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BIODIVERSITY RESEARCH

Herbarium collections and field data-based plant diversity maps for Burkina Faso

Marco Schmidt[1]*, Holger Kreft[2], Adjima Thiombiano[3] and Georg Zizka[1]

[1]*Abt. Botanik, Forschungsinstitut Senckenberg und J.W. Goethe-Universität, Senckenberganlage 25, 60325 Frankfurt am Main, Germany;* [2]*Universität Bonn, Nees Institute for Biodiversity of Plants, Meckenheimer Allee 170, 53115 Bonn, Germany;* [3]*Université de Ouagadougou, Laboratoire de Biologie et Ecologie Végétales, UFR/SVT, 03 BP 7021 Ouagadougou 03, Burkina Faso*

*Correspondence: Schmidt, Marco, Abt. Botanik, Forschungsinstitut Senckenberg und J.W. Goethe-Universität, Senckenberganlage 25 60325 Frankfurt am Main, Germany. Tel: +49 69 97075-615. Fax: +49 69 97075-137. E-mail: mschmidt@senckenberg.de

ABSTRACT

A map of plant species diversity in Burkina Faso is presented based on field observations and specimen data from the Ouagadougou University Herbarium (OUA) and the Herbarium Senckenbergianum (FR). A map of collecting intensity and field observations illustrates centres of botanical research activities in Burkina Faso. To overcome problems associated with biased sampling intensity, distributions of species have been modelled and extrapolated to maps of vascular plant diversity, life forms and diversity of four selected families (Poaceae, Cyperaceae, Dioscoreaceae and Rubiaceae). The area of most intensive collection and observation is around Gorom-Gorom and Fada N'Gourma. Modelled diversity generally increases towards the south, as does the proportion of phanerophytes, lianas and hemicryptophytes, while the opposite trend is observed for therophytes. Poaceae diversity is highly correlated with total vascular plant diversity, making the family especially suitable as an indicator for overall plant diversity. Cyperaceae are rather evenly distributed throughout the country, Dioscoreaceae are restricted to the Sudanian Zone. Rubiaceae have their highest diversities in the very south.

Our approach can be transferred to areas with a similar database, certainly to other areas within West Africa. Future research should focus on distribution data for rare species, enabling our approach to evaluate the West African system of protected areas.

Keywords

Burkina Faso, collection data, life forms, plant diversity maps, species distribution models, West Africa.

INTRODUCTION

Assessing biodiversity and understanding mechanisms of its changes are difficult in many areas of West Africa because field data are incomplete or lacking. To improve the existing database to allow biodiversity research and management, two approaches were chosen: (1) digitization of collection data and field observations; and (2) modelling of distribution areas and diversity maps. Recent comparable studies in other regions in Western Africa have been performed by Wieringa and Poorter (2004), Chatelain *et al*. (2001), Gautier *et al*. (1999) and Daget and Gaston (2001). The first three studies focus on the Guinean zone and exclude the Sahelian zone. The estimator approach used by Wieringa and Poorter cannot produce meaningful results for a poorly and unevenly collected country like Burkina Faso, because the database is insufficient or lacking for too many grid cells. Chatelain *et al*. (2001) focus on distributions of single species using two different modelling approaches. Their potential distributions could be summarized in much the same way as in our study, especially because they rely on a very profound database. Daget and Gaston (2001) provide species richness data for western Chad, but these are based on a very limited database and at low resolution.

Elsewhere in the world, a very similar study in data sources (both specimens and observations) and methods has been performed by Gioia and Pigott (2000) for the forests of Western Australia. Our study shows that this method works well even with less numerous and unevenly distributed data, as it is the case in many African countries, where there is an urgent need to know patterns of distribution and species richness in order to effectively protect biodiversity.

We are presenting here analyses of collection and field observation density, species diversity and life form composition for vascular plants of Burkina Faso as a whole.

