BIO5-BIO6)
Bioclim 8 - Mean Temperature of Wettest Quarter
Bioclim 9 - Mean Temperature of Driest Quarter
Bioclim 10 - Mean Temperature of Warmest Quarter
Bioclim 11 - Mean Temperature of Coldest Quarter
Bioclim 12 - Annual Precipitation
Bioclim 13 - Precipitation of Wettest Month
Bioclim 14 - Precipitation of Driest Month
Bioclim 15 - Precipitation Seasonality (Coefficient of Variation)
Bioclim 16 - Precipitation of Wettest Quarter
Bioclim 17 - Precipitation of Driest Quarter
Bioclim 18 - Precipitation of Warmest Quarter
Bioclim 19 - Precipitation of Coldest Quarter
Aridity index (mean annual precipitation / mean annual evapotranspiration)
Texture
Lithology
Drainage
Morphometric features (peaks, ridges, passes, channels, pits and planes).
Terrain wetness index
CGIAR-CSI SRTM 90m digital elevation model (DEM)

Table 3. *Model statistics of probability distribution models for PNVs***.** *The area under the curve (AUC) of the Receiver operating characteristic (ROC) of the modeled probability distributions of the listed potential natural vegetation types (PNVs). The AUC was computed using all raster cells in the region except those where the PNV was mapped as part of a compound vegetation type. To avoid extreme low commission errors, and thus overly high AUC values related to very low presence/absence ratios, the AUC was also calculated for areas limited to a 50 km zone around the mapped distribution of the PNVs (AUC_{50km})*

	AUC			
PNV	**All**	**50 km**	**25 km**	**10 km**
Afromontane bamboo (B)	0.999	0.970	0.940	0.852
Acacia-Commiphora stunted bushland (Bds)	0.981	0.834	0.784	0.712
Afromontane rain forest (Fa)	0.978	0.953	0.935	0.897
Afromontane undifferentiated forest (Fb)	0.984	0.932	0.902	0.840
Single-dominant Hagenia abyssinica forest (Fd)	0.999	0.967	0.918	0.780
Zanzibar-Inhambane transitional rain forest (Fg)	0.993	0.924	0.890	0.820
Zanzibar-Inhambane lowland rain forest (Fo)	0.990	0.845	0.770	0.660
Somalia-Masai semi-desert grassland and shrub land (S)	0.988	0.854	0.800	0.694
Miombo woodland on hills and rocky outcrops (Wmr)	0.984	0.960	0.944	0.895

DATA

File name	Description
pnv_ea.tif	The map is available as a geotif raster layer (data type: CELL, Projections: Albers Equal Area, resolution: 900m)
pnv_ea.xls	The attribute table with the columns: RASTERID: category values to link the table to the raster PNVCODE: Codes of the potential natural vegetation types as used in Table 1. PNVNAME: Names of the potential natural vegetation types as used in Table 1 Category: Vegetation types grouped in main ‘physiognomic’ groups Excluded: The potential natural vegetation types with an incomplete mapped distribution. COLOR: RGB color codes

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