

## MODELLING THE DISTRIBUTION OF PHOTOSYNTHETIC TYPES OF GRASSES IN SAHELIAN BURKINA FASO WITH HIGH-RESOLUTION SATELLITE DATA

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**Abstract.** We combined grass (Poaceae) occurrence data from the Sahelian parts of Burkina Faso, West Africa, with data on the photosynthetic type of these species. Occurrence data were compiled from relevés and collections of the Herbarium Senckenbergianum, and the assignment of photosynthetic types was taken from the literature and completed by leaf anatomical observations of our own. We used the occurrence data to model species distributions using GARP (Genetic algorithm of rule-set production) and high-resolution satellite data (Landsat ETM+) as environmental predictors. In a subsequent step we summarized the distributions of single species for each photosynthetic type. The resulting distribution patterns reflect the ecological preferences connected with photosynthetic pathways. The only C3 species is strictly bound to watercourses and temporary lakes, C4 MS species mainly occur on the dunes, C4 PS-PCK species are mainly from dunes and watercourses, C4 PS-NAD type species dominate the drier peneplains. *Accepted 11 January 2011.*

**Keywords:** C3, C4, ecological niche modelling, Poaceae, photosynthesis, Sahel, savanna, satellite data, water stress.

### INTRODUCTION

In tropical and dry climates, C4 photosynthesis is known to be more efficient than C3 photosynthesis in using water, light, and nitrogen (Ehleringer & Monson 1993). C4 plants therefore have advantages compared with C3 plants in habitats with high light intensity and high temperatures. There are three subtypes of C4 photosynthesis with anatomical and physiological differences, usually named NAD-ME, NADP-ME, and PCK after their decarboxylating enzymes (for more details, see Table 1). Studies on grass distributions in Namibia (Schulze *et al.* 1996), Argentina (Cabido *et al.* 2008), the United States (Taub 2000), Australia (Hattersley 1983) and the Middle East (Vogel *et al.* 1986) showed a difference in the ecological preferences of these photosynthetic

subtypes. NAD-ME plants are found more often in the most arid environments, NADP-ME plants in the more humid ones, and grasses with the PCK subtype are in between. Physiological investigations (Ghannoum *et al.* 2002) have confirmed the higher water use efficiency of NAD-ME, as compared to the other subtypes.

Poaceae is the plant family containing the majority (60%) of all known C4 plants. The C4 pathway evolved at least 17 times independently within the family (Christin *et al.* 2008). The success of grasses in tropical savannas is closely linked to the evolution of C4 photosynthesis and the whole diversity of its physiological subtypes is found within this family.

In the semi-arid savannas of the West African Sahel, grasses are the most species-rich and most abundant plant family in the ground layer (e.g. Becker & Müller 2007, Schmidt *et al.* 2008). Investigations have also shown the value of grasses as in-

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TABLE 1. Number of grass species in the study area according to photosynthetic (sub)types. In C4 photosynthesis three different pathways are distinguished and named after their bundle sheath decarboxylation enzymes: NAD malic enzyme (NAD-ME), NADP malic enzyme (NADP-ME), and phosphoenolpyruvate carboxykinase (PCK or PEP-CK). The number in brackets is species with at least 15 occurrences. These species were used in the distribution models.

Bundle sheath anatomy	Physiological type	No. of species
non-“Kranz” anatomy	C3	3 (1)
MS	C4 NADP-ME	32 (14)
PS	C4 PCK or NAD-ME	2 *
PS-PCK	C4 PCK	12 (10)
PS-NAD	C4 NAD-ME	19 (9)

\* For two species, it was not possible to determine the position of chloroplasts within the parenchyma sheath. Both occurred only once in the study area and were not modelled.

dicators of overall plant diversity in savannas (Schmidt *et al.* 2007). The local economy is based on livestock production with extensive grazing systems and grasses as the main fodder.

Average annual precipitation values in the Sahel decrease northwards by 1 mm per kilometer, but the water availability for plants during the growing period also depends on soil properties which are linked to different landscape units (Table 2). The soil water

content is one of the most important habitat factors for plant life in the Sahel (Furley 1994).

Based on known occurrences from herbarium collections and botanical observation data, we modelled species distributions of grasses using high-resolution satellite data and summarized these for the photosynthetic pathways to obtain distribution patterns for the photosynthetic (sub)types. We expect the resulting distribution patterns to be different

TABLE 2. Landscape units in the study area in northern Burkina Faso, with predominant soil types, land-use system, and properties relevant for water availability for plants during the growing period (rainy season).

