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Source: Candollea, 71(2) : 265-274

Published By: The Conservatory and Botanical Garden of the City of Geneva (CJBG)

URL: https://doi.org/10.15553/c2016v712a11

The impact of land use on species composition and habitat structure in Sudanian savannas – A modelling study in protected areas and agricultural lands of southeastern Burkina Faso

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Abstract

SCHMIDT, M., E. MBAYNGONE, Y. BACHMANN, K. HAHN, G. ZIZKA & A. THIOMBIANO (2016). The impact of land use on species composition and habitat structure in Sudanian savannas – A modelling study in protected areas and agricultural lands of southeastern Burkina Faso. *Candollea* 71: 265-274. In English, English abstract. DOI: http://dx.doi.org/10.15553/c2016v712a11

Sudanian Savannas are under high agricultural pressure and are therefore changing rapidly. Due to high population densities and an increasing need for food and cash crops, the mosaic of traditional agroforestry systems, fallows and savanna is being transformed into intensively used croplands and savannas only remain in protected areas. The focus of this study is to characterize the differences in plant diversity and composition between protected areas and surrounding agricultural lands and to identify areas most important for plant conservation. Building on observation and collection records, we modelled distributions of individual plant species and summarized these. We mapped the species richness of vascular plants in general, of woody plants, graminoids and forbs, the share of weeds and the average size of grasses and trees and calculated means for the reserves and outside areas. Distinct differences between protected areas and agricultural lands have been found in the richness of herbs (both forbs and graminoids) and weeds as well as in the size of grasses: Woody species seem to be less affected by human impact in the agricultural lands concerning both species richness and plant size. Weeds are playing an important role in the higher species richness of the agricultural lands.

Keywords

Growth form composition – Plant size – Protected areas – Sudanian savannas – Species richness – West Africa

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Submitted on May 24, 2016. Accepted on July 20, 2016. First published online on August 2, 2016.

ISSN: 0373-2967 – Online ISSN: 2235-3658 – *Candollea* 71(2): 265-274 (2016)

Introduction

Tropical grassy biomes, long neglected, are increasingly moving into the focus of research and conservation, especially in Africa, where they cover a third of the continental land surface (Parr et al., 2014). Sudanian savannas, located in West Africa between the Sahelian drylands and the Guinean rainforests, are a biome characterized by high grasses of the Andropogoneae (Bocksberger et al., 2016). They are particularly under threat by expanding agriculture with one of the highest human population densities on the continent. Due to the increasing need for food and cash crops, vast areas have been transformed into croplands and only few larger patches of close-to-natural savanna remain in protected areas (PAs). On the other hand the economic importance of wild plant products for the population is high, as many species are regularly used for food, medicine and crafts (Mbayngone & Thiombiano, 2011; Zizka et al., 2015).

The partial faunal reserve of Pama is the westernmost part of the so-called WAPO (W-Arly-Pendjari-Oti) complex of PAs in the border region of Burkina Faso, Niger, Benin and Togo. With an area of 223,500 ha it is one of the largest PAs in Burkina Faso and belongs to the category IV of the IUCN. Different Sudanian savannas and woodlands (Hahn, 1996), gallery forests along the Singou and Pendjari rivers and rocky habitats of the Gobnangou hills (Ouédraogo & Schmidt, 2010) are included in the reserve. The local population mainly consists of Gourmantché, followed by Mossi and Peulh, the largest town in the study area is Pama, but the closeby regional capital Fada N'Gourma (c. 45 km to the north of the reserve) certainly also has an influence. During the last decades, areas outside the reserves experienced large scale conversions of savannas and woodlands to mosaics of fields and fallows and even larger areas of bare soil (Soulama et al., 2015).

Although the large reserves of the area have mainly been installed for the protection of fauna and particularly large mammals (see, e.g., Henschel et al., 2014), they contribute also to the protection of Burkina Faso's flora, even more so with expanding and intensified land use, pushing the agricultural frontier to the very borders of the PAs (UNEP, 2008; Gnoumou, 2013) and in some cases even beyond. With the growing importance of PAs for plant conservation, it becomes important to identify the key areas for the conservation of plant diversity. Pama reserve is home to 450 species of vascular plants (Mbayngone et al., 2008), for Arly National Park 490 species have been documented (Ouédraogo et al., 2011), a large proportion of the 2067 species documented for Burkina Faso (Thiombiano et al., 2012). The purpose of this study is to identify areas of high diversity and areas important for the conservation of rare species.

