

# INDICATOR VALUE OF DIFFERENT VASCULAR PLANT FAMILIES FOR OVERALL PLANT DIVERSITY IN THE SAVANNA BELT OF WESTERN AFRICA (ABRIDGED TITLE: GRASSES AS INDICATORS OF PLANT DIVERSITY)

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*Abstract.* Detailed plant diversity information is lacking for Africa, as for many other regions in the tropics, therefore we have used our collection and observation databases to search for possible indicator groups. Digitization of specimen label data for Burkina Faso from the Herbarium Senckenbergianum (FR) and the Ouagadougou University Herbarium (OUA) led to a database containing 18 000 specimens. Field observations from about 3700 relevés (Braun-Blanquet method, BIOTA standard relevés, simple inventories) were added to the database and together used to model potential species distributions for Burkina Faso on a ten-minute grid. Genetic Algorithm for Rule-set Production (GARP) was used with temperature, precipitation, humidity, and elevation data. Based on these modeled distributions, overall vascular plant diversity was correlated to the diversities of the ten commonest families (Poaceae, Fabaceae, Cyperaceae, Rubiaceae, Combretaceae, Euphorbiaceae, Mimosaceae, Asteraceae, Caesalpiniaceae, Malvaceae). Poaceae and Fabaceae turned out to be the most suitable taxa. The value of these families as indicators for assessing biodiversity is discussed. The results are compared to similar analyses based on relevés only. *Accepted 2 August 2007.*

*Key words:* biodiversity indicator, BIOTA, Burkina Faso, GARP, Poaceae, species distribution modeling.

## INTRODUCTION

In a world of rapidly vanishing biodiversity it is all the more important to find ways of rapidly assessing biodiversity. Even in comparatively well-known areas with a long history of botanical inventories, like Central or Northern Europe, large parts of the biodiversity (e.g., soil fauna) are still insufficiently known. All broad-based approaches to assess biodiversity in tropical countries are far too slow to answer pressing questions about (e.g.) conservation strategies or the effects of changing agricultural practices. In the assessment of overall biodiversity we are therefore already used to the practice of relying on surrogates or indicators. Since most easily accessible, the most commonly used indicator is the diversity of vascular

plants (Tracheophyta). Plants provide primary production and crucial ecosystem structure, thus high plant diversity might be associated with high consumer diversity (e.g., Hutchinson 1959). Analyses support the underlying hypothesis that there is a correlation between the diversity of vascular plants and at least selected animal groups (Barthlott *et al.* 1999, Mutke & Barthlott 2005), but a complete assessment of vascular plants is still very time-consuming and requires expert knowledge, a scarce resource.

One of our approaches was to search for indicator groups for vascular plant diversity which might be quicker and easier to handle than the total vascular plant flora. As Mutke & Barthlott (2005) have illustrated, diversity might change considerably according to the applied indicator (e.g., genera instead of species). In our study, we concentrated on selected plant families and tested their usefulness as putative indicators to assess overall vascular plant species diversity.

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Our study focuses on Burkina Faso, a country that is experiencing substantial changes in its vegetation due to climate change, human population increase and migration, and increased cultivation of cash crops, especially cotton. People depend strongly on the richness of native plants for medicine, energy, construction, and food (e.g., Lykke *et al.* 2004, Thiombiano *et al.* 2002, Wezel 2002). According to present knowledge, the vascular plant flora comprises 1630 species (16 spp. Pteridophyta, 1614 spp. Magnoliopsida; Coniferopsida, Cycadopsida, and Gnetopsida do not occur in Burkina Faso) (Schmidt 2006). Our basic data consist of herbarium specimen data (FR, OUA) and vegetation surveys undertaken in the course of the BIOTA Africa (Biodiversity monitoring transect analysis in Africa) project and the SFB 268 (Collaborative Research Center 268 – “Cultural development and language history in the natural habitat of the West African savanna”). An analysis of the general patterns of species richness and its life-form composition has appeared recently (Schmidt *et al.* 2005).