Landscape units	Predominant soil types (FAO soil classification)	Water availability for plants during growing period	Main land use system
penneplain	very heterogeneous; lithosols, eutric regosols, (eutric, vertic) cambisols, luvic arenosols	low to medium (infiltration reduced by surface crusts. High surface runoff and sheet flow)	no agricultural use, grazing, firewood and timber collection
fixed sand dune	(luvic, chromic or cambic) arenosols, eutric regosols	high (good water retention capacity, high infiltration rate and high ground water level during rainy season)	millet cultivation, grazing, firewood and timber collection
lateritic crusts and inselbergs	lithosols, regosols	very low (higher in crevices and depending on relief)	grazing, firewood and timber collection
seasonal ponds and temporary watercourses	fluvisols, vertisols	very high (continuously or repeatedly flooded during rainy season)	grazing
tiger bush formation	regosols, cambisols	medium (banded vegetation functions as a natural water harvesting system)	grazing, firewood and timber collection

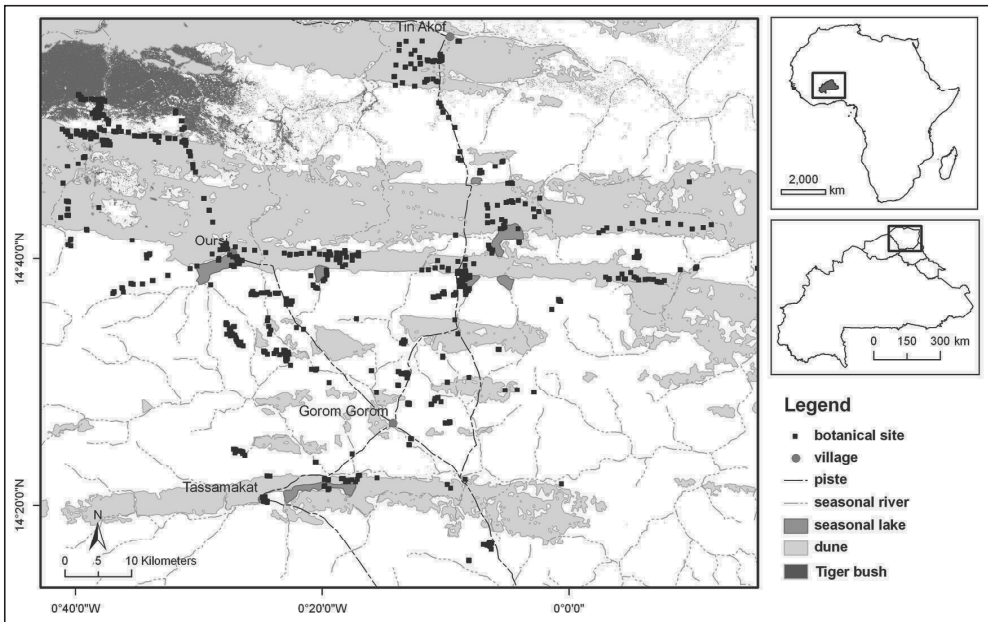


FIG. 1. Study area in the northernmost province of Burkina Faso with important landscape types and distribution of botanical relevé and collection data.

from each other and to depend on local water availability, either directly linked to the precipitation gradient or to soil types in the different landscape elements (Albert 2002).

The connection between water availability and photosynthetic types may well be used to monitor changing water availability in the soils, e.g. as a result of atmospheric and climate change on a local scale. Especially in the Sahel where therophytes prevail, most grass species have a short life cycle, therefore changes in the spectrum of photosynthetic types might occur with comparatively little delay to changes in water availability.

## METHODS

**Study area.** The study was conducted in the Sahel region of Burkina Faso (West Africa) within the largest legally protected area of the country, the “Réserve sylvo-pastorale et partielle de la faune du Sahel” (IUCN category IV). Elevations in this area are between 240 m above sea level in the valleys of the Gorouol and Béli rivers and 498 m on the peak of Tin-Edia. The climate is characterized by a strong seasonality; annual precipitation values range from 280 to 450 mm; rainfall is restricted to one rainy

season from July to September. The mean annual temperature is 30°C, leading to high evapotranspiration rates (2800 mm per year, Claude *et al.* 1991).

The predominant landscape elements are pen- plains and fixed sand dunes, interspersed by lateritic crusts, inselbergs, small seasonal ponds, and depressions with temporary watercourses (Table 2). The prevailing vegetation is open savannas with thorny shrubs and small trees, mainly *Acacia* spp. and *Balanites aegyptiaca*. In remote areas, on certain inselbergs and mountain massifs, and near watercourses, a denser and higher vegetation can be found. The tiger bush, a peculiar banded vegetation formation with a regular pattern of stripes of woody vegetation alternating with bare ground, can be found in remote areas in the northwestern parts of the study area.