Methods

We are building on extensive vegetation surveys in the area of the Pama reserve (Schmidt, 2006; Mbayngone, 2008), inventories of the BIOTA biodiversity observatories (Jürgens et al., 2012), records from georeferenced photo records (Dressler et al., 2014) and collection data from the herbaria of Senckenberg (FR) and the University of Ouagadougou (OUA), combining these data types in order to account for their specific strengths and weaknesses (Schmidt et al., 2010). The vast majority of coordinates was recorded using a GPS with a spatial accuracy of c. 10 m, in the case of vegetation plot data, the center point location has been assigned to all species occurring within the plot, thereby additionally reducing the accuracy by a few meters (herb layer relévés usually on 10 m × 10 m, woody layer relevés on 30 m × 30 m). In order to avoid the influence of the roads on species composition and the satellite signals corresponding to their localities, records were usually taken > 500 m from the road. After data cleaning, removing doubles, resolving synonymies and assigning infraspecific taxa to the respective species rank using the Vascular Plant Catalogue of Burkina Faso (Thiombiano et al., 2012) as a nomenclatural reference, we had an occurrence dataset of 10878 records for 648 species of vascular plants, more species than known from the two checklists of Pama and Arly (see above). Measures of plant size for grasses and trees have been taken from Poilecot (1995, 1999), Schmidt et al. (2011) and Schmidt et al. (2013), classification as weeds is based on Le Bourgeois & Merlier (1995) and Ataholo (2001).

Due to limited accessibility within the reserve, especially towards the end of the rainy season, when the majority of plant species can be identified, most data have been taken close to roads and close to the enclaves around villages. To close the resulting gaps in species occurrence data we modelled species distributions using Maxent v. 3.3.3 and environmental predictors consisting of a set of topographic and remote sensing (RS) variables closely linked to environmental factors and with sufficient spatial resolution for the task.

For an optimal choice of environmental data and botanical occurrence data as well as full coverage of the Pama reserve we restricted our study to the area between 0.5°E-1.5°E and 11°N-12°N (Fig. 1). The area is covered by a single Landsat 8 scene. Therefore no edge effects occur within the RS data. The Landsat 8 scene from the 13th of October 2013, WRS path 193/row 52, was downloaded from the US Geological Survey website [http://earthexplorer. usgs.gov]. After rescaling the values of the Top of the Atmosphere (TOA) spectral radiance and the Thermal Infrared Sensor data to at-satellite brightness temperature [http://landsat.usgs.gov/Landsat8_Using_Product.php], the following ecologically important predictor variables were calculated from the RS data: NDVI, MSI, SAVI, ferrous minerals, iron oxide, clay minerals and at-satellite brightness temperature (Kriegler et al., 1969;