STUDY AREA AND STATE OF RESEARCH

Burkina Faso, a landlocked West African country, covers an area of 274.200 km² between 9–15° N and 6° W–3° E and is inhabited by well over 13 million people. Biogeographically, the country

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extends from the Sahelian zone in the north to the Sudanian zone in the south. Botanical exploration of the area now known as Burkina Faso only started at the turn to the 19th century with Auguste Chevalier in the land of the Mossi, in Yatenga and Gourma. Some botanical studies were conducted under French colonial rule. Very important compilations for the whole region are the *Flora of Tropical Africa* (Oliver *et al.*, 1868–1937), Aubréville's *Flore Forestiere Soudano-Guinéenne* (1950), and especially the *Flora of West Tropical Africa* (Hutchinson *et al.*, 1954–72), although the latter work rarely refers to Burkina Faso specimens. Research activities increased in the 70s. Guinko's (1984) *Végétation de la Haute-Volta* and the *Catalogue des Plantes Vasculaires du Burkina Faso* by Lebrun *et al.* (1991) are the latest comprehensive contributions. Nevertheless, an updated flora, or even an updated checklist are lacking. The latter is an absolute necessity for the near future and would considerably accelerate progress in botany and forestry research. The digitized specimen data and taxonomic information at hand now should serve as the nucleus for such a checklist, for which work has begun in 2003. For neighbouring countries, more recent compendiums like *Flore de la Cote d'Ivoire* (Ake Assi, 2001, 2002) and *Flore Analytique du Togo* (Brunel *et al.* 1984) have been published. Outstanding among the flowering plants are the Poaceae as far as taxonomic revisions are concerned. An updated treatment of the Poaceae of Burkina Faso is lacking, but for neighbouring or nearby countries like Ivory Coast (Poilecot, 1995), Niger (Poilecot, 1999), Togo (Scholz & Scholz, 1983), Cameroon (van der Zon, 1992) and Ghana (Innes, 1977), excellent modern grass floras are at hand.

The most comprehensive treatment of the Flora of Burkina Faso by Lebrun *et al.* (1991) lists 1203 species, with the Poaceae (211 species), Fabaceae (134) and Cyperaceae (100) being the most species-rich families. Since then the number of recorded species has increased by *c.* 250 species. It should be mentioned, that this important study was based on the investigation of *c.* 5925 specimens. At the time the study was compiled, this was probably the most extensive study possible with the available material at the time. In the meantime the available amount of material has greatly increased and our study bases on more than twice as many specimens.

The most relevant data sources for the types of analyses presented here are herbarium collections. Principal collections from Burkina Faso are kept in Ouagadougou (OUA and HNBU) and Frankfurt (FR). Other important European herbaria housing numerous material from the area are at Aarhus (AAU), Montpellier (ALF), Paris (P) and Wageningen (WAG).

Although widely neglected in the past, field observations, especially in the form of relevés, provide another valuable data source for diversity and biogeographical analyses. In the course of recent interdisciplinary research projects, a few thousands of such phytosociological inventories were produced in Burkina Faso alone. These data are usually precisely georeferenced and offer a wealth of information for modelling distribution and diversity.

Within the interdisciplinary research projects 'Kulturentwicklung und Sprachgeschichte im Naturraum Westafrikanische Savanne' (SFB 268) and the BIOTA project, intensive herbarium collections and field observations (relevés) were made since 1988 (e.g. Hahn-Hadjali, 1998; Kéré, 1998; Müller, 2003; Krohmer, 2004). The herbarium collections are deposited in the Herbarium of the University of Ouagadougou (OUA) and the Herbarium Senckenbergianum (FR) at Frankfurt.

METHODS

Herbarium collections and relevés form the base of the presented study. The relevant specimens of the Herbarium of the University of Ouagadougou (OUA) and of the Herbarium Senckenbergianum (FR) were digitized and georeferenced. In total, *c.* 17,000 specimens from Burkina Faso have been included in the analyses presented here.