There are several approaches to using biological entities as easier to handle surrogates for biological diversity, in order to assess it in a broader framework and to predict changes. The “Higher-Taxon Approach” in particular has been used by conservation biologists, and is proven to allow predictions of alpha diversity on the basis of the diversity of higher taxa (e.g., Balmford *et al.* 1996, Gaston 2000, Grelle 2002, Prinzing *et al.* 2003). The principal advantage of this method is that an inventory of higher taxa is far more easily achieved. Genera and families have been shown to be reliable predictors of species diversity, while orders performed less well. Limitations were found especially for the prediction of beta diversity (Prinzing *et al.* 2003). This is a serious weakness, because for conservationists the crucial question is to which extent are areas complementary in their species composition.

Other authors have used selected taxonomic or functional groups which were important but easy to observe elements of flora or fauna, or of special relevance to conservation. Kati *et al.* (2004) tested various systematic and ecological groups (woody plants, orchids, birds, aquatic herpetofauna, terrestrial herpetofauna, Orthoptera) as indicators of species diversity in a predominantly forested reserve in Northern Greece. Diversity of woody plants was best correlated with bird diversity. Cardoso *et al.* (2004) studied

spiders (Araneae) from Portuguese protected areas and found a combination of two spider families to be a good indicator of species richness.

A third approach is to use selected species whose occurrence has been proven to coincide with overall species diversity (“nestedness analyses”, e.g., Sahlén & Ekestubbe 2001, Mac Nally & Fleishman 2004). This rarely chosen approach may work well for homogeneous vegetation types but probably has disadvantages when applied to larger areas with high habitat- and geodiversity. As Mac Nally & Fleishman (2004) concluded, their predictive model of species richness based on indicator species is transferable to larger areas, “provided those areas have similar climate, pools of species, and land-cover and land-use patterns”. For an area as large and diverse as Burkina Faso, these prerequisites are not fulfilled. In the future, such approaches may prove valuable for the planning of conservation activities in smaller, ecologically more homogeneous areas in Burkina Faso, e.g., for the large reserves in the south-east of the country (Arly and W National Parks, Reserves of Pama, Singou, etc.).

Apart from the indicator approach, other predictions would use species distribution models, interpolations and/or rarefaction methods from existing regional primary diversity data (e.g., herbarium specimens, relevé data). While the use of indicators is more helpful in small-scale studies with little data requirements, these approaches need much more data, but can result in spatially continuous predictions for larger areas.

In the search for rapid and, at the same time, meaningful biodiversity indicators there is also an enormous potential in remote-sensing data. The detailed, spatially continuous and up-to-date information from remote sensing is an important alternative to the time-consuming assessment of field data. Nevertheless, the development of such an indicator requires ground truth data on flora and vegetation to calibrate and verify it.

It is evident that species diversity is only one side of the coin. In Burkina Faso, in disturbed areas alpha diversity might increase compared with less affected areas (e.g., Hahn-Hadjali *et al.* 2006). Nevertheless, these changes are principally caused by the appearance of widespread species (e.g., Fabaceae, annual Poaceae) and mask the observed decrease in perennial grass species of usually high pasture value. Ideally, an indicator group for vascular plant diversity would also offer the possibility of detecting such qualitative changes.

TABLE 1. The ten commonest families in our model of Burkina Faso vascular plant diversity. Occurrences in the model, number of species, and life forms were used to characterize the species composition.

	Modeled Occurrences	Species	Therophyte	Hydrophyte	Geophyte	Helophyte	Hemicryptophyte	Chamaephyte	Liana	Phanerophyte
Poaceae	135699	159	100		8	1	46	3		1
Fabaceae	69680	95	40				1	18	11	25
Cyperaceae	27768	43	22		7	1	13			
Rubiaceae	25953	37	9			2	2	3	1	20
Mimosaceae	19368	23		1						22
Euphorbiaceae	19228	29	7			1	3	2	1	15
Combretaceae	18427	19				1		1	17	
Asteraceae	17742	28	17				6	2		3
Caesalpiniaceae	16240	20	2							18
Malvaceae	14977	18	3				2	13		
Vascular Plants	595843	802	290	9	40	10	89	73	56	235

Another important aspect of plant diversity is the presence of different plant functional groups. Life forms, as established by Raunkiaer (1905) and amended with the group “lianas”, were used to assess the functional diversity in our studies.