**Botanical occurrence data.** Two different types of botanical data were used for our analysis: (1), species distribution data were collected in various vegetation studies (e.g. Müller 2003, Krohmer 2004, Schmidt 2006) and combined in a database, which was complemented by (2), specimen data from the West Africa collection of the Herbarium Senckenbergianum (FR). The joint analysis of observation and specimen data has the advantage of reducing the

inherent biases of the different data sources (Guralnick *et al.* 2005, Schmidt *et al.* 2010). Only those data that were geo-referenced by GPS with a spatial accuracy of less than 10 m were used in the study. Plant species names follow the nomenclature in the African Flowering Plants Database (accessed 2008), which is based on Lebrun & Storck (1991-1997) for our study area.

*Photosynthetic type data.* Information on photosynthetic types was taken from the literature (Downton 1975, Ellis *et al.* 1980) and completed by our own analyses of the bundle sheath anatomy of some species. Leaf parts of herbarium material were stored in a 10% solution of diocetyl-sulfosuccinate-sodium salt (Peterson *et al.* 1978) for 24 h for softening, and afterwards transferred to 70% ethanol. Cross-sections were taken by hand and embedded in glycerine jelly (after Zander 2003).

The C4 photosynthetic pathway was recognized through the occurrence of a chlorenchymatous bundle sheath, the Photosynthetic Carbon Reduction (PCR or "Kranz") tissue around the vascular bundles. Different C4 types were distinguished on the basis of the following characters (according to Ellis *et al.* 1980): presence (PS) or absence (MS) of a mestome sheath between PCR bundle sheath cells and metaxylem vessel elements of primary vascular bundles, and (in the case of presence) the centrifugal (PS-PCK) or centripetal (PS-NAD) position of chloroplasts in PCR bundle sheath cells.

This anatomical approach for discrimination between photosynthetic types worked quite well with the herbarium material. In *Eragrostis tenella* and *Panicum anabaptistum*, however, the position of the chloroplasts could not be reliably discerned. In addition, the results for *Panicum* spp. and *Eragrostis* spp. have to be handled with caution, as they can show structurally a PS-PCK type but are biochemically a NAD-ME type (Hattersley & Watson 1992).

*Remote sensing data.* Environmental data layers for ecological niche modelling were derived from LANDSAT satellite scenes taken in the middle of the rainy season (5./12.08.2000) and at the beginning of the dry season (22./29.10.1999). Based on the raw satellite data, vegetation indices and other measurements relevant for the distinction of habitats have been calculated: The digital signatures of bands 3 to 6 were converted into reflectance values, following Chavez (1996). We calculated three vegetation indices: the normalized vegetation index (Rouse *et al.*

1974), the transformed vegetation index (Deering *et al.* 1975), and the mean soil adjusted vegetation index (Qi *et al.* 1994). Additionally a "tasseled cap" transformation (Kauth & Thomas 1976) was calculated and integrated in the modelling approach. Information on soil was derived from the ratio of band 5/band 7 and band 5/band 4, which reflect properties of clay and Fe-minerals (Madeira *et al.* 1997). The spatial resolution of these data layers was reduced to 60 m to reduce possible mismatching of remote sensing pixels with the botanical occurrence points due to the inaccuracy of GPS readings and the spatial extent of relevé plots.

*Modelling approach.* We developed empirical species distribution models using GARP (Genetic Algorithm for Rule-Set Production; Stockwell & Noble 1992) with the above mentioned presence-only data. GARP divides occurrence points into training data for the development of the model rules, test data for the refinement of these rules within the algorithm, and another set of test data for evaluation. It produces pseudo-absences from pixels where the species has not been detected and uses these also for model refinement and evaluation. In an iterative process of modification and selection of rule sets (we allowed the rules to include bioclimatic rules, logistic regressions and others), the algorithm develops a model either until there is no further improvement or until a pre-defined number of iterations has been run. The random aspect in the rule modifications causes different results in each run. Following Anderson *et al.* (2003), we chose 5 models from 20 runs after their commission and omission values (with an extrinsic omission <20% and commission values closest to average) and coded only those pixels as present where at least 3 of these 5 models predicted presence.

As the quality of GARP models depends on the number of occurrence points used (Stockwell & Peterson 2002), we only modelled species distributions with at least 15 known occurrences.

## RESULTS

*Floristics.* Of a total of 354 documented higher vascular plant species in the study area, 68 (19%) were grasses, belonging to 34 different genera. Thirty-four out of these 68 grasses were documented at 15 or more localities and were therefore used in the distribution models (Table 3). The majority of species (52 = 76%) were annuals, 16 were perennials. The most frequent perennial species were *Andropogon gayanus*,

TABLE 3. Grass species in the study area with number of occurrences, life form, photosynthetic type, and large-scale distribution. Only species with at least 15 occurrences were used in the distribution models. For these species, values for commission (percentage of the prediction area that exceeds the recorded occurrence) and extrinsic omission (percentage of the test points that are omitted from the prediction, mean value 10.96%) are also shown.