Digitization of these collections already started in the 1990s and has been updated, including georeferencing, in the last years. The database used for this purpose is BRAHMS (Botanical Research and Herbarium Management System, University of Oxford, 2003). Principal reasons for choosing this software have been the successful introduction and use in herbaria in the Netherlands and the distribution of this database in herbaria in West Africa (Benin, Ghana, Cameroon, Gabon).

The herbarium of the Institute of Environment and Agricultural Research (HNBU), another principal collection from Burkina Faso, comprises about 6500 specimens. Estimates for the number of collections from Burkina Faso kept in other important European herbaria are not available for us at the moment. A principal issue for the future is including data from these collections in similar or subsequent studies.

Additionally, field observations from *c.* 3000 phytosociological relevés were georeferenced and digitized and combined with herbarium data for analyses. Collection and relevé sites are shown in Fig. 1.

The relevés usually had GPS coordinates attached. Coordinates for herbarium specimens prior to 1995 often had to be assigned by means of a geographic gazetteer. For this purpose we usually used the Geonet Names Server (NGA, 2004) or the average of all GPS-coordinates we had for a certain location. In rare cases we used a topographical map. While the GPS coordinates are very accurate, coordinates assigned by gazetteer or maps may well have inaccuracies of 5–10 km. Nevertheless, this error is negligible at a countrywide scale.

Another important aspect is the different accuracy of specimen and relevé data. While herbarium specimens are in general much more reliably determined than mere observations, they are more biased towards rare or unusual species, collectors' bias to more favourable groups and often exclude species difficult to reach or preserve. On the other hand, relevés include all species on a rather small surface, thereby usually representing the most frequent species, and often excluding less common species. Besides improving the database, the combined analysis of specimen and relevé data offers the advantage to minimize the bias of each of the sets.

To show the distribution of our basic data, the number of herbarium specimens per 1° grid cell is given in Fig. 2. A first map counting the species per 1° grid cell from these specimens and

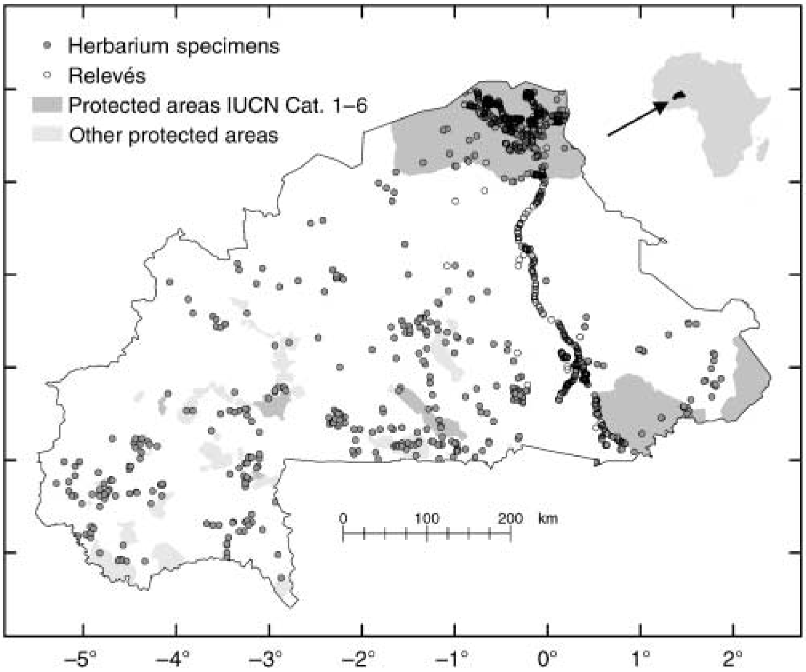

Figure 1 Map of collecting and relevé sites with outlines of IUCN protected areas (WDPA Consortium 2003) and position of Burkina Faso within Africa.