For our research, and especially for conservation purposes in Burkina Faso, we were searching for an indicator group that is highly correlated with the alpha diversity of vascular plant species but also sensitive to the qualitative changes which take place in the course of increasing human impact, most obviously since the time of the Sahel droughts in the 1970s. Our hypothesis was that one, or a combination of a few vascular plant families should serve this purpose best. We assumed that such (a) family/ies should be comparatively species rich and widespread in the study area. Based on our diversity data from Burkina Faso, the usefulness of different vascular plant families for this purpose was tested.

## METHODS

Our study is based on a combination of collection data and relevés. The West Africa collection of the Herbarium Senckenbergianum (FR) and the Ouagadougou University Herbarium (OUA) contain about 18 000 digitized and georeferenced specimens. Ad-

ditionally, our vegetation database VegDa contains about 3700 relevés, including different types: Braun-Blanquet method relevés, BIOTA standard relevés (Schmiedel & Jürgens 2005), species lists with or without values for frequency or coverage. Nearly all the collection data is from the last 15 years and most relevés, which contribute most to the number of occurrences, were made after 2001.

In order to obtain comparable species sets throughout the country, we used modeled species distributions, avoiding the heterogeneous sampling patterns of primary diversity data. To obtain sufficiently reliable distribution models, we chose only those 802 species with at least five records in our database, thereby limiting the total database to 25 339 distribution records. We used the Genetic Algorithm for Rule Set Production (GARP; Stockwell & Noble 1992) to model the species ranges based on abiotic factors, comprising mean monthly precipitation of the driest and wettest month, difference between driest and wettest month, mean annual rainfall, coefficient of variation of mean annual precipitation, mean annual relative humidity, and mean annual temperature (New *et al.* 2002). GARP develops a rule-set in an iterative process to circumscribe the known occurrences in ecological space. This model is then applied to the

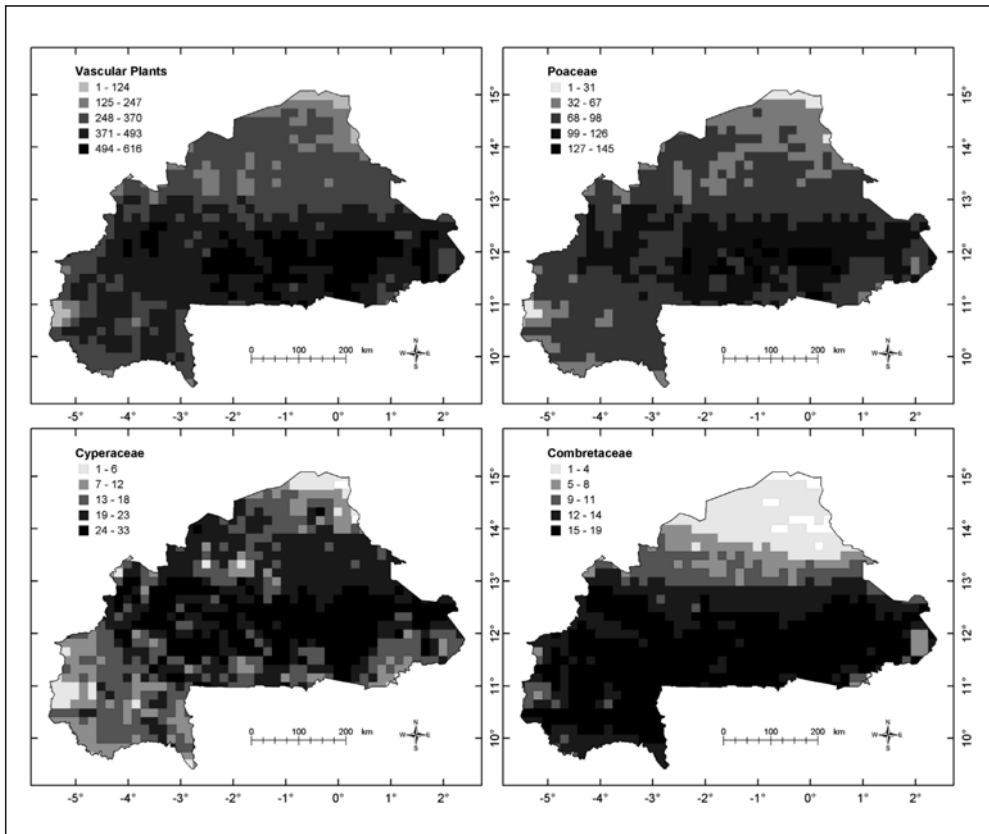


FIG. 1. Species richness maps of all vascular plants, Poaceae, Cyperaceae, and Combretaceae on a 10' grid. Values from modeled distributions of 802 plant species.

ecological layers and thereby reprojected into geographical space (Fig. 1). An analysis of countrywide patterns of species richness and life-form composition has already been published (Schmidt *et al.* 2005).

## RESULTS

The ten families chosen for the analysis of their indicative properties are the commonest families, i.e. those with the most species occurrences (Table 1), thereby being species rich and neither rare nor spatially restricted, which would not make for a good indicator. These are (listed with decreasing number of occurrences): Poaceae, Fabaceae, Cyperaceae, Rubiaceae, Mimosaceae, Euphorbiaceae, Combretaceae, Asteraceae, Caesalpiniaceae, and Malvaceae (Table 1). We calculated the species richness of the grid cells of

the model for these ten families and overall vascular plants and created a correlation matrix (Table 2).

Based on the digitized distribution records and modeled distribution, the ten families with the highest number of modeled occurrences were tested for the correlation between species richness within the family and overall species richness of vascular plants. The selection is nearly identical with the ten most species-rich families of the flora (Schmidt 2006), nevertheless, the ranking differs slightly: Asteraceae, Malvaceae, Convolvulaceae, and Acanthaceae being more species rich than frequent; Rubiaceae, Mimosaceae, Combretaceae and Caesalpiniaceae being more frequent than species rich.

Table 1 sums up data for the ten tested families. As an attempt to characterize the families' diversity

TABLE 2. Pearson's R for the correlations of all vascular plants and the ten commonest families with each other. Values  $\geq 0.85$  in bold. In this table the correlations with vascular plant richness are based on all vascular plants, and different values in Fig. 2 result from the exclusion of the respective family.

										Vasc.Plants	
									Poaceae	0,97	
								Fabaceae	0,87	0,96	
							Cyperac.	0,51	0,75	0,67	
						Rubiaceae	0,15	0,83	0,65	0,77	
					Combretac.	0,85	0,29	0,74	0,73	0,78	
				Euphorb.	0,54	0,61	0,61	0,78	0,81	0,83	
			Mimosac.	0,59	0,38	0,38	0,69	0,75	0,78	0,80	
		Asteraceae	0,50	0,74	0,84	0,91	0,29	0,87	0,77	0,85	
	Caesalpin.	0,84	0,66	0,63	0,77	0,86	0,31	0,91	0,76	0,87	
Malvaceae	0,59	0,46	0,84	0,57	0,45	0,32	0,73	0,66	0,81	0,77	

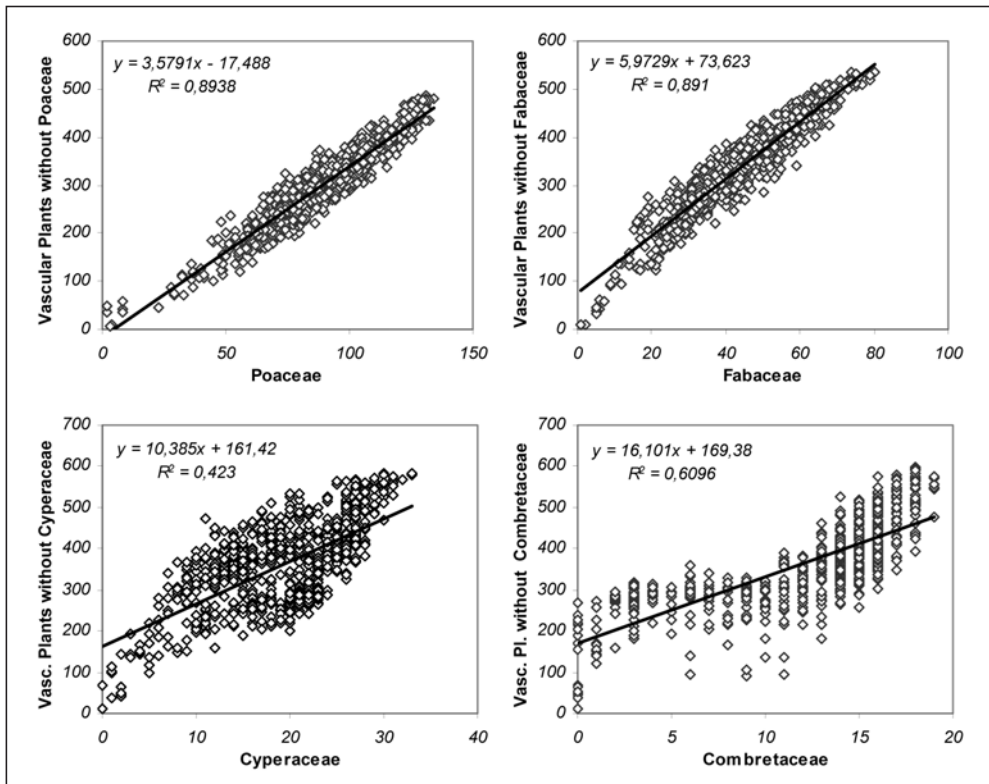


FIG. 2. Species richness of Poaceae, Fabaceae (*sensu stricto*), Cyperaceae, and Combretaceae plotted against the remainder of vascular plants within the 10' grid cells of our model.

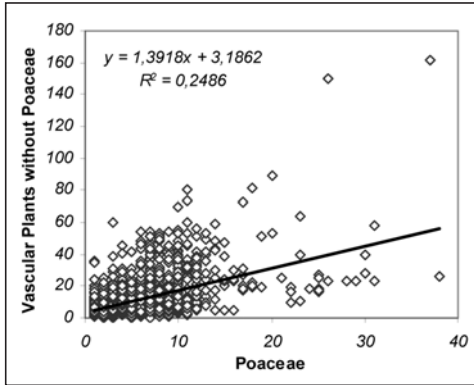


FIG. 3. Species richness of Poaceae and remaining vascular plants from 2330 inventories or relevés of herb layer or all strata ranging from a few m<sup>2</sup> to 1 km<sup>2</sup>.

in plant functional types, the number of species is given for each life/growth form represented within the family. The list illustrates a principal difference between the families with the most occurrences: the almost exclusively herbaceous Poaceae and Cyperaceae contain high numbers of geophytes and hemicryptophytes, while these are rare or lacking in Fabaceae, Rubiaceae, and Euphorbiaceae, where phanero- and chamaephytes dominate and even some lianas occur. In Mimosaceae, Caesalpiniaceae, and Combretaceae a smaller diversity of life forms is found, making this group less appropriate as indicators of overall vascular plant diversity.

Table 2 identifies Poaceae and Fabaceae as the two families whose species richness is best correlated with that of the vascular plants ( $R^2 = 0.97$  and  $0.96$  respectively). The scatter plot for these families (Fig. 2) illustrates the good correlation. Next are the Caesalpiniaceae (0.87) and the predominantly herbaceous Asteraceae (0.85). Lowest values for the correlation are found in Cyperaceae (0.67), Rubiaceae (0.77), Malvaceae (0.77), and Combretaceae (0.78), which makes them less relevant for indication purposes.

Species richness of Cyperaceae displays the lowest correlation with vascular plants species richness. It is evident that more or less the same Cyperaceae diversity can occur in habitats highly differing in overall vascular plant diversity (Figs. 1, 2). To a lesser extent this also holds true for Combretaceae (Figs. 1, 2). The graph for this family is unusual because of the local minimum of vascular plant richness when Combretaceae richness is around 10.

As far as the interfamilial correlations are concerned, a considerable variability can be observed (0.15–0.91; Table 2). The highest correlation coefficients can be found for the pairs Asteraceae - Rubiaceae and Caesalpiniaceae - Fabaceae. Again, Cyperaceae are the family whose species richness is clearly least correlated with the other families. Noteworthy is also the low correlation between Rubiaceae and both Mimosaceae and Malvaceae.

To compare modeled data with original relevé data, we also plotted species richness within the relevés for Poaceae. While the correlation between the species richness of Poaceae and the remaining vascular plants is very good for the modeled distributions, quite different results are obtained from the original relevé data (Fig. 3).

## DISCUSSION

Because of the heterogeneity in primary distribution data, consisting of relevés and collections, we used modeled distribution ranges for the correlation analyses. Relevés often included only either herbs or woody species, while collections focused in many cases on certain habitats or taxonomic groups. Simply counting species per grid cell would be unsuccessful due to the heterogeneity in geographical sampling intensity. On the other hand, methodological aspects, like the choice of environmental layers for the modeling, also influence the result.

Poaceae and Fabaceae, the two most species-rich families in Burkina Faso, are most suited to be used as a surrogate to assess vascular plant species richness. A similar result has been found for generic richness by Lughadha *et al.* (2005), with Fabaceae (*sensu lato* in their study, *sensu stricto* in ours) ranking before Poaceae. Both families are well represented in the savanna herb layers and in virtually every widespread habitat (Müller 2003).

Besides being a good predictor, an indicator should also be much easier to record than the entity it indicates. This is certainly the case for Poaceae in West Africa, where determination of species is facilitated by a comprehensive literature (Innes 1977, Scholz & Scholz 1983, van der Zon 1992a, b, Poilecot 1995, 1999), and many locals know most grass species by their common names (Krohmer 2004).

Another fact supports the indicator value of Poaceae: the representatives of this group clearly react to land-use type as well as to its intensity in Burkina Faso. Detailed inventories of the Poaceae can serve not only as a surrogate for plant diversity but can also be

used to characterize type and intensity of human impact, such as the decline of tall perennial grasses with higher grazing intensity in the Sudanian zone (e.g., Hahn-Hadjali *et al.* 2006). To create an indicator of human impact, the grass species would have to be assigned an indicator value for their reaction to human impact (degree of hemeroby), information lacking up to now. In the context of global climate change, the occurrence of photosynthetic subtypes of Poaceae might also be used to assess changes in water availability (Schmidt 2006).

The available floras and additional indicative properties, which could be exploited at the same time, give Poaceae an advantage over Fabaceae as an indicator group. Using the combined diversity of the two families as a surrogate hardly seems feasible: difficulties with the identification of Fabaceae and the high number of species that would have to be handled would minimize the advantages of using such an indicator group.

Of course, disadvantages with the Poaceae also exist: the comparison with the original relevé data (Fig. 3) shows the scale-dependency of our results. Local habitat variability, with a higher proportion of Poaceae in open savannas than (e.g.) in gallery forests (Schmidt 2006), is smoothed out by the 10' grid of our models. Therefore, Poaceae as an indicator should be used for areas about as large or larger than 10' x 10', like nature reserves, national parks, or administrative divisions. The data used here have been collected in a region mainly consisting of savannas. In the more humid climate of the Guinea Zone, where savannas are replaced by species-rich forests with only a few Poaceae, our conclusions will not be applicable. In spite of these limitations it should be kept in mind that more or less similar species inventories, climate, and land-use types as in Burkina Faso can be found in the whole Sahelo-Sudanian savanna belt. We therefore expect Poaceae to be a good vascular plant diversity indicator in this region.

Cyperaceae and some other families are obviously of little use in indicating overall vascular plant diversity. In the case of Cyperaceae this can be explained: although the group is quite common, its species richness is more evenly distributed throughout the country (Fig. 1) and most collections and observations are fromazonal habitats. These mainly periodically or permanently wet habitats belong to the least documented and investigated habitats in Burkina Faso.

For the unusual relationship between Combretaceae richness and vascular plant richness (Fig. 2) we

could not find any biological explanation, and regard it as an accidental coincidence of lower vascular plant richness and Combretaceae richness of around 10 (values around 10 often fall within the subsahelian zone, which is slightly undersampled and may thus underrepresent especially rare species; see Schmidt *et al.* 2005, Thiombiano *et al.* 2006). Such a putative random effect is more likely in less species-rich plant groups.

The use of Poaceae as an indicator group of vascular plant diversity can be recommended for the sahelo-sudanian savanna region, not only because of the highest correlation with vascular plant diversity, but also because relevant floras are available, the family is of high economic importance, and knowledge of its species composition is also useful for the assessment of changes in land use and water availability.

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