Species	Occ.	life form	Photosynth.	Distribution	Com. %	Om. %
<i>Andropogon fastigiatus</i>	15	annual	C4 MS	pantropical	44	11
<i>Andropogon gayanus</i>	60	perennial	C4 MS	African	48	15
<i>Aristida adscensionis</i>	239	annual	C4 MS	pantropical	65	15
<i>Aristida funiculata</i>	140	annual	C4 MS	paleotropic	69	3
<i>Aristida hordeacea</i>	8	annual	C4 MS	African		
<i>Aristida mutabilis</i>	187	annual	C4 MS	paleotropic	66	11
<i>Aristida rhiniochloa</i>	1	annual	C4 MS	African		
<i>Aristida sieberana</i>	51	perennial	C4 MS	paleotropic	49	9
<i>Aristida stipoides</i>	9	annual	C4 MS	African		
<i>Brachiaria lata</i>	121	annual	C4 PS-PCK	African	70	4
<i>Brachiaria orthostachys</i>	99	annual	C4 PS-PCK	African	47	13
<i>Brachiaria ramosa</i>	21	annual	C4 PS-PCK	paleotropic	41	12
<i>Brachiaria villosa</i>	13	annual	C4 PS-PCK	paleotropic		
<i>Brachiaria xantholeuca</i>	60	annual	C4 PS-PCK	African	65	15
<i>Cenchrus biflorus</i>	471	annual	C4 MS	paleotropic	53	12
<i>Cenchrus ciliaris</i>	96	annual	C4 MS	paleotropic	56	9
<i>Cenchrus setigerus</i>	1	perennial	C4 MS	paleotropic		
<i>Chasmodonium caudatum</i>	1	annual	C4 MS	African		
<i>Chloris barbata</i>	1	annual	C4 PS-PCK	pantropical		
<i>Chloris pilosa</i>	94	annual	C4 PS-PCK	African	72	10
<i>Chrysopogon nigritanus</i>	1	perennial	C4 MS	African		
<i>Cymbopogon schoenanthus</i>	14	perennial	C4 MS	African		
<i>Cynodon dactylon</i>	13	perennial	C4 PS-NAD	cosmopolitan		
<i>Dactyloctenium aegyptium</i>	532	annual	C4 PS-PCK	paleotropic	73	10
<i>Digitaria ciliaris</i>	446	annual	C4 MS	pantropical	59	12
<i>Digitaria gayana</i>	7	annual	C4 MS	African		
<i>Digitaria horizontalis</i>	2	annual	C4 MS	Afro-Neotropical		
<i>Diheteropogon hagerupii</i>	8	annual	C4 MS	African		
<i>Echinochloa colona</i>	115	annual	C4 MS	pantropical	54	15
<i>Echinochloa pyramidalis</i>	11	perennial	C4 MS	African		
<i>Echinochloa stagnina</i>	29	perennial	C4 MS	paleotropic	21	14
<i>Elionurus elegans</i>	1	annual	C4 MS	African		
<i>Elytrophorus spicatus</i>	7	annual	C3	paleotropic		
<i>Enteropogon prieurii</i>	245	annual	C4 PS-PCK	paleotropic	69	15
<i>Eragrostis aegyptiaca</i>	1	annual	C4 PS-NAD	African		
<i>Eragrostis atrovirens</i>	13	perennial	C4 PS-PCK	paleotropic		
<i>Eragrostis cilianensis</i>	21	annual	C4 PS-NAD	cosmopolitan	24	16
<i>Eragrostis ciliaris</i>	1	annual	C4 PS-PCK	pantropical		
<i>Eragrostis japonica</i>	4	annual	C4 PS-PCK	paleotropic		
<i>Eragrostis pilosa</i>	178	annual	C4 PS-NAD	cosmopolitan	68	17
<i>Eragrostis tenella</i>	1	annual	C4 PS	pantropical		