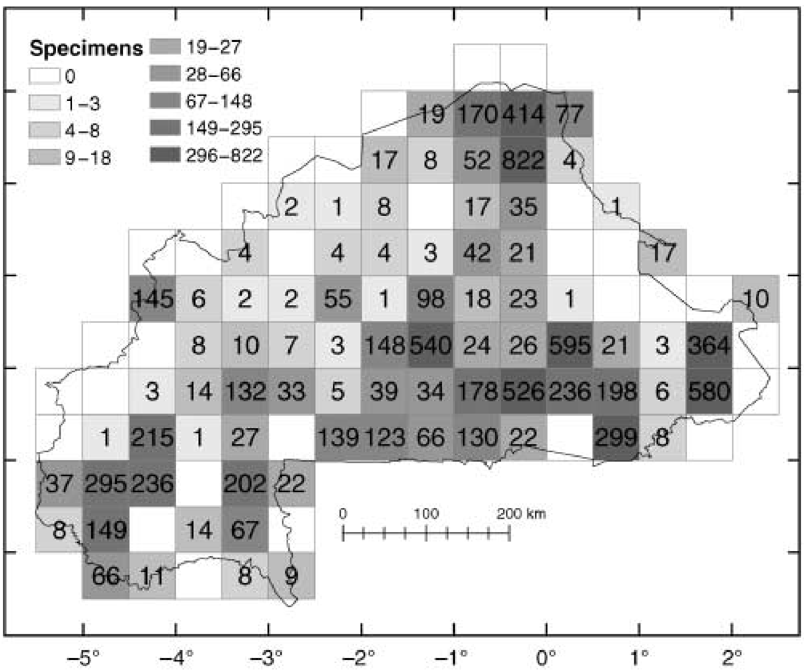

Figure 2 Number of herbarium specimens from the Ouagadougou University Herbarium (OUA) and Herbarium Senckenbergianum (FR) per 0.5°-grid cell.

from the relevés is shown in Fig. 3. To overcome the uneven distribution of species records, we decided to model potential species distributions of single species and combined these to a map of potential species richness (Fig. 4).

To overcome shortcomings of uneven distribution of species records, we modelled potential ranges of single species and combined these to maps of potential species richness, distribution of selected families and different life forms. We used the Genetic Algorithm for Rule-Set Prediction (GARP, Stockwell & Noble, 1992; Stockwell & Peters, 1999) and the desktop version of the implementing program (http://www.lifemapper.org/desktopgarp/) to model potential ranges of species on the basis of abiotic factors. All species with a poor coverage of records were excluded. Only species with five or more records in our database were selected for these analyses, resulting in 25,339 positive distribution records for 802 species (mean number of positive records per species = 31.6). Potential ranges were modelled on the basis of climate GIS-layers, which are thought to reflect crucial parameters for plant distributions in Burkina Faso on a 10-min resolution: mean monthly precipitation of the driest and wettest month,

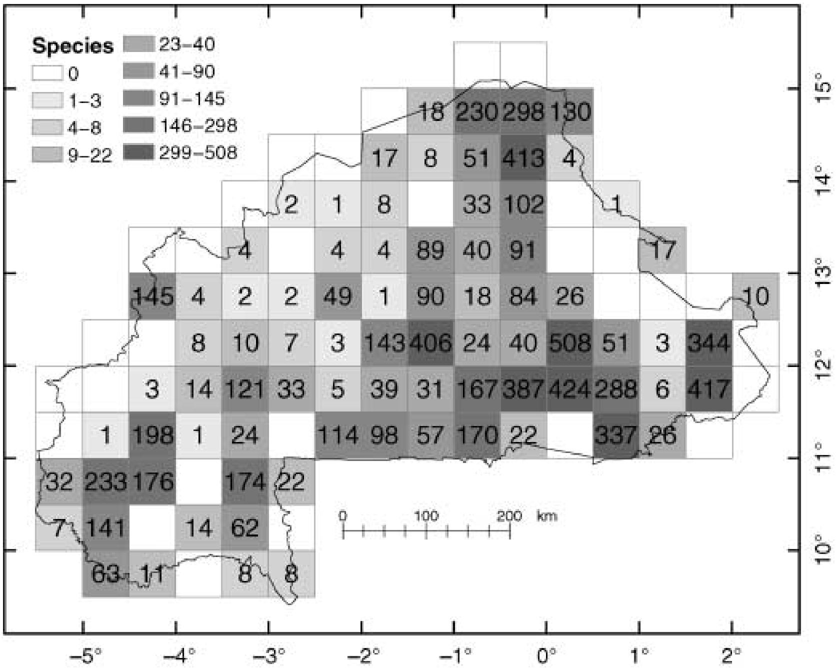

Figure 3 Species numbers from specimen and relevé data per 0.5°-grid cell.

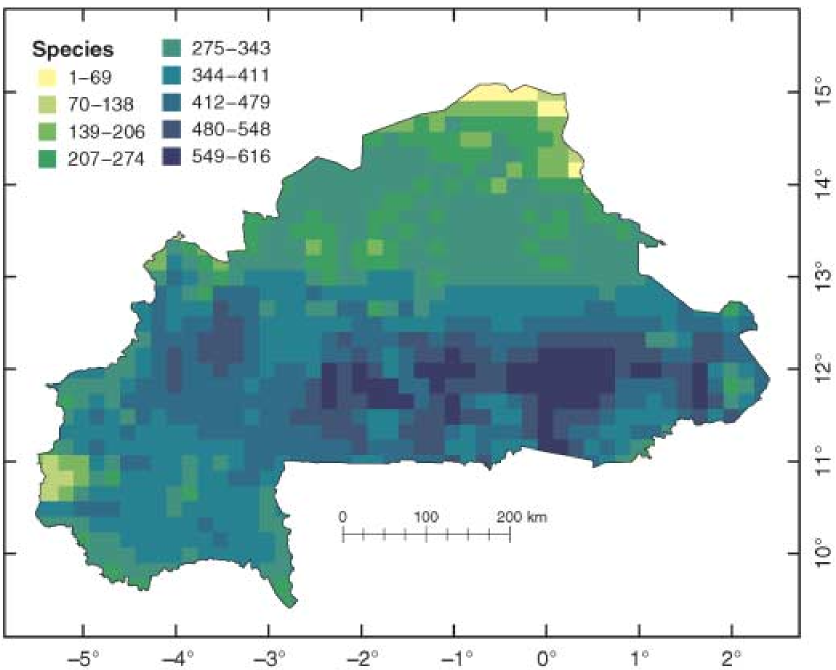

Figure 4 Modelled diversity map at a 10-min resolution. Potential distributions of all species with at least five known distinct distribution points are overlaid.

difference between driest and wettest month, mean annual rainfall, coefficient of variation of mean annual precipitation (as a measure of interannual variation), mean annual relative humidity and mean annual temperature. All climatic variables were derived from the data set of New *et al.* (2002) (http://www.cru.uea.ac.uk/cru/data/tmc.htm).

Using the potential distribution of single species, we also analysed the change in life form composition of the predicted species per grid cell (Fig. 5). The life form spectrum has often been used to characterize the flora of a region. It principally reflects the environmental conditions, especially climate and human impact. The classification systems in use are more or less based on Raunkiaer (1905). Our system follows Raunkiaer's life forms but additionally distinguishes lianas, which were added as a group characteristic for more humid conditions.

A similar analysis for the family composition was done, but preliminary analysis showed only minimal differences across the country for the 10 most commonly recorded families. We therefore decided to select four families of different ecology to represent different distribution patterns (Fig. 6): Poaceae as the

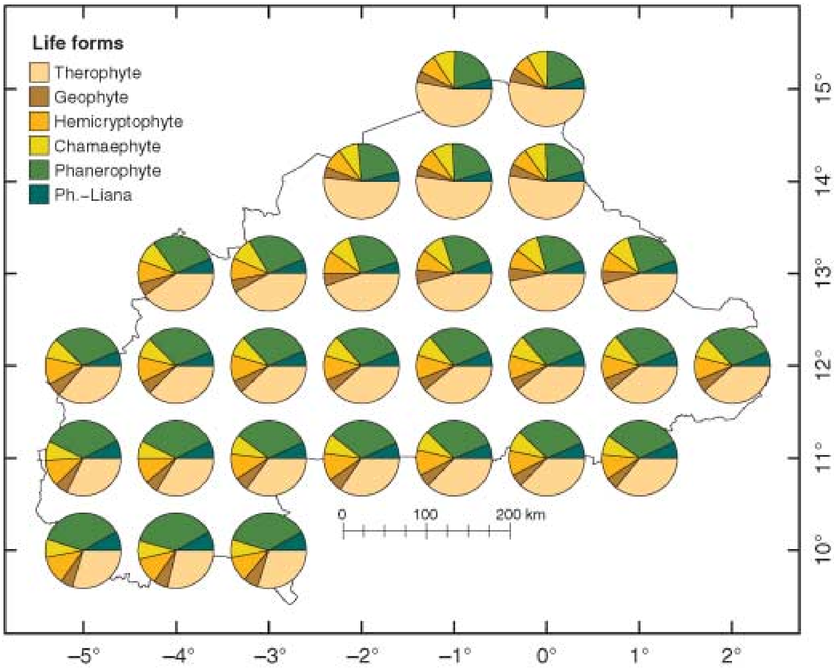

Figure 5 Proportions of different life forms per 1°-grid cell.

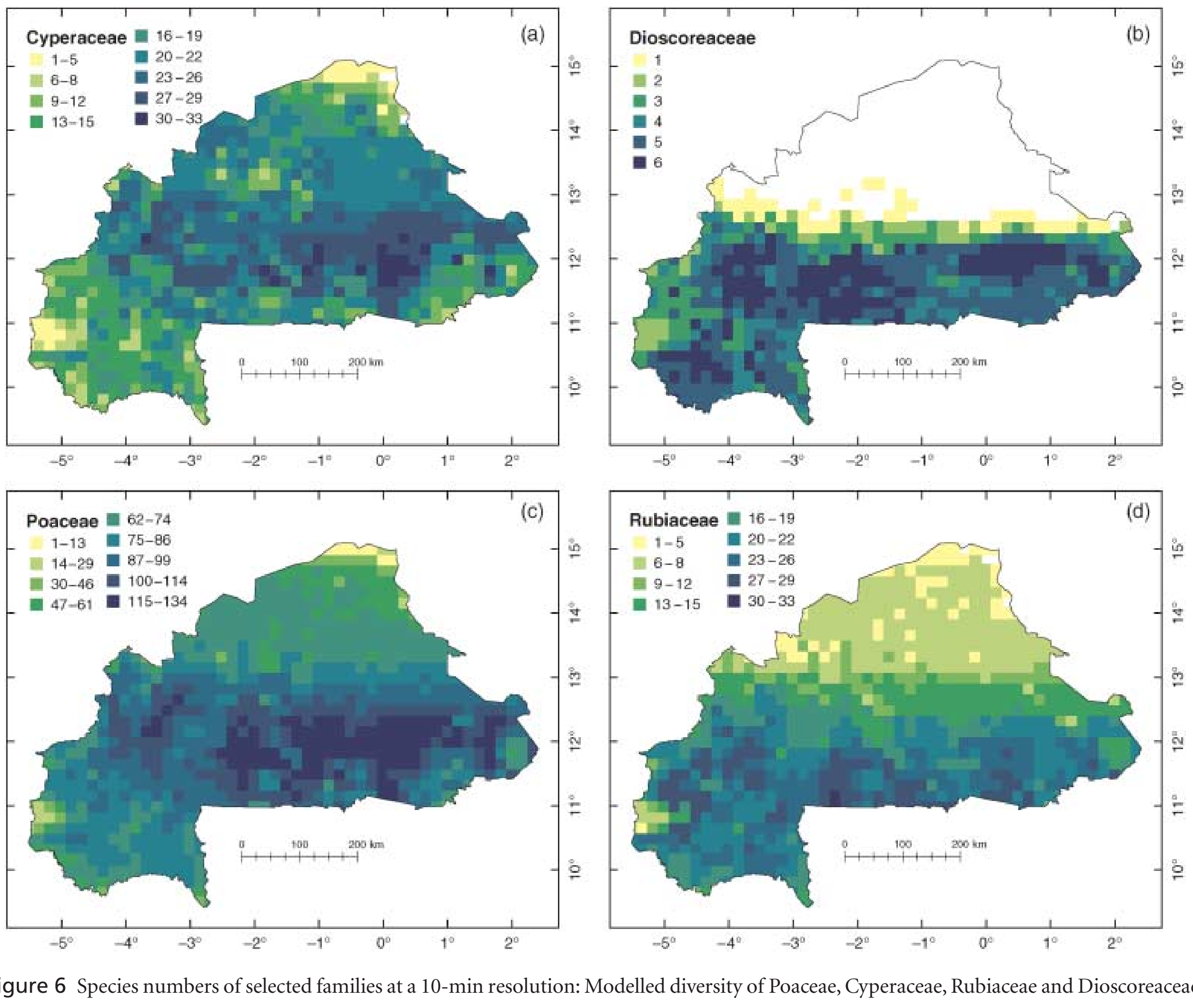

Figure 6 Species numbers of selected families at a 10-min resolution: Modelled diversity of Poaceae, Cyperaceae, Rubiaceae and Dioscoreaceae.

most species-rich family and most important for the savannas, Cyperaceae for their often azonal habitats, Dioscoreaceae as an invariably lianescent family and Rubiaceae for its richness in woody species.

RESULTS

Collecting intensity

Some areas of research focus were identified in the Sahel around Gorom-Gorom and in the North Sudanian Zone around Fada N'Gourma (Figs 1–3). The collecting/observation sites display a very uneven distribution across the country, principally due to collecting in the course of regionally restricted studies and in more easily accessible areas. For some areas, a bias due to insufficient collecting has to be postulated. This is especially true for the western part of Burkina Faso. Although there is a strong concentration of study sites in the eastern part of the country, we know from climatic data (New *et al*., 2002), that both parts are subject to a similar latitudinal gradient of temperature and precipitation.

Data on collecting intensity give an important tool for directing further field studies and collecting. Especially the areas close to the south-western border with the Ivory Coast and the mountains around Sindou and Orodara deserve more attention in future field research.

With respect to the protected areas of Burkina Faso that are of essential importance for the conservation of the country's biodiversity, a good database is presently lacking, stressing the need for further fieldwork and collecting. This is especially true for the reserves in the south-east, which are difficult to access during the rainy season.

Diversity of vascular plants

Species richness

As could be expected, a gradual increase in species richness from north to south for the most part of the country (Fig. 4) is observed. This gradient corresponds to the increase of precipitation and includes the Sahelian, north Sudanian and south Sudanian vegetation zones.

An exception from this is the SW of the country, which has a lower species richness than the centre and SE. This is presumably an artefact, mainly due to the lower sampling intensity and climatic conditions unique to this part of the country. The highest values for species richness are observed in the Gourma region.

Life form spectrum

The composition of life forms as shown in Fig. 5 reveals highest percentages of annuals in the Sahelian region of BF. Towards south, the share of therophytes decreases, while that of the phanerophytes and hemicryptophytes increases. An increase in number of annuals could be expected for the arid northern part of the country, nevertheless it is not possible for us to differentiate, to which extent arid climate and human impacts (grazing) have contributed to the observed pattern. The percentage of phanerophytes and lianas strongly increases toward the south, the zone of the Sudanian savannas. The distribution of the Dioscoreaceae (Fig. 6b) reflects habitat suitability for climbing species. The hemicryptophytes increase towards the more humid south. Tall perennial grasses play a major role in this group and do not only increase in terms of species richness, but also in abundance (Fournier, 1991; own observations). Some questions remain with respect to the chamaephytes. For this group, no clear tendency along the north–south humidity gradient is visible. The group is favoured under increasing grazing pressure, while perennial grasses decreased (Hahn-Hadjali *et al*., 2005). A closer look at the species level with analysis of species ecology and distribution should follow, as it may provide interesting results at a smaller scale.

Diversity of selected families

Poaceae is the most species-rich family of Burkina Faso and its diversity pattern (Fig. 6c) is highly correlated with that for all vascular plants ($R^2 = 0.9323$; $P < 0.001$). Cyperaceae have a more even distribution throughout the country, probably due to their preference of seasonally or permanently wet sites like water holes or small rivers, where they can readily exist even in the dryer north. Dioscoreaceae, represented only by the genus *Dioscorea*, are confined to the Sudanian zone (south of *c*. 13° 'N). This is probably due to limited dense woody vegetation further north, which provides the necessary support and microclimate. The Rubiaceae are distributed throughout the country with most species in the south. The higher numbers in the south are mainly due to woody species, many of which reach the northern limit of their distribution in southern Burkina Faso.

CONCLUSIONS

Being a rather flat country with low topodiversity, Burkina Faso nevertheless exhibits a steep gradient in precipitation from the South Sudanian savannas to the Sahel. It has a high cattle density (White & Nackoney, 2003) and is thus very typical for the Sahelo–Sudanian Savanna belt. Since most plants have a wide distribution in this region, general results like the trends in life form composition will presumably also be valid for neighbouring countries.

The link between digitized species occurrence data, climatic maps and modelling algorithms offers important advantages for the documentation, assessment and conservation of biodiversity. This is especially true for many tropical countries, where specimen-based diversity information as detailed and comprehensive as it is available for some European countries is not yet in sight. Moreover, the very scarce biodiversity information is usually focused on certain systematic groups or (better accessible) regions, leaving many 'white spots' on the map (cf. ter Steege *et al*., 2000 for Guyana). In contrast to many studies at continental scale (Linder, 2001; Taplin & Lovett, 2003) or in very species rich countries (Funk *et al*., 1999; Vargas *et al*., 2004), we were able to include about 50% of all vascular plant species occurring in Burkina Faso, thus limiting our bias toward particular groups.

The problems caused by the lack of data from the south-west of Burkina Faso have been mentioned before and can only be solved through additional fieldwork. Further improvement of the distribution models can be expected from detailed soil data, which are not available at the moment. A principal issue for the future will be linking biodiversity data with measures characterizing human impact, e.g. population and cattle density. These analyses have already been performed on a continental scale (Küper *et al*., 2004), but sufficient information for an appropriate study on a smaller scale are presently not available.

Guidance for focused collecting activities in the future is provided by the maps of specimens and species per grid cell (Figs 2 and 3) in combination with topography. The available information and analysing tools also form an exceptional base for the 'next step' to follow, which is an updated checklist of angiosperms and a modern flora for Burkina Faso.

Another important analysis that could be based on the potential distribution data presented here is an evaluation of the network of protected areas in Burkina Faso. Such an analysis, however, requires more data from the south-west, where many small reserves exists, and more importantly needs more data on rare species.

Further studies in diversity and indicator value, especially of Poaceae including the composition of C fixation types, height and dispersal mode are presently being conducted.

Although species richness as a diversity measure is a fundamental approach, it does have some principal weaknesses. From a global viewpoint of conservation and diversity, the conservation value of species differs according to their distribution and for many species can be roughly negatively correlated with the size of the distribution area. A selection of widespread, even cosmopolitan weeds in a heavily grazed area could be regarded as being of lesser value from a conservational point of view than a smaller number of species with limited distribution. Approaches to apply a 'quality criterion' to species have been attempted, for example by classifying species according to the size of their distribution area (Kier & Barthlott, 2001; Küper *et al*., 2004). A comparable analysis is presently not possible with the available data set, because there is not enough large-scale distribution data available for our species set.

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