

Patterns of vascular plant diversity at continental to global scales

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The studies presented in this paper analyse diversity patterns of land plants (mosses, ferns, gymnosperms, and angiosperms) at continental to global scales. A revised version of our earlier world map of vascular plant species richness and the first maps of species richness of mosses and gymnosperms on a global scale are presented. Diversity patterns of vascular plants are correlated with different measures of geodiversity (the diversity of the abiotic environment). Global centres of vascular plant diversity coincide with highly structured, geodiverse areas in the tropics and subtropics. These are the Chocó-Costa Rica region, the tropical eastern Andes and the north western Amazonia, the eastern Brazil, the northern Borneo, and New Guinea, as well as the South African Cape region, southern Mexico, East Himalaya, western Sumatra, Malaysia, and eastern Madagascar. Constraints imposed by the physical environment, such as the length of the thermal vegetation period or water availability, shape large scale trends of biodiversity. However, important centres of species richness and endemism can only be explained when taking into account the history of the floras. The main diversity centres in SE Asia are the same for gymnosperms as for all other vascular plants, but in other parts of the tropics and subtropics there is low gymnosperm diversity. The exceptions to this pattern are Mexico and California, which have almost as many species of gymnosperms as SE Asia. The increase in the number of species and genera published during the last 250 years is documented, based on data from the *Index Kewensis*. The first continental maps of Cactaceae diversity at species and genus level are used to show how choice of the taxonomic level affects the analysis and its implications for priority setting in biodiversity conservation. In this context, global biodiversity hotspots are discussed and an alternative world map of hotspots is proposed.

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This paper is dedicated to Prof. Dr. h.c. Loki (Hannelore) Schmidt on her 85th birthday.

Introduction

Knowledge on spatial distribution of biodiversity is crucial for its further exploration, use, and conservation. The relevance of this – in

the context of politics and conservation – is demonstrated by large research programmes of several international environmental NGOs. The hotspot analyses of Myers and Conservation International (Myers *et al.* 2000), the Global 200 programme by the WWF (Olson & Dinerstein 1998), or the Endemic Bird Areas by Birdlife International (Bibby *et al.* 1992;

Stattersfield *et al.* 1998) may be the most prominent examples. Extensive assessments of the knowledge of spatial distribution of biodiversity on earth were performed by the WCMC (Groombridge 1992; Groombridge & Jenkins 2002), in the context of the Global Biodiversity Assessment (Heywood 1995), or by WWF & IUCN (Davis *et al.* 1994-1997). Gaston (1998) presented a review of diversity mapping analyses for a large range of organisms.

In this paper we give an overview on continental to global patterns of land plant diversity. We focus on vascular plants, comparing diversity patterns of large sub-groups like ferns, gymnosperms, or angiosperms, but we also present a preliminary map of the diversity of mosses on a global scale.

History of large scale plant diversity mapping

Despite the increasing importance of these analyses, biodiversity maps on continental to global scale are still scarce. In general, there are two basic approaches to generate quantitative diversity maps. The first approach is taxon-based (Barthlott *et al.* 1999c), where distributional information for single species or taxa (*e.g.*, plant collection localities or polygon maps drawn by specialists) are overlaid to generate synoptical maps of their species richness or, *e.g.*, endemism. The second approach is inventory-based (Barthlott *et al.* 1999c), where summary data on the floras of operational geographical units, such as the species numbers of different countries, islands, mountain ranges, or national parks are used for the analyses.

Both approaches use different ways to reduce the amount of information to be processed. The taxon-based approach requires very detailed information, and there are even a few examples (mostly at microhabitat scale) where every single individual of a plant species has been recorded. More often, the occur-

rence in a larger geographical unit is documented – which might be a political unit, an ecoregion or a grid cell. The advantage of the taxon-based approach in comparison to the inventory-based approach is the much wider range and detail of possible analyses. Furthermore, only taxon-based datasets can be used for complementarity based priority setting analyses (Balmford *et al.* 2001; Burgess *et al.* in press). The disadvantage is the extremely large amount of data to be processed. In the context of the BIOTA Africa framework (www.biota-africa.de), we established a database on the distribution of approximately 6,200 African vascular plant species. This dataset is the result of a close co-operation with Jon Lovett, Peter Linder and many others (compare Küper *et al.* 2004; Burgess *et al.* in press; Linder *et al.* 2005). Though the database contains more than 200,000 distribution records (status as of January 2004), reliable distribution data are simply not available yet for several areas such as the northern Congo (Brazzaville), the Ethiopian-Sudanian border region, vast areas in the southern and eastern part of the Congo basin, in Angola and Mozambique (Küper *et al.* in prep.). Since these artificial gaps influence subsequent analyses (Kier *et al.*, in press), they have to be overcome by range modelling techniques, *e.g.*, based on climate.

Thus, inventory-based approaches still seem to be the only possibility for the mapping of groups of organisms as large as the 300,000 vascular plant species, at least at a global scale. Analyses and maps that can be classified as inventory-based date back at least to the work of Alexander von Humboldt (Humboldt 1815, 1817). In these works, Humboldt was the first to discuss quantitative differences in the floras of various regions on earth regarding total species numbers as well as the relative importance of different families. However, his data were only published on a map 20 years later, in 1838, in “Dr. Heinrich Berghaus Physikalischer

Atlas" (Berghaus 1837-1847) and in the famous Kosmos Atlas (Bromme 1851/1852). The Berghaus Atlas also includes diversity maps for birds and reptiles and graphs showing the importance of different plant families at different latitudes. A detailed discussion on the history of plant distribution maps is given by Friis (1999).