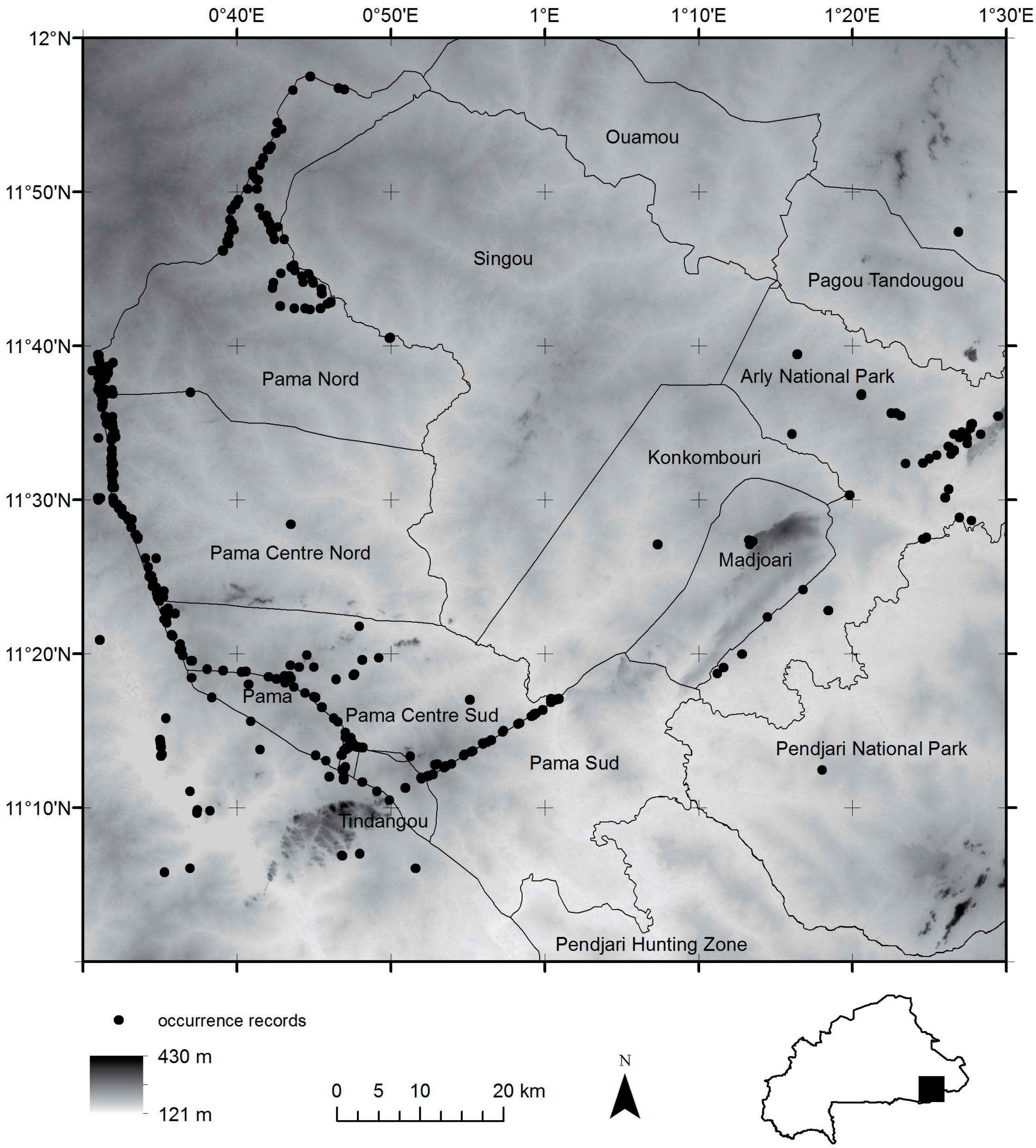

Fig. 1. – Study area including the Pama reserve and neighbouring PAs of the western WAPO complex. The Pama, Tindangou and Madjoari areas are enclaves where agriculture is allowed. The small country map in the lower right shows the position of the study area within Burkina Faso.

Huete, 1988). Furthermore slope and the Topographic Wetness Index (TWI, Beven & Kirkby, 1979) were calculated from the ASTER GDEM V2. To avoid problems with multicollinearity we excluded the RS layers highly correlated with the NDVI (SAVI, MSI, ferrous minerals, iron oxide), resulting in five final predictor variables: NDVI, at-satellite brightness temperature, clay minerals, slope and TWI. All datasets were clipped to the extent of the study area. Analysis was conducted at the spatial resolution of 30 m. Processing was done with ERDAS Imagine 13 (Intergraph Corporation), SAGA-GIS 2.0 (SAGA Development Team) and ArcGIS 10 (ESRI Inc.).

Only the 209 species with 10 or more spatially unique occurrence points have been considered for the modelling approach. SDMs of 21 species with an AUC < 0.7 have also been excluded from the further analysis. Probabilities of occurrence have been transformed into presence/absence using the Equal sensitivity and sensibility threshold (Liu et al., 2005) and stacked to produce maps of species richness for all species and specific groups. The calculation of average values for the different areas concerned has been done in R (v. 3.2.2), using the 'raster' library. The southernmost areas (Pama-Sud, Pendjari Hunting zone and Pendjari National Park) have been excluded from this analysis, because of their low sampling density.

Results

We modelled distributions of 188 species of vascular plants. The average AUC was 0.78, the predictor variable with the largest contribution to the models was at-satellite brightness temperature (with an average contribution of 44%), followed by NDVI (19%), clay minerals (17%), slope (12%) and TWI (8%).

The stacked SDM maps of species richness (Fig. 2) and plant size (Fig. 3) show clear differences between the PAs and the agricultural areas (see also Table 1 for average values). Although the species richness map of all vascular plants (Fig. 2A) doesn't show clear-cut differences between reserve and surroundings, the averaged values are distinctly higher for outside areas. Within the reserve larger differences between high and low diversity areas exist. Especially Pama Centre Nord and the northern parts of Pama Nord seem to be more diverse. Growth forms react differently (Fig. 2): while the diversity patterns of grass-like species (Fig. 2B) are very similar to the general patterns of species richness, forbs are comparatively more diverse in the agricultural land (Fig. 2C) and woody species are rather evenly distributed among land use types but with highest values in Pama centre Nord and Pama Nord (Fig. 2D). Distinctly higher diversities in the agricultural land are shown for weedy species (Fig. 2E) and only slightly higher values for non-weedy species (Fig. 2F).

The maps of maximum plant size (Fig. 3) and average values in Table 1) show very clear patterns of higher grasses (Fig. 3A) within the reserve, while size patterns of woody plants are quite indifferent to protection status (Fig. 3B).

Discussion

Our approach clearly showed differences in species diversity patterns and structural parameters between the reserve and the agricultural areas. These are in line with the findings of Hahn-Hadjali et al. (2006) from the BIOTA observatories of the same area: The higher species richness found there in Kikidéni (communal lands/cattle grazing) as compared to Natiabouani (Pama Nord) is mainly attributed to lower size annual species, a group largely overlapping with the weedy species set of the present study. Devineau et al. (2009) also found higher numbers of weeds and annuals outside and more perennial herbs inside the reserves in western central Burkina Faso. The effective protection of tall grass species within the reserve (Fig. 3a) is contributing to wildlife conservation in the PAs concerning both food and habitat requirements.

Woody species in our study area seem to be generally less affected by human impact in the agricultural lands, concerning both species richness and plant size, a result also found in Sissili (South Central Burkina Faso) by Paré et al. (2009) and in the closeby W-National Park by Nacoulma et al. (2011), but contrary to the findings of Traoré et al. (2012) from SW Burkina Faso. With the growing intensification of agriculture linked to cotton cultivation, replacing the traditional agroforestry systems with their mosaics of fields and fallows, the woody species are expected to be more heavily impacted in the future.

The use of high resolution remote sensing and topographic variables representing factors known to have a direct impact on the organisms (temperature, soil, water availability) made it possible to reach a high spatial resolution and a good distinction between protected area and agricultural lands. The results show clearly the importance of these variables for small-scale distribution studies, where the interpolated climate grids often used on larger scales reach the limits of their predictive power.

Recent works on grass traits (Pasturel et al., 2016) in African savanna biomes stressed the importance of plant size in defining functional types of grasses especially in their response to climate. Our results show that such types would also be useful for the study of different land use systems.

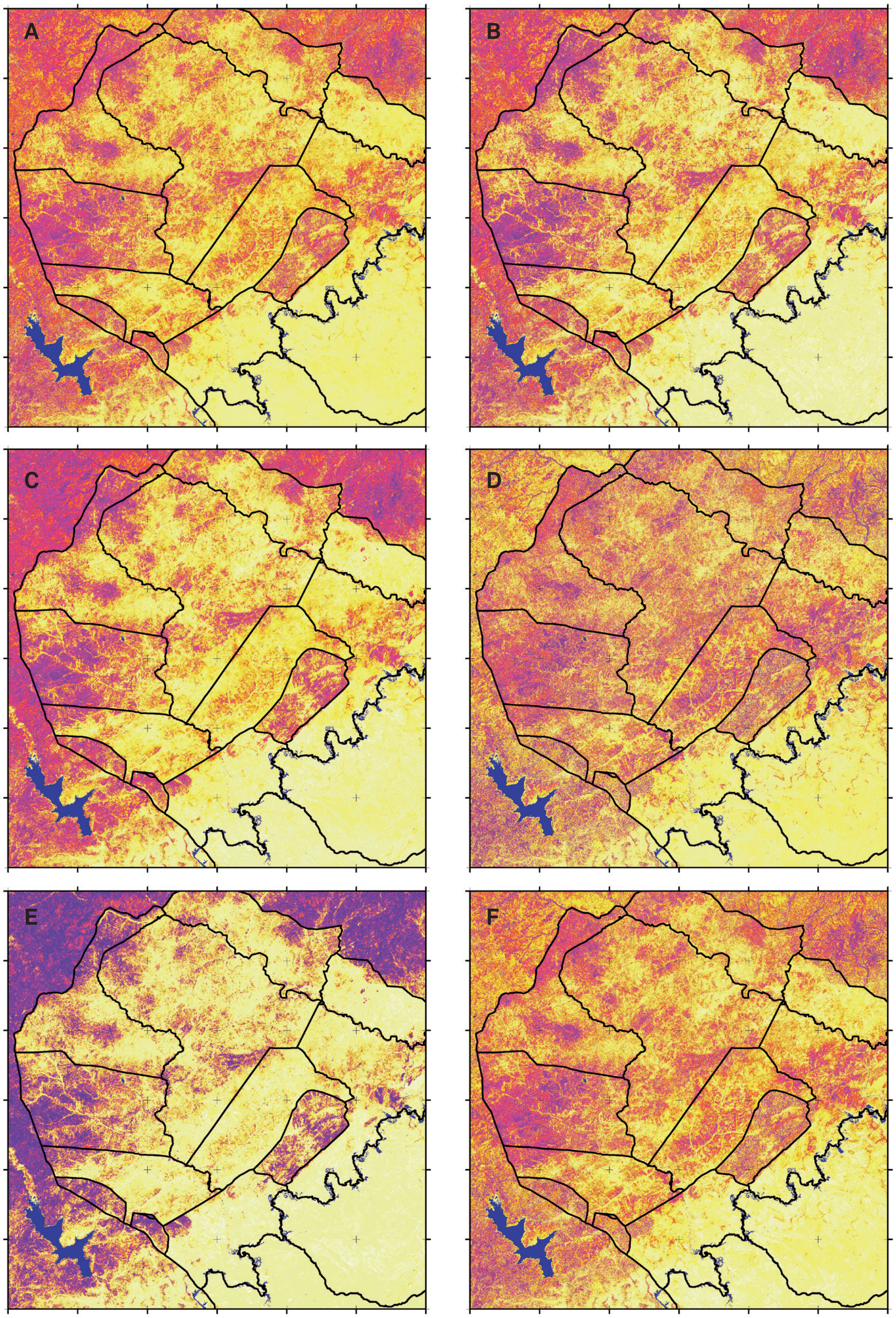

Fig. 2. – Maps of species richness. **A.** All plant species (2-211 spp.); **B.** Graminoids (0-50 spp.); **C.** Forbs (0-86 spp.); **D.** Woody species (0-52 spp.); **E.** Weedy species (0-48 spp.); **F.** Non-weedy species (0-140 spp.). The color coding stretches from light yellow for the lowest values via orange and red to violet for the highest values.

Table 1. – Average values of species richness of plants in general, groups of growth form and weeds/non-weeds summarized from the stacked SDM models for the different PAs in the western WAP complex and cultivated lands in the enclaves and outside the PAs. The last two columns give average values of plant height for grasses and trees.

	All species	Forbs	Graminoid	Woody	Non weeds	Weeds	Grass height [cm]	Tree height [cm]
Enclaves/outside								
Madjoari	78.11	31.80	17.57	19.12	51.40	18.08	157.22	9.43
Tindangou	84.16	37.29	19.59	17.69	51.18	24.13	140.54	9.75
Pama	90.36	39.98	21.43	19.52	56.56	24.71	139.85	9.75
outside PAs	94.13	42.69	22.59	19.18	56.83	28.47	135.68	9.10
Protected Areas								
Konkombouri	59.50	18.89	11.54	18.86	44.19	5.95	186.29	9.09
Pama Centre Nord	91.33	36.50	22.18	23.21	62.67	20.16	166.98	8.83
Pama Centre Sud	60.16	20.67	13.17	17.09	42.76	9.42	177.37	9.22
Pama Nord	75.56	28.81	18.05	19.92	52.10	15.79	173.01	8.96
Singou	60.24	21.10	13.72	16.99	42.50	10.48	178.59	9.08
Pagou Tandougou	39.90	12.00	7.23	12.43	27.83	5.05	172.92	9.06
Arly	55.37	18.43	11.06	16.47	39.64	8.11	172.24	9.00
Ouamou	61.83	22.40	14.72	16.73	43.45	11.51	177.14	9.22
meanOut	**92.42**	**41.54**	**22.06**	**19.16**	**56.24**	**27.36**	**137.81**	**9.15**
meanPA	**64.51**	**23.16**	**14.54**	**17.94**	**45.33**	**11.51**	**175.30**	**9.04**

Acknowledgements

We acknowledge financial support by the UNDESERT project (EU FP7 grant 243906) and the University of N'Djaména for funding a research stay of E. Mbayngone at Senckenberg. M. Schmidt finished this manuscript while being funded by the GFBio project (DFG grant HI 1538/2-2). We would like to thank the two reviewers Cyrille Chatelain and Jean César for their valuable feedback during the review process.