Species	Occ.	life form	Photosynth.	Distribution	Com. %	Om. %
<i>Eragrostis tremula</i>	210	annual	C4 PS-PCK	paleotropical	53	10
<i>Eriochloa fatmensis</i>	6	annual	C4 PS-PCK	paleotropical		
<i>Hackelochloa granularis</i>	3	annual	C4 MS	pantropical		
<i>Leptothrium senegalense</i>	2	annual	C4 PS-PCK	paleotropical		
<i>Microchloa indica</i>	14	annual	C4 PS-PCK	pantropical		
<i>Oryza barthii</i>	11	annual	C3	African		
<i>Oryza longistaminata</i>	18	perennial	C3	Afro-Malagasy	19	7
<i>Panicum anabaptistum</i>	1	perennial	C4 PS	African		
<i>Panicum laetum</i>	328	annual	C4 PS-NAD	African	66	14
<i>Panicum subalbidum</i>	38	annual	C4 PS-NAD	African	55	8
<i>Paspalum scrobiculatum</i>	7	perennial	C4 MS	paleotropical		
<i>Pennisetum americanum</i>	6	annual	C4 MS	pantropical		
<i>Pennisetum pedicellatum</i>	157	annual	C4 MS	paleotropical	64	9
<i>Pennisetum violaceum</i>	2	annual	C4 MS	African		
<i>Rottboellia cochinchinensis</i>	2	annual	C4 MS	paleotropical		
<i>Schizachyrium exile</i>	17	annual	C4 MS	paleotropical	31	10
<i>Schoenefeldia gracilis</i>	377	annual	C4 PS-NAD	paleotropical	74	11
<i>Setaria pallide-fusca</i>	28	annual	C4 MS	paleotropical	58	10
<i>Sporobolus festivus</i>	8	perennial	C4 PS-PCK	Afro-Malagasy		
<i>Sporobolus helvolus</i>	1	perennial	C4 PS-NAD	paleotropical		
<i>Sporobolus microprotus</i>	25	annual	C4 PS-NAD	African	28	12
<i>Tetrapogon cenchroides</i>	77	annual	C4 PS-NAD	paleotropical	64	11
<i>Tragus berteronianus</i>	143	annual	C4 PS-NAD	cosmopolitan	70	11
<i>Tragus racemosus</i>	83	annual	C4 PS-NAD	Afro-Mediterranean	67	9
<i>Urochloa mutica</i>	19	perennial	C4 PS-PCK	pantropical	13	2
<i>Urochloa trichopus</i>	19	annual	C4 PS-PCK	Afro-Malagasy	39	9
<i>Vossia cuspidata</i>	2	perennial	C4 MS	paleotropical		

*Aristida sieberiana*, and *Echinochloa stagnina*. Many species have a wide distribution range throughout the African savannas and often into the Middle East and southern Asia; quite a number are even pantropical or cosmopolitan species (Table 3).

**Spectrum of photosynthetic types.** The majority of the grasses use the C4 photosynthetic pathway, only the water-bound species *Elytrophorus spicatus*, *Oryza barthii*, and *O. longistaminata* having C3 photosynthesis (Table 1). Within the C4 species, most species belong to the NADP-ME subtype, including the genera *Andropogon*, *Aristida*, *Digitaria*, and *Pennisetum*. The most frequent species of this type are *Cenchrus biflorus* and *Digitaria ciliaris*. NAD-ME species are found in the genera *Eragrostis*, *Panicum*, and *Tragus* among others, with *Schoenefeldia gracilis* and *Panicum laetum* as the most frequent species. PCK species occur in genera such as *Brachiaria*, *Chloris*, and *Eragrostis*; *Dactyloctenium aegyptiacum* and *Chloris*

*prieurii* are their commonest representatives. While the relative share of C3 and PCK species hardly changes between (a) the group of all grasses in the study area and (b) the subset of species with at least 15 occurrence points, there are less NADP-ME and more NAD-ME species in the subset (Table 1).

**Modelled distributions.** Of all C3 species, only *Oryza longistaminata* had enough occurrence points in the data set to pass our threshold of 15. Its modelled distribution retraces watercourses and shores of seasonal lakes (e.g. the Mare d'Oursi in the center of the study area (Fig. 2). The Dune of Oursi, on the other hand, crosses the study area as a band nearly bare of any predicted distribution. In the NW of the study area are some scattered predictions in wetter parts of the tiger bush (see above).

The highest species richness of NADP-ME species (Fig. 3) is predicted in the tiger bush and in an area between Oursi and Gorom-Gorom. The Dune