A first inventory-based world map of vascular plant species numbers showing some 140 species richness figures for almost all areas on earth was published by Wulff (1935). Though the most important trends are already visible, species numbers on this map are difficult to compare, as they refer to units of different area sizes (Fig. 1). Lebrun (1960) presented a map of African plant species richness, which – in contrast to Wulff's map – referred to a standard area size on the basis of c. 70 species richness figures. Species richness has been standardized for this map by the use of a modified version of the species-area model of Evans *et al.* (1955). A world map of vascular plant species richness referring to standard areas of 100,000 km² was presented by Malyshev (1975) on the basis of c. 400 species richness figures and a standardisation by the use of the classical species-area model of Arrhenius (Arrhenius 1920, 1921). In 1996 we published a new world map referring to standard areas of 10,000 km² based on a much larger dataset of almost 1800 species richness figures from which 1030 were selected as suitable for this mapping approach (Barthlott *et al.* 1996). In contrast to the methodology used for the complete revision of this map, which is presented here, Barthlott *et al.* (1996) used the species-area model of Lebrun (1960) for the standardisation of the species richness figures. Recently, the raw dataset has been revised and expanded, and it includes now more than 3150 species richness figures. Also the methodology has been further developed (see below and compare, *e.g.*, Mutke *et al.* 2001 and Kier *et al.*, in press).

The comparison of Figs 1 and 3 demonstrates the fact that the most important global patterns of plant species richness have been known at least since the work of Wulff (1935). His map already showed such important features as the humid tropics of South-East Asia and the Neotropics as global maxima of plant diversity. However, a look at the details, especially for many tropical areas, reveals that the data available at that time were still incomplete.

Fig. 2 shows the increasing number of plant species and genera published during the 250 years since Linnaeus (1753). This analysis (Mutke *et al.* in prep.) is based on the CD-ROM version of the *Index Kewensis* (Royal Botanic Gardens Kew 1993) and refers only to the c. 550,000 new species excluding the 330,000 new combinations documented in that dataset. The highest rates of new names published were reached in the 1820s and 1830s for genera and between the 1880 and 1940 for species. For example, in 1912 more than 8,000 new plant species were published while the mean rates for the 1980s and 1990s were 2,000 to 3,000 species per year. At the time when Humboldt (Humboldt & Bonpland 1805-1839) began to publish his analyses, only 2% of the plant species included in the *Index Kewensis* had been named. At his death, in 1859, this figure had increased to 15%. During his lifetime, more than 50% of all known plant genera had been described. In 1935, when Wulff published his map, more than 70% of the current species had been published, whereas this figure had reached about 90% at the time of the analysis of Malyshev (1975).

Global patterns of plant diversity

Background

The world map of species richness of vascular plants presented in Fig. 3 has been generated with the inventory-based methodology. It is a

Vegetationskarte der Erde auf Grund der Artenzahl.

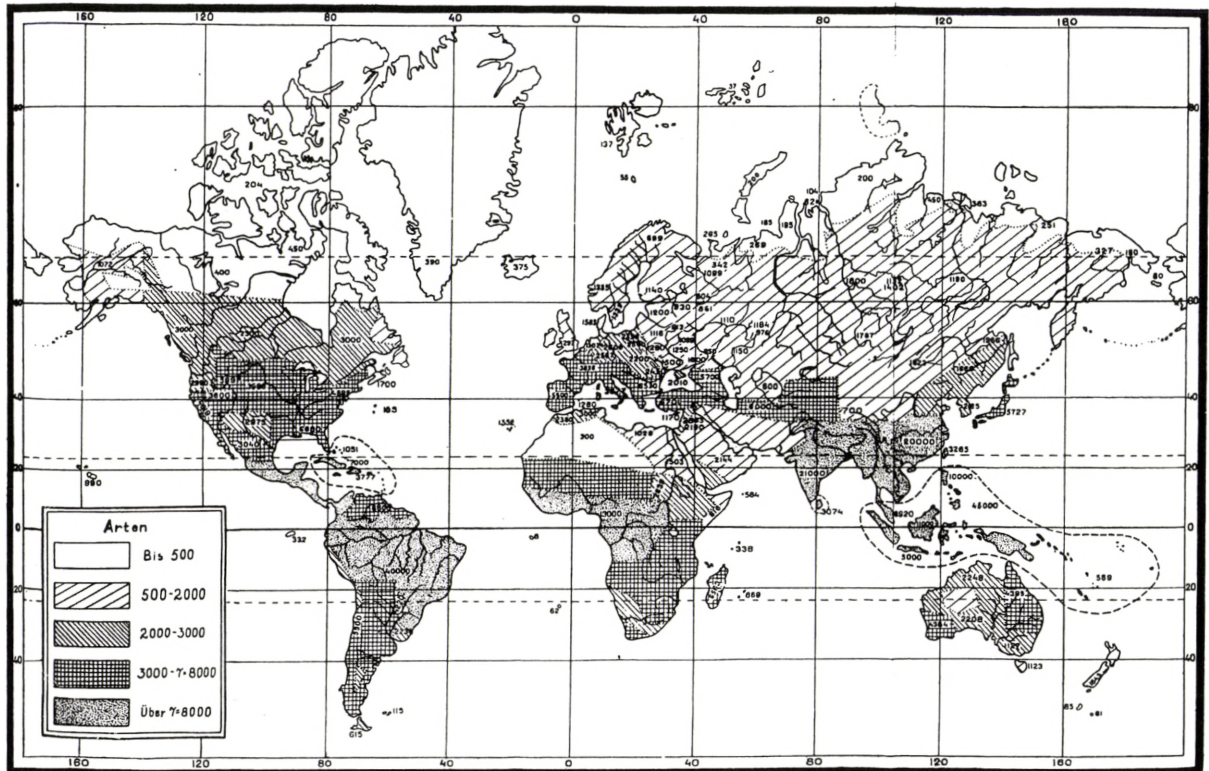


Fig. 1. World map of species richness of vascular plants (Wulff 1935).