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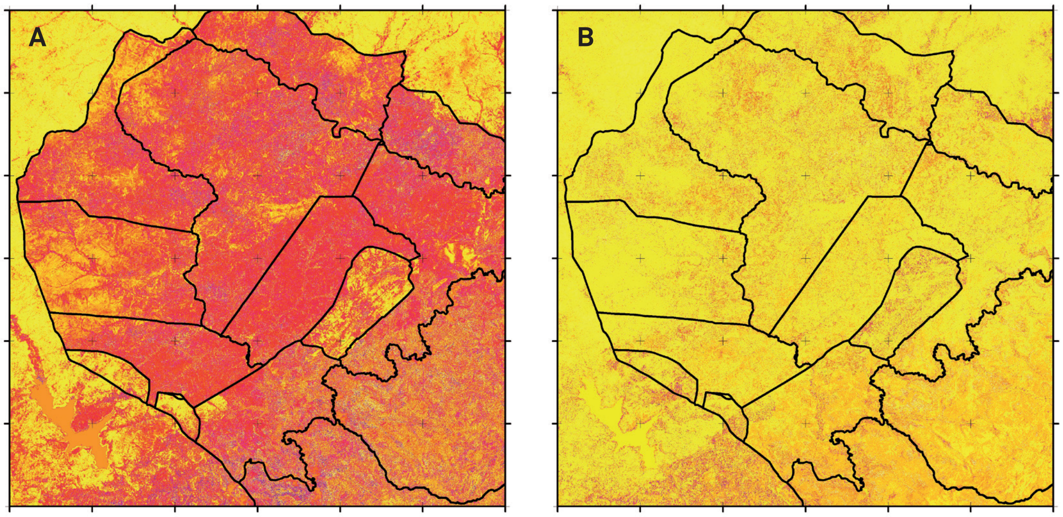

Fig. 3. – Maps of mean maximum plant size (calculated as average of maximum plant size of all species predicted as present within a grid cell). **A.** Grasses (Poaceae) (30-360 cm); **B.** Woody species (3-25 m). The color coding stretches from light yellow for the lowest values via orange and red to violet for the highest values.

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Appendix 1. – List of species with 10 or more spatially unique occurrences in the study area. For each species the number of samples, the AUC of the species distribution models (mean value out of 100 runs), the growth form and the assignment to the weed categories are provided.

Species	#samples	AUC	Growth Form	Weed
Abildgaardia abortiva	35	0.74	graminoid	N
Abildgaardia coleotricha	26	0.78	graminoid	N
Abildgaardia filamentosa	38	0.74	graminoid	N
Abildgaardia hispidula	61	0.75	graminoid	Y
Acacia dudgeonii	126	0.77	woody	N
Acacia gourmaensis	127	0.78	woody	N
Acacia hockii	91	0.79	woody	N
Achyranthes aspera	22	0.79	forb	Y
Alysicarpus ovalifolius	60	0.78	forb	Y
Alysicarpus rugosus	18	0.71	forb	Y
Andropogon chinensis	75	0.78	graminoid	N
Andropogon fastigiatus	72	0.75	graminoid	Y
Andropogon gayanus	175	0.72	graminoid	N
Andropogon pseudapricus	161	0.74	graminoid	N
Aneilema lanceolatum	63	0.76	forb	N
Annona senegalensis	118	0.75	woody	N
Anogeissus leiocarpa	72	0.73	woody	N
Aristida adscensionis	15	0.88	graminoid	Y
Aristida kerstingii	110	0.75	graminoid	Y
Aspilia bussei	106	0.77	forb	N
Aspilia helianthoides	26	0.75	forb	N
Balanites aegyptiaca	52	0.76	woody	N
Blepharis linariifolia	26	0.81	forb	N
Bombax costatum	22	0.72	woody	N
Brachiaria jubata	44	0.80	graminoid	N
Brachiaria lata	37	0.85	graminoid	Y
Brachiaria serrata	25	0.75	graminoid	N
Brachiaria villosa	75	0.81	graminoid	N
Brachystelma bingeri	30	0.80	forb	N
Bridelia scleroneura	49	0.74	woody	N
Buchnera hispida	11	0.77	forb	N
Burkea africana	11	0.72	woody	N
Cassia mimosoides	181	0.74	forb	Y
Cassia obtusifolia	13	0.85	forb	Y
Chasmopodium caudatum	59	0.78	graminoid	N
Chloris pilosa	27	0.82	graminoid	Y
Chlorophytum limosum	31	0.79	forb	N
Chrysopogon nigritanus	17	0.85	graminoid	N
Cienfuegosia heteroclada	16	0.86	forb	N
Cissus adenocaulis	29	0.79	forb	N
Cissus flavicans	37	0.82	forb	N
Cissus populnea	24	0.71	forb	N
Cleome viscosa	10	0.89	forb	Y
Cochlospermum planchonii	51	0.75	forb	N
Cochlospermum tinctorium	83	0.77	forb	N
Combretum adenogonium	49	0.74	woody	N
Combretum collinum	116	0.75	woody	N
Combretum glutinosum	202	0.73	woody	N
Combretum molle	75	0.74	woody	N
Combretum nigricans	91	0.74	woody	N
Commelina benghalensis	12	0.79	forb	Y
Commelina erecta	15	0.72	forb	N
Commiphora africana	13	0.77	woody	N
Corchorus olitorius	22	0.77	forb	Y
Corchorus tridens	29	0.90	forb	Y
Crossopteryx febrifuga	83	0.80	woody	N
Crotalaria macrocalyx	61	0.71	forb	N
Crotalaria microcarpa	53	0.73	forb	N
Crotalaria naragutensis	10	0.82	forb	N
Ctenium newtonii	31	0.77	graminoid	N
Curculigo pilosa	10	0.84	forb	N
Cyanotis longifolia	19	0.88	forb	N
Cymbopogon caesius	33	0.77	graminoid	N
Dactyloctenium aegyptium	17	0.96	graminoid	Y
Desmodium gangeticum	21	0.73	forb	N
Desmodium velutinum	22	0.76	forb	N
Detarium microcarpum	19	0.73	woody	N
Dichrostachys cinerea	40	0.73	woody	N
Digitaria argillacea	95	0.75	graminoid	Y
Diheteropogon amplectens	59	0.76	graminoid	N
Diospyros mespiliformis	34	0.75	woody	N
Entada africana	17	0.75	woody	N
Eragrostis turgida	13	0.90	graminoid	Y
Euclasta condylotricha	21	0.80	graminoid	N
Euphorbia convolvuloides	100	0.78	forb	Y
Feretia apodanthera	88	0.75	woody	N
Flueggea virosa	45	0.74	woody	N
Gardenia erubescens	24	0.77	woody	N
Gardenia ternifolia	90	0.76	woody	N
Grewia bicolor	16	0.82	woody	N
Grewia cissoides	68	0.76	forb	N
Grewia lasiodiscus	45	0.76	woody	N
Grewia mollis	44	0.74	woody	N
Gymnosporia senegalensis	146	0.73	woody	N
Hackelochloa granularis	81	0.79	graminoid	Y
Heliotropium strigosum	12	0.76	forb	N
Heteropogon contortus	22	0.72	graminoid	N
Hexalobus monopetalus	16	0.78	woody	N
Hibiscus cannabinus	106	0.72	forb	N
Hyparrhenia glabriuscula	15	0.74	graminoid	N
Hyparrhenia involucrata	96	0.75	graminoid	N
Hyparrhenia smithiana	25	0.80	graminoid	N
Hyparrhenia subplumosa	28	0.76	graminoid	N
Hyperthelia dissoluta	20	0.78	graminoid	N
Hyptis spicigera	43	0.74	forb	Y
Hyptis suaveolens	10	0.80	forb	Y

Species	#samples	AUC	Growth Form	Weed
Indigofera aspera	14	0.90	forb	N
Indigofera bracteolata	113	0.76	forb	N
Indigofera colutea	14	0.79	forb	N
Indigofera dendroides	87	0.76	forb	N
Indigofera leprieurii	58	0.73	forb	N
Indigofera leptoclada	22	0.81	forb	N
Indigofera microcarpa	10	0.77	forb	N
Indigofera paniculata	21	0.80	forb	N
Indigofera stenophylla	57	0.72	forb	Y
Ipomoea coscinosperma	61	0.81	forb	N
Ipomoea eriocarpa	45	0.80	forb	Y
Kohautia tenuis	20	0.81	forb	Y
Lannea acida	93	0.77	woody	N
Lantana ukambensis	11	0.73	forb	N
Lepidagathis anobrya	107	0.77	forb	N
Leucas martinicensis	23	0.89	forb	Y
Lippia chevalieri	10	0.73	forb	N
Loudetia togoensis	19	0.81	graminoid	N
Ludwigia hyssopifolia	12	0.71	forb	Y
Mariscus squarrosus	10	0.88	graminoid	Y
Merremia kentrocaulos	14	0.82	forb	N
Microchloa indica	81	0.74	graminoid	Y
Mitracarpus hirtus	11	0.86	forb	Y
Mitragyna inermis	15	0.80	woody	N
Monechma ciliatum	46	0.77	forb	Y
Mukia maderaspatana	46	0.73	forb	N
Pandiaka angustifolia	183	0.73	forb	N
Panicum pansum	53	0.79	graminoid	Y
Paspalum scrobiculatum	15	0.82	graminoid	Y
Pennisetum pedicellatum	116	0.78	graminoid	Y
Pericopsis laxiflora	10	0.84	woody	N
Philenoptera laxiflora	32	0.80	woody	N
Phyllanthus amarus	39	0.74	forb	Y
Piliostigma reticulatum	56	0.78	woody	N
Piliostigma thonningii	126	0.74	woody	N
Polycarpaea eriantha	18	0.75	forb	N
Polycarpaea linearifolia	17	0.76	forb	N
Polygala arenaria	64	0.73	forb	Y
Pseudocedrela kotschyi	35	0.73	woody	N
Pteleopsis suberosa	45	0.80	woody	N
Pterocarpus erinaceus	59	0.77	woody	N
Rhynchosia minima	11	0.79	forb	N
Rottboellia cochinchinensis	38	0.76	graminoid	Y
Schizachyrium exile	44	0.80	graminoid	N
Schizachyrium nodulosum	29	0.81	graminoid	N
Schizachyrium rupestre	63	0.76	graminoid	N
Schizachyrium sanguineum	40	0.77	graminoid	N
Schoenefeldia gracilis	52	0.86	graminoid	N
Scleria pergracilis	16	0.84	graminoid	N
Scleria sphaerocarpa	25	0.72	graminoid	N
Sclerocarya birrea	25	0.78	woody	N
Securidaca longipedunculata	11	0.81	woody	N
Setaria barbata	17	0.78	graminoid	N
Setaria pumila	69	0.86	graminoid	Y
Sida alba	62	0.80	forb	N
Sida rhombifolia	14	0.96	forb	N
Sida urens	15	0.88	forb	N
Siphonochilus aethiopicus	20	0.77	forb	N
Spermacoce chaetocephala	31	0.90	forb	Y
Spermacoce filifolia	60	0.75	forb	N
Spermacoce radiata	156	0.73	forb	Y
Spermacoce stachydea	163	0.73	forb	Y
Sporobolus festivus	99	0.74	graminoid	Y
Sporobolus pyramidalis	22	0.77	graminoid	Y
Sterculia setigera	17	0.82	woody	N
Stereospermum kunthianum	156	0.75	woody	N
Striga asiatica	18	0.77	forb	N
Striga hermonthica	29	0.84	forb	Y
Strychnos spinosa	53	0.78	woody	N
Stylochiton hypogaeus	32	0.81	forb	N
Stylochiton lancifolius	21	0.77	forb	N
Tacca leontopetaloides	33	0.76	forb	N
Tamarindus indica	29	0.72	woody	N
Tephrosia bracteolata	115	0.78	forb	N
Tephrosia linearis	17	0.74	forb	Y
Tephrosia pedicellata	58	0.79	forb	Y
Terminalia avicennioides	144	0.73	woody	N
Tinnea barteri	40	0.84	forb	N
Trichilia emetica	11	0.71	woody	N
Tripogon minimus	28	0.79	graminoid	N
Triumfetta lepidota	43	0.78	forb	N
Triumfetta pentandra	13	0.75	forb	Y
Vigna filicaulis	12	0.76	forb	N
Vigna heterophylla	10	0.78	forb	N
Vigna racemosa	56	0.71	forb	N
Vitellaria paradoxa	119	0.74	woody	N
Wissadula rostrata	18	0.78	forb	N
Ximenia americana	122	0.73	woody	N
Ziziphus abyssinica	38	0.78	woody	N
Ziziphus mauritiana	18	0.87	woody	N
Ziziphus mucronata	31	0.78	woody	N
Zornia glochidiata	11	0.90	forb	Y