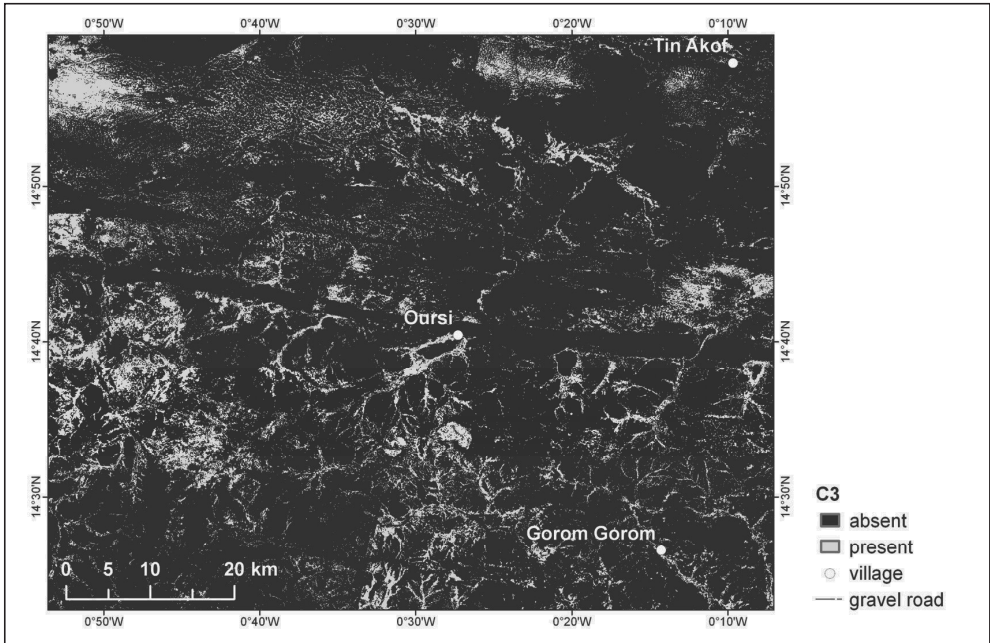


FIG. 2. Modelled distribution of the only modelled C3 species, *Oryza longistaminata*. Watercourses and shores of temporary lakes can be recognized.

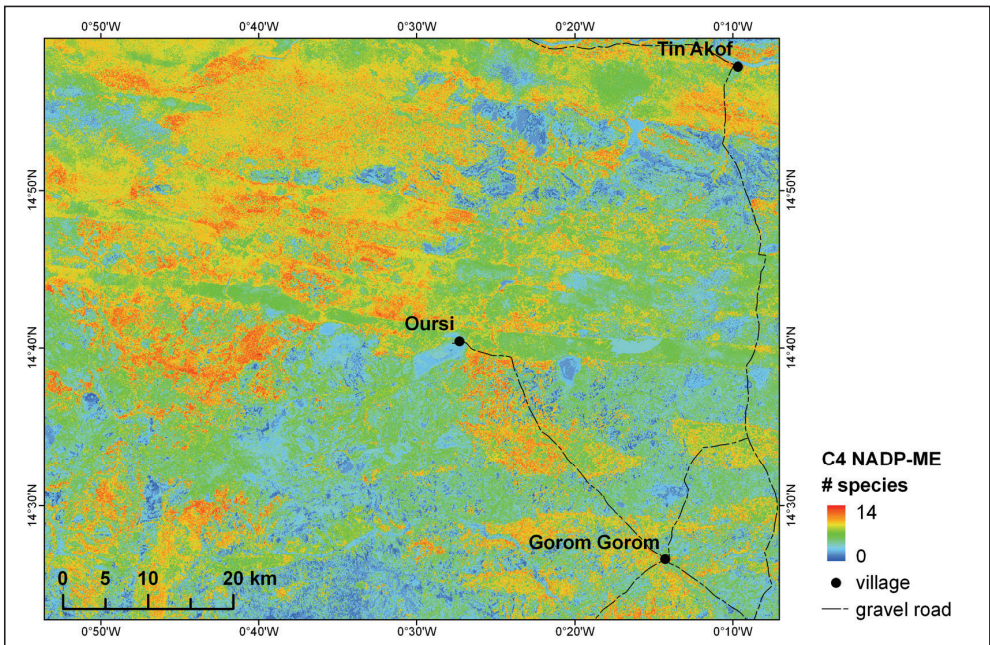


FIG. 3. Modelled species richness of C4 grasses of the NADP-ME type. Highest species richness on dunes and in the tiger bush areas of the NW of the study region, lowest species richness on peneplain.

of Oursi has moderate species richness predictions; peneplain areas in the south of the study area display the lowest values.

Most species of the NAD-ME type (Fig. 4) are predicted on the peneplain, especially in the southern half of the study area. Dunes are areas of lowest NAD-ME species richness; predicted species richness in the tiger bush is intermediate.

The modelled species richness pattern of the PCK type (Fig. 5) mainly reflects dunes, tiger bush, and watercourses. More arid peneplain areas are predicted to be poorest in PCK-type species.

**Validation.** Model validation was carried out with independent test points, randomly chosen from the total set of occurrence points. We obtained for each species at least five distribution models with extrinsic omission (false absences) lower than 20% for each of the species. Within the set of models chosen among these (see section 2.5 and Anderson *et al.* 2003), the mean value of extrinsic omission was 10.96%, meaning that 89.04% of independent test points were correctly predicted as present (Table 3).

## DISCUSSION

**Botanical data.** We detected 68 grass species in our study area, which is about 27% of all grasses occurring in Burkina Faso (Lebrun *et al.* 1991, Schmidt 2006), and with 19% of the local vascular plant flora slightly higher than the share of 15% for the whole country's flora (Schmidt 2006). This underlines the relative importance of grasses in the study area.

The threshold of 15 occurrence points per species to be included in the distribution models did not substantially change the composition of the species spectrum. Therefore we do not expect our results to differ substantially from the distribution patterns including all species.

The high density of occurrence data is unusual for the region. Observation data are usually supported by herbarium specimens, so we have great confidence in the accuracy of determination. A geographically broader sampling might have been desirable, but in the close neighbourhood there were no recordsets available to us. More distant records ranging into other ecoregions, e.g. of the Sudanian zone, were not included because of other land-use systems or different plant communities changing the satellite signatures.

Unfortunately it was not possible for us to physiologically determine the photosynthetic sub-

types, and it is known for *Eragrostis* and *Panicum* that some of the "anatomical PCK" species (*E. atrovirens* and *E. tremula* in our study) might physiologically be NADP-ME species (Hattersley & Watson 1992). However an assignment of these two species to the NADP-ME type would only have resulted in minor changes, the general pattern of preferred landscape types would have been preserved.

**Environmental data.** Until now, high-resolution satellite data have only rarely been used in ecological niche modelling. Very few studies, such as a comparison of environmental data sets for modelling (Peterson & Nakazawa 2008) or a study on highly valued timber trees in the Amazon (Prates-Clark *et al.* 2008), have used satellite data at all. Usually climate grids and digital elevation models are used as environmental layers. An important advantage of satellite data is the high resolution of spatially continuous measurements. Only the high resolution of the environmental layers enabled our detailed results differentiating small-scale habitat variability. At a coarser resolution, or with just interpolated point data (as in climate grids), the habitat preferences would not have been detectable, simply because the variability would have been smoothed out in the environmental data.

A large part of our environmental data consists of vegetation indices. Even though these are used to predict species that are part of the vegetation, there is no circularity involved. If a single species' spectral signature contributes to the distribution model of the very same species (which could only be the case for very abundant species) it would really improve the prediction.

**Modelling approach.** A range of recently published articles compares algorithms and approaches in species distribution modelling (e.g. Elith *et al.* 2006). Although in some of these GARP was not the best performing algorithm, Peterson *et al.* (2007) showed its robustness against overfitting and its good performance in undersampled areas. Therefore we believe that GARP is a very reasonable choice for our study and its rather uneven sampling intensity.

**Modelled distributions.** The evaluation with independent test points (Table 3) showed that on average, c. 90% of species occurrences were correctly predicted by the distribution models.

The resulting distributions agree with other studies in other tropical areas investigating the distribution of photosynthetic types along rainfall gradients or within certain areas (Ellis *et al.* 1980, Hattersley



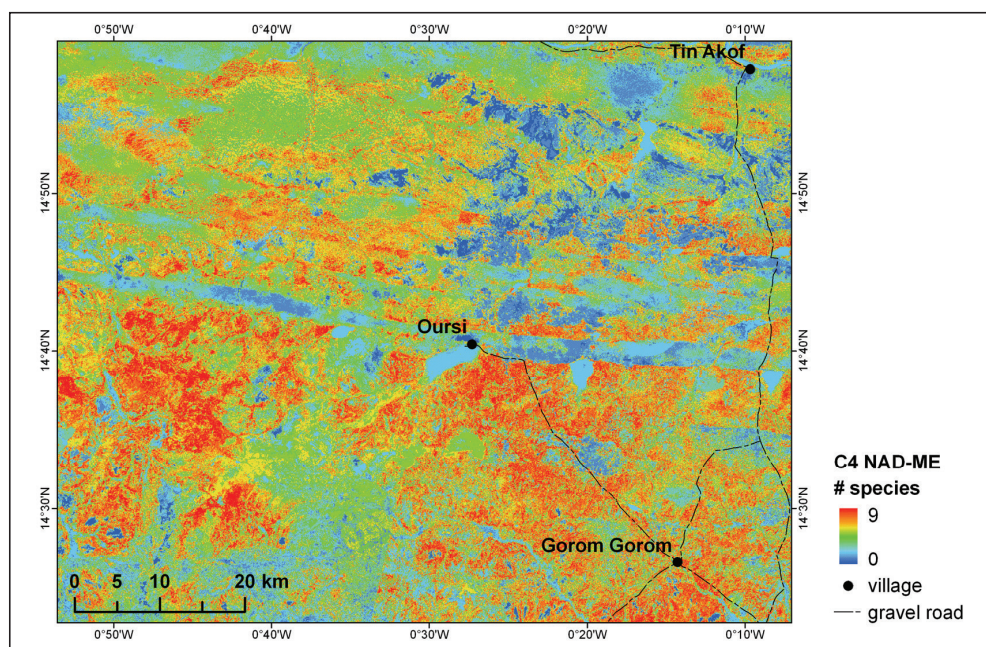


FIG. 4. Modelled species richness of the C4 grasses of the NAD-ME type, with highest values in the peneplain, low values on dunes and in tiger bush.

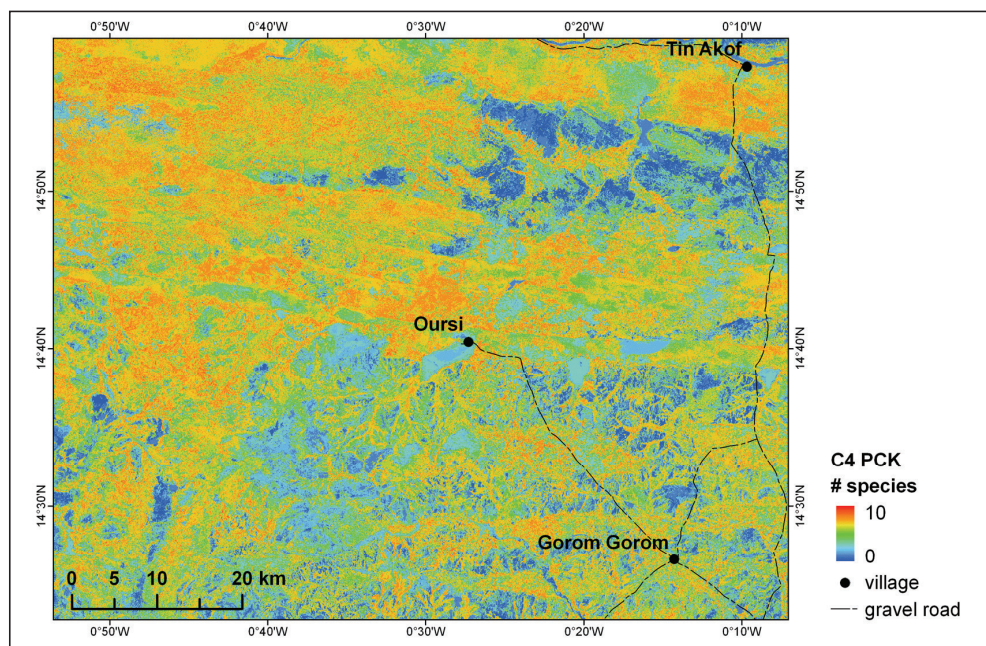


FIG. 5. Modelled species richness of the C4 grasses of the PCK type, with highest values NW of Oursi including tiger bush, lowest values on arid peneplains.

1983, Taub 2000, Cabido *et al.* 2008). The only C3 species in our study, *Oryza longistaminata*, is only found close to seasonally inundated areas. Of course one species distribution in itself is not enough to infer any ecological significance for the C3 species as a whole, but the two other C3 species of our study area are also known to prefer wet habitats (Poilecot 1999). NAD-ME species occupy the ecologically dry end of the range of habitats, NADP-ME species the more humid habitats, and PCK species occupy both relatively dry and humid habitats. In contrast to previous studies our approach of using species distribution models allows spatially continuous information on the composition of photosynthetic types in grasses to be obtained.

**Relevance.** Grasses as a food base for livestock are of high economic importance in the whole Sahel; some species are additionally used as wild cereals (*Panicum laetum*) or for rooftops and straw mats (*Andropogon gayanus*). The geographically detailed knowledge of their distribution patterns will be useful in the sustainable management of these natural resources. Photosynthetic types are just one important aspect in studying grass distribution patterns. Geographical distributions of other traits more closely linked to grazing will supply valuable information for pasture management, e.g. at the level of pastoralist organizations.

**Transferability.** Our approach of using high-resolution satellite data to model species distributions on a local scale is fully transferable to areas of large-scale landscape elements, but will probably experience difficulties in fine-scale landscape mosaics, e.g. in the more humid Sudanian bioclimatic zone south of our study area. The analysis of the geographical distribution of plant functional traits by ecological niche-modelling approaches is a promising technique for the discovery or confirmation of local, regional, and global patterns.

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