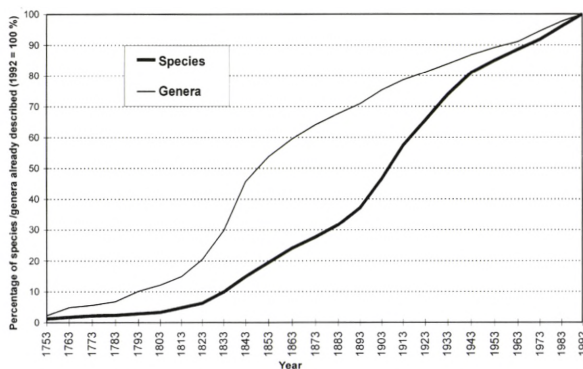


Fig. 2. Increase in numbers of published names of species and genera during the last 250 years (after Mutke et al. in prep., based on the CD-ROM edition of the Index Kewensis (Royal Botanic Gardens Kew 1993)).

preliminary version of a complete revision of our earlier map (Barthlott *et al.* 1996, 1999a). More than 3,270 species richness figures for more than 2,460 different operational geographical units, such as countries, provinces, mountains, islands, national parks, and others were collected on a global scale. On the basis of criteria such as area size, spatial homogeneity of the operational unit, and quality and completeness of data, 1,480 of these species richness figures were selected as suitable for our mapping approach and the standard area size of 10,000 km². The species richness was standardized to the standard area by use of the species-area model of Arrhenius (1920, 1921). The final map was interpolated on the basis of

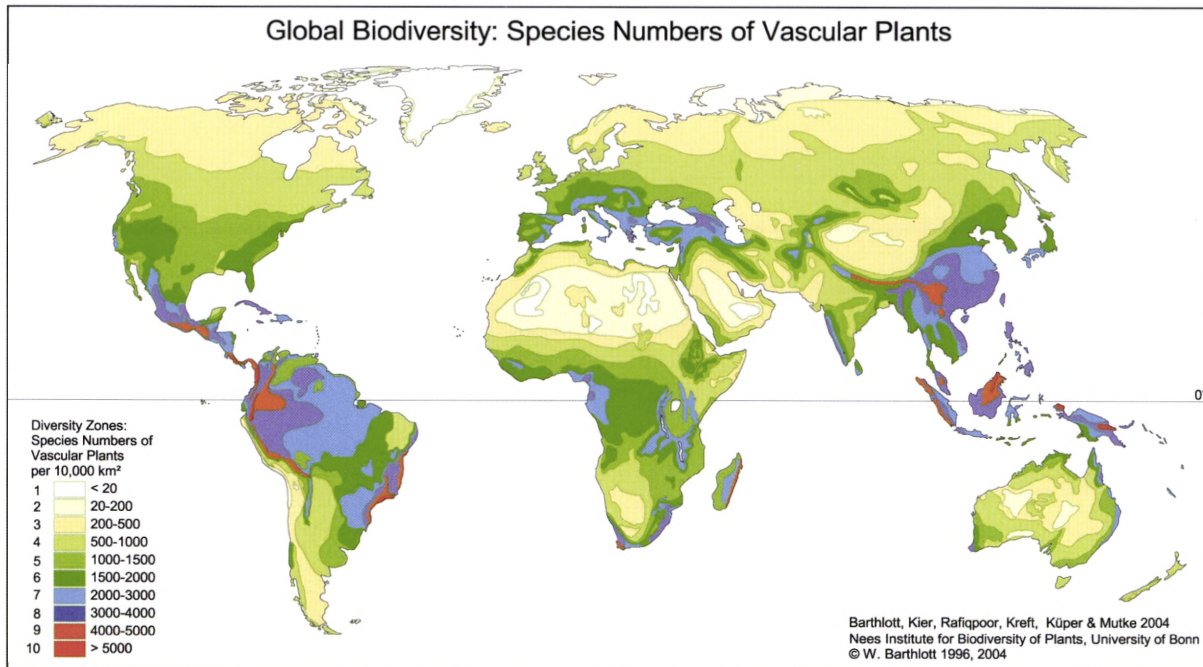


Fig. 3. World map of species richness of vascular plants after Barthlott *et al.* (1996, 1999a) – preliminary version of a complete revision (Mutke *et al.* in prep.).

GIS layers of the suitable geographical units and additional data on vegetation, climate, topography, and other parameters. For details on the dataset and methodology, compare Mutke *et al.* (2001), Mutke (2002) and Kier *et al.* (in press).

The analyses on diversity patterns of mosses (Mutke *et al.* in prep.) use more or less the same inventory-based approach and are based on c. 570 species richness figures referring to more than 450 operational units.

In contrast, the world map of species richness of gymnosperms (Mutke *et al.* in prep) is based on a detailed taxon-based information system comprising distribution maps for all c. 860 gymnosperm species. These data have been digitized from a range of published sources (*e.g.* Farjon 1984, 1990, 1998; Jones 1993; Golte 1993, and others).

The latitudinal gradients of vascular plant

species richness given in Fig. 6 and the correlation to climate in Fig. 7 have been based on the same dataset as used for the map in Fig 3. For Fig. 6, the latitude of the geographical mid-points of the suitable operational units is plotted against the species density per 10,000 km². In Fig. 7, mean values of potential evapotranspiration and maxima of number of wet days per operational unit were queried using GIS and plotted against species density per 10,000 km² (Mutke 2002, Mutke *et al.* in press).

Global patterns of angiosperm diversity

Even though the map presented in Fig. 3 shows species richness of all vascular plants, the patterns mainly reflects angiosperm diversity. Fig. 4 shows that the absolute maximum of gymnosperm diversity peaks at less than 60 species per 10,000 km². The proportion of fern species within floras reaches maxima of approximately

15% only on some oceanic islands or in montane rainforests (see below). Thus, 85 to 99% of the patterns shown in Fig. 3 are patterns of angiosperm diversity.

As discussed in the first paragraphs, many important trends in the geographical distribution of vascular plant species richness have been known at least since the work of Wulff (1935). However, during the last decade we have greatly improved our understanding of these patterns. Some of the most prominent examples, like the latitudinal gradient of species richness, are further discussed below in the section "Biodiversity vs. Geodiversity".

Areas representing global maxima of vascular plant species richness are the Chocó-Costa Rica region, tropical eastern Andes and north western Amazonia, eastern Brazil, northern Borneo, and New Guinea, as well as the South African Cape region, southern Mexico, East Himalaya, western Sumatra, Malaysia, and eastern Madagascar.

In general, regions of high geodiversity (Barthlott *et al.* 1996, see below), especially in mountain areas of the humid tropics and subtropics, harbour the highest species numbers. A comparison of species richness of biomes as delineated, *e.g.*, by WWF (Olson *et al.* 2001), shows that tropical broadleaf forest reaches species numbers up to 10,000 species per 10,000 km², *e.g.*, in the mountain ranges of Costa Rica (Davis *et al.* 1997) or c. 5,000 species on 1,200 km² at the Mt. Kinabalu, Borneo (according to Beaman in this publication). These absolute maxima are closely linked to mountainous areas. However, also lowland forests, *e.g.*, in the western Amazon basin, harbour very high plant diversity. A high number, 473, of tree species and a total of 1,000 vascular plant species are documented in 1 ha lowland rainforest in the Amazonian part of Ecuador (Valencia *et al.* 1994), and 3,000 species have been found in 24 ha in the Chribibiquete-Araracuara-Cahuinari region of Colombian Amazon (Davis *et al.* 1997).

Tropical and subtropical coniferous forests and Mediterranean climate areas are also very species rich. In contrast, Tundra and Taiga regions harbour lowest mean species richness, whereas absolute minima can be found in hyperarid areas of the Sahara and Atacama desert, as well as in Arctic and Antarctic environments.

Global patterns of gymnosperm diversity

Though new genera are still being described (Farjon *et al.* 2002), the gymnosperms might be one of the best documented groups of land plants (*e.g.*, Jones 1993; Farjon 1998; Farjon & Page 1999). However, until now, there has been no global map of total gymnosperm diversity. Thus, in Fig. 4 we present a first draft of a species richness map of all gymnosperms at the global scale.

The most important centres of gymnosperm diversity are located in SE Asia. Especially the forests of the Chinese provinces of Yunnan and Sichuan with almost 60 species co-occurring on an area size of 10,000 km² are very species rich. Other centres with more than 30 species per 10,000 km² are SE China in general (with more than 100 species in total), New Caledonia, northern Borneo with Mt. Kinabalu, the central range of New Guinea, southern Mexico, and California. Large areas of the southern hemisphere harbour no or only few gymnosperm species. Exceptions are New Caledonia with more than 40 species, eastern Australia, Tasmania, and New Zealand, the South African Drakensberg area, and parts of the South American Andes. The largest contiguous coniferous forests of the world, the northern hemisphere boreal forests or taigas, harbour only few species with only 5 to 10 species co-occurring in an area of 10,000 km². Less than 15 species in total can be found in the almost 10 Mio. km² of Siberia as delineated in the TDWG scheme (Hollis & Brummitt 1992).

Only few gymnosperm species are found in

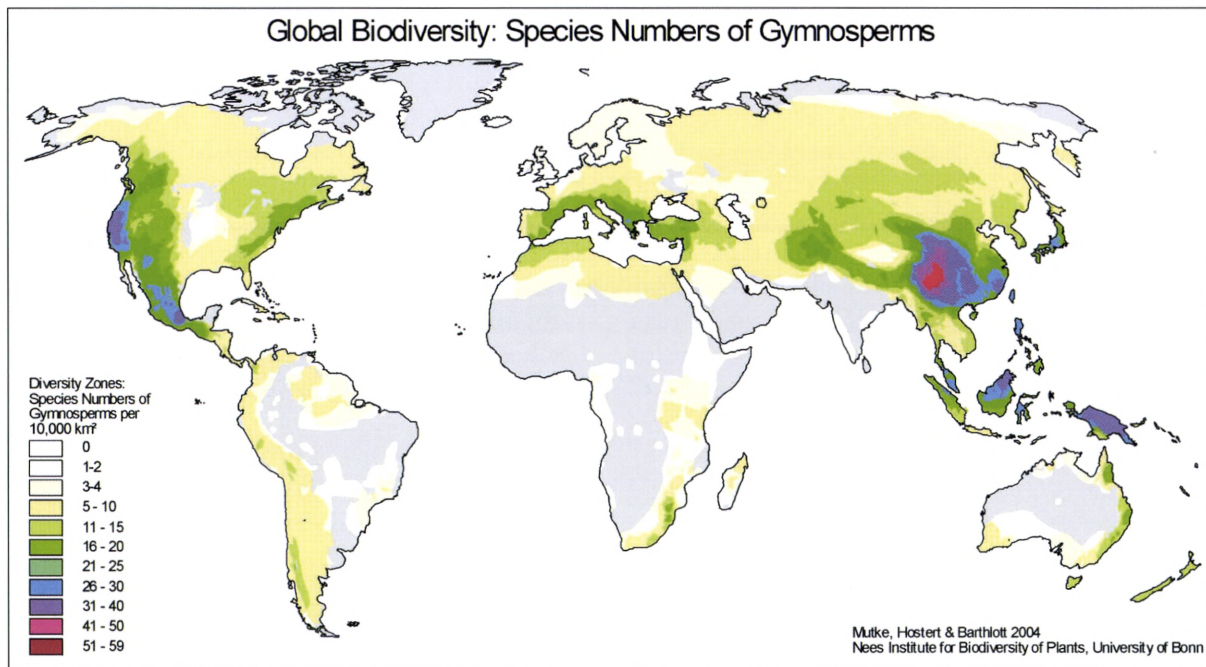


Fig. 4. Global patterns of gymnosperm species richness on area sizes of 10,000 km² (Mutke *et al.* in prep.)

tropical Africa. The whole continent harbours c. 90 species, which are mainly concentrated in southern Africa and the Mediterranean. There are, *e.g.*, only two species documented for West Tropical Africa and less than 15 species in the rainforests of the central Congo basin. Areas without or with very few species are large parts of the Sahara, southern parts of the Arabian peninsula, the western part of the Amazon basin and parts of the Cerrado and Caatinga regions in South America, and the central dry lands of Australia.

Global patterns of fern and bryophyte diversity

The diversity patterns of the approximately 10,000 to 15,000 species of ferns are not as well documented as those of the gymnosperms. There are still many new species to be discovered, especially in the tropical humid mountain forests (see a case study from Bolivia,

Kessler 2001). However, Hassler and Swale (2001) provide statistics on species numbers at regional and national scale based on their “Checklist of World Ferns”. Global maxima of fern species richness seem to coincide with centres of overall vascular plant species richness. At (sub-) continental scale, South America and the area of the Flora Malesiana show highest species richness with 3281 and 3227 documented species, respectively. Highest species numbers at the national scale can be found in China, the tropical Andean countries of Colombia, Ecuador, Venezuela, and Peru, as well as Brazil, Borneo, and New Guinea (Hassler & Swale 2001, after various sources).

Integrating additional data from our own dataset which has been used for the map in Fig. 3, data from Groombridge (Groombridge 1992), and from checklists such as the Flora Europea (Tutin *et al.* 1964-1980) or the PLANTS database (USDA & NRCS 2001),

some general trends become visible. Looking at the well documented fern floras of Europe and North America, there is a clear latitudinal gradient of fern diversity. Total fern species richness per country or state increases both in Europe and North America with decreasing latitude. On the other hand, the proportion of ferns in the overall vascular plant flora decreases, *e.g.*, from c. 5% in the Scandinavian countries to less than 2.5% in southern Europe. In general, the highest proportions of fern species can be found on many oceanic islands with, *e.g.*, more than 10% at the Azores Islands (after data in Tutin *et al.* 1964-1980), or 15 to 20% at the West Indies (Groombridge 1992). Other centres of high fern diversity are humid mountain forests in the tropics and subtropics. At the eastern slopes of the Peruvian Andes, the proportion of fern species in the total vascular plant flora is about 15% (after Young 1991). In contrast, low fern diversity with regard to total species numbers and the ratio to the overall vascular plant flora can be found especially in arid regions of Africa and the Middle East with, *e.g.*, only 12 fern species documented from Egypt (Hassler & Swaile 2001, after various sources). However, it is also interesting that South Africa – together with China the most important non-tropical centre of vascular plant diversity – shows only moderate fern diversity. Though having at least 380 fern species (Groombridge 1992), this is only slightly more than 1.6% of the overall vascular plant flora.

Unfortunately, the documentation of patterns of bryophyte diversity is still very incomplete. A few years ago, a world checklist of mosses with 12,800 accepted names was published (Crosby *et al.* 1999). There are some national and regional checklists such as the List of Mosses of China by Redfearn (Redfearn 1994), the LATMOSS catalogue of Neotropical Mosses (Delgadillo *et al.* 1995), or the list for Sub-Saharan Africa (O'Shea 1997). Though

these lists allow some floristic comparisons, the overall known distribution of bryophyte species still reflects a pattern of research intensity rather than a pattern of genuine diversity (Fig. 5). The unrealistically low figure of only eight documented species in Benin (O'Shea 1997), or two species known from the Bolivar state of Colombia (Churchill & Linares C. 1995), reveals the lack of adequate available information on mosses. At the regional scale, total species numbers for mosses as, *e.g.*, more than 3,500 documented species in South America (Delgadillo *et al.* 1995), 2,800 in Tropical Africa (O'Shea 1997), 2,500 in China (Redfearn 1994), 1,320 species in North America (Vitt & Buck 1992), and around 1,400 species in Europe (Frahm, pers. comm.), might give a first idea about the magnitude of diversity.

Biodiversity vs. geodiversity: Large scale trends of vascular plant diversity

Looking at the diversity of landscapes or ecosystems, one can differentiate between their biological diversity and their geodiversity – the diversity of abiotic parameters like topography, climate, or soils (Barthlott *et al.* 1996, 2000; Faith & Walker 1996; Jedicke 2001; Braun *et al.* 2002).

Diversity patterns of vascular plants are correlated with different measures of geodiversity (Barthlott *et al.* 1996, 2000). Global centres of vascular plant diversity coincide with highly geodiverse areas in the tropics and subtropics. In addition to the spatial heterogeneity, absolute values of limiting parameters are important. In cold and temperate zones high correlation can be found, *e.g.*, with potential evapotranspiration (PET), mean annual temperature, or the length of the thermal vegetation period (Fig. 7). 78% of the spatial variation of species richness of North American ecoregions is statistically explained by PET and

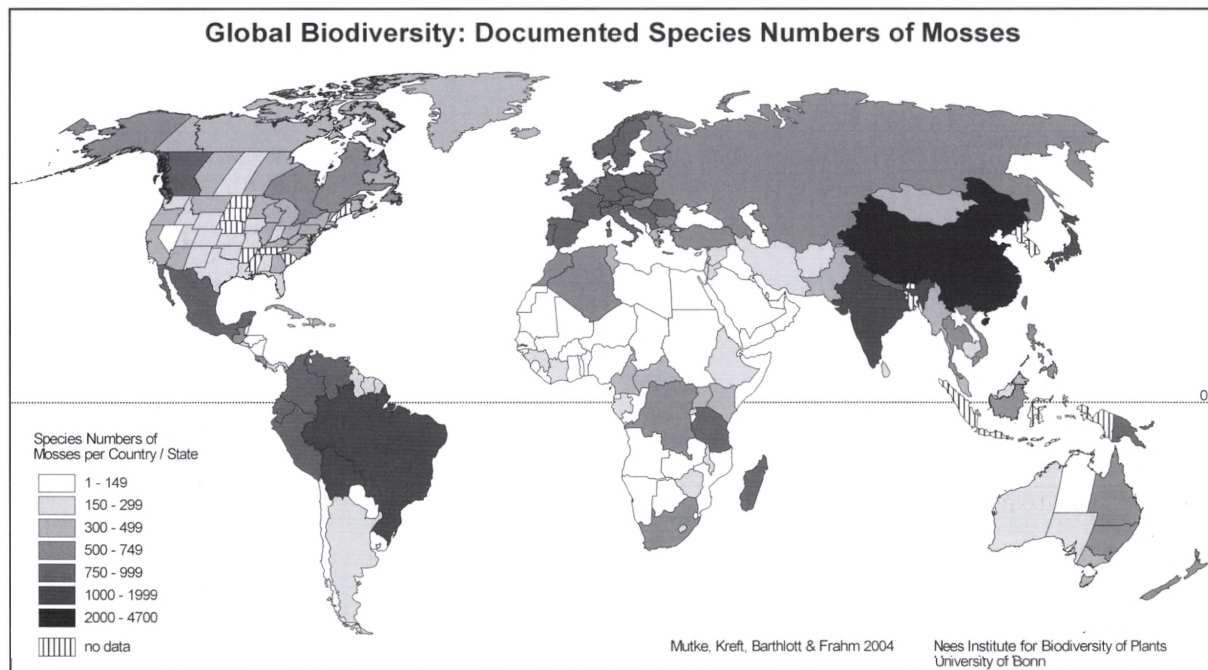


Fig. 5. World map of species richness of mosses as documented in literature (Mutke et al., in prep., after various sources). Please note that total species numbers per country/state are given without referring to a standard area.

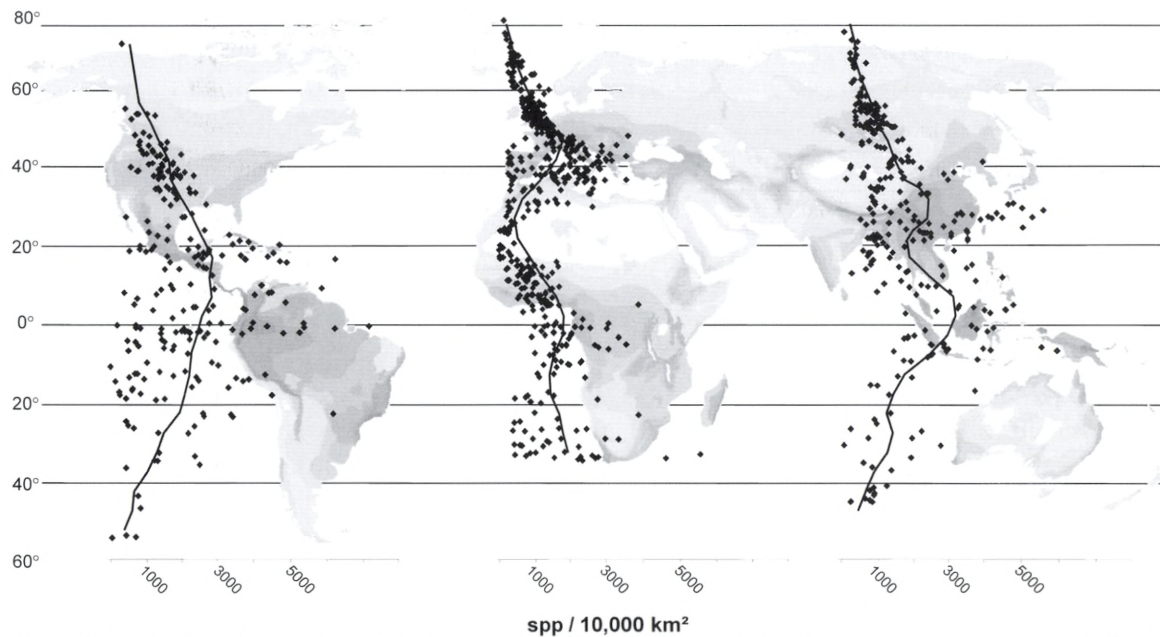


Fig. 6. Latitudinal gradients of vascular plant species richness (Mutke 2002). Each dot represents one operational geographic unit used as raw data for the map in Fig. 3. Mean species number per 10,000 km² is plotted against latitude of the geographic midpoint of the operational unit.

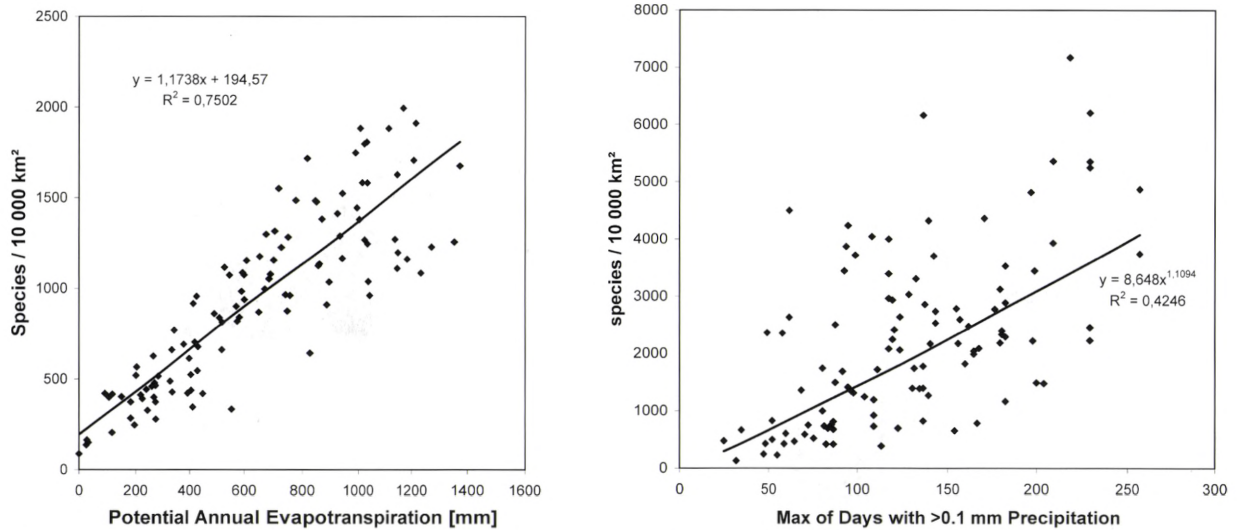


Fig. 7. Statistical relationship of vascular plant species richness to climatic parameters. Species richness of a) North American ecoregions vs. mean potential evapotranspiration within each ecoregion, b) South American operational units vs. maximum number of days with precipitation (Mutke 2002 and Mutke *et al.* in press, based on CRU climate data by New *et al.* 1999).

topodiversity (Mutke 2002). For the Neotropics (Fig. 7) and Africa we found close correlation, *e.g.*, to water balance, topodiversity and a negative correlation to different aspects of seasonality (Mutke *et al.* 2001; Mutke 2002). However, important centres of species diversity and endemism can only be explained to a minor degree on the basis of today's climate without taking the history of the floras into account. This has been documented, *e.g.*, for the South African Cape region by Cowling and Procheş (in this publication). At the global scale, Jansson (2003) showed that number of endemics per country can be explained by climatic stability of a given area.

There has always been – and still is – a vivid discussion, to which degree current environment on the one hand, and its history on the other hand, shapes the biodiversity of a given area. McGlone (1996) argues that the most important process for diversity patterns at regional to continental scale – speciation – acts far too slowly in comparison to historic climatic

changes to shape a given flora on the basis of the current climate. Many papers in this volume show how current diversity of different taxa has been developed during their evolutionary history. On the other hand, especially during the last decade, many analyses have been published that document correlations between current climate and total diversity of various groups of organisms (Lauer & Frankenberg 1979; Currie & Paquin 1987; Linder 1991; Currie 1991; Woodward & Rochefort 1991; O'Brien 1993, 1998; Carroll & Pearson 1998; Wohlgemuth 1998; Mutke 2000; Rahbek & Graves 2001; Kerr *et al.* 2001; Olff *et al.* 2002; Mutke *et al.* 2001; Mutke 2002; Francis & Currie 2003). McGlone (1996) argues that this relationship is found because current and past climates of an area are often correlated. In contrast, Tuomisto and Ruokolainen (1997), Kerr and Currie (1999), and Hawkins and Porter (2003) argue that in most analyses current environmental parameters, especially the climate, show more consistent relations and

stronger statistical correlations to species richness patterns than historical factors do. With a process-based modelling approach, Kleidon and Mooney (2000) tested the performance of a large number of theoretical plant functional types under different climates at a global scale. Using a $2.8 \times 2.8^\circ$ grid, their map of growth strategy diversity reproduces most of the important trends and centres of plant diversity shown in Fig. 3. This led them to the conclusion that constraints imposed by the physical environment may be a dominant force in shaping the observed species richness patterns.

Strongest correlation of climatic parameters and species diversity can be found where there is one important limiting factor, i.e., energy or water. This is the case in Europe and North America where influence of frost, a restriction of the thermal vegetation period, or energy availability in general are strong predictors of plant species richness. Further south, where energy is abundant, water availability becomes more important. A good example is the gradient from the West African moist forests to the Sudanian savannahs, the Sahel, and the Sahara, showing an increasing limitation and seasonality of the water available on the one hand and decreasing plant species diversity on the other hand. In these areas with strong climatic gradients in a more or less north-south direction, a strong correlation of plant diversity with latitude can be found (Fig. 6). This correlation is relatively tight, e.g., in Europe and northern Africa, where important features like the Alps, the Mediterranean Sea, or the Sahara are oriented in east-west direction. The resulting low spatial heterogeneity of the climate per latitudinal belt seem to explain to some extent the low variation of species richness at a given latitude. In contrast, the Sierra Madre in Central America and the South American Andes with their mainly North-South direction cause great climatic differences, especially of the water balance, within

single latitudinal belts. This might be the most important factor for the high variance of species densities of Central and South American geographical units compared to Europe and northern Africa. The fact that the graph presented for the Americas in Fig. 6 resembles the one published for New World birds by Gaston (2000) might serve as an indication that this variation is more than an artefact based on uneven sampling of the respective floras.

Comparing the diversity patterns of different groups of plants and animals

If we want to understand the patterns of overall biodiversity, we have to know, how diversity patterns of various groups of organisms coincide. At the global scale, Barthlott *et al.* (1999b) demonstrated that there is close correlation between vascular plant species numbers per country and vertebrate richness ($R^2=0.73$, $n = 124$) and between vascular plant and insect diversity ($R^2=0.93$, $n = 14$; based on insect data published by Gaston 1996). However, animal diversity is often closely related to structural diversity of the vegetation instead of plant species richness, at least in small study plots (e.g., Pianka 1967). The comparison of Figs 3 and 5 shows important differences between diversity patterns of the main groups of land plants, while important centres like SE Asia coincide. This is especially true when looking at the diversity patterns of smaller sub-groups, e.g., within the gymnosperms (Mutke *et al.* in prep.). These differences are very important for priority setting analyses for conservation purposes. In the past, many of these analyses were based on single groups of organisms (e.g., Balmford *et al.* 2001). Trying to incorporate the maximum of floristic as well as of faunistic diversity in the proposed protected areas unfortunately results in much larger areas needed. This is especially true, if patterns of endemism differ between these groups.

Quality of biodiversity

An important question for the evaluation of biodiversity patterns is: which aspect of biodiversity is measured? Barthlott *et al.* (1999c) discussed a list of possible indicators. The most important are species number, different measures of rarity including endemism, phylogenetic or taxonomic diversity, intactness of ecosystems and species composition, relevance for ecosystem functioning, and current and potential economic value.

As shown in Fig. 8, diversity patterns might change considerably with taxonomic level. Centres of species richness of cacti are located, *e.g.*, in Mexico, SW U.S.A., and the Bolivian

Andes. On the other hand, areas like the Brazilian Caatinga, Cuba, or Southern Central America are more important at the genus level (Barthlott *et al.* in prep.). Though often correlated, there might be important differences between patterns of species richness and endemism (Kier & Barthlott 2001). Qian and Ricklefs (1999), Mutke and Barthlott (2000) and Mutke (2002) have shown for the United States that different measures such as species richness, family richness, endemism, percentage of rare species or of non-natives result in considerably different spatial patterns. This has important implications for conservation planning.

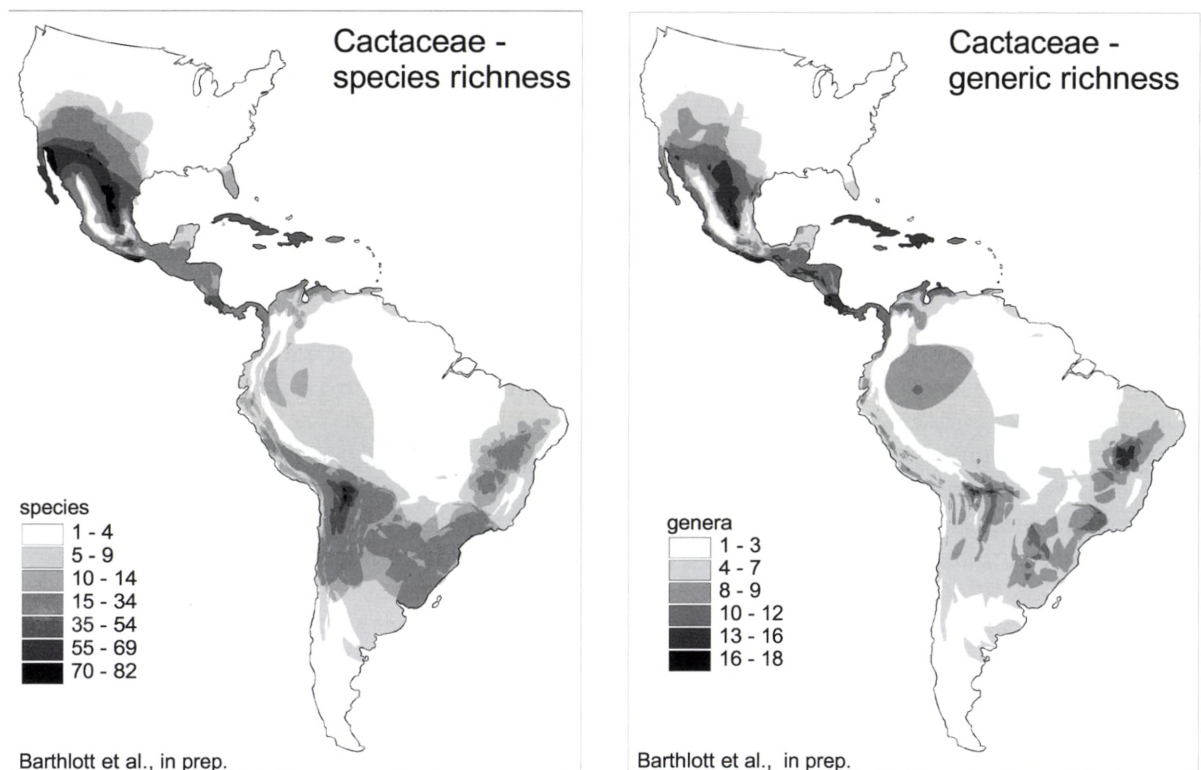


Fig. 8. Comparing diversity patterns at different taxonomic levels. Species richness and generic richness of Cacti in the new world (after Barthlott *et al.* in prep.).

Human impact on biodiversity

Since the early 1990s, the threat to global biodiversity has played an increasingly important role in political discussions. The Convention on Biological Diversity, which was one result of the Earth Summit in Rio de Janeiro 1992, obliges the member countries to protect biodiversity and support further research on this topic. It was also in the 1990s that the international environmental NGOs started large scale priority setting programmes to focus conservation action. Most prominent examples are the Endemic Bird Areas (EBAs) and Important Bird Areas (IBAs) of Birdlife International (Bibby *et al.* 1992; Stattersfield *et al.* 1998), the Biodiversity hotspots by N. Myers and Conservation International (Myers 1988; Myers *et al.* 2000) and the Ecoregion approach and Global 200 programme of the WWF (Olson & Dinerstein 1998; Olson *et al.* 2001).

Due to the simplicity of the main messages, the hotspots approach has been very popular in political discussions. The basic approach was to search for areas containing at least 0.5% of global plant diversity being endemic to that area and with a loss of 70% or more of its primary vegetation (Myers *et al.* 2000). An important reason for the frequent use of hotspots in public discussion is probably that the main centres are so evident that only details would change if the methodologies for identifying the hotspots were changed. This is shown, *e.g.*, in Fig. 9 which compares the hotspots as published by Myers *et al.* (2000) with areas with more than 3000 species per 10,000 km² (on the basis of Fig. 3) and higher than mean human impact as measured by the "human footprint index" of Sanderson *et al.* (2003).

An important drawback of these approaches is that areas without centres of diversity but with other unique features are completely neglected. To include highest complementar-

ity of floras, faunas, and ecosystems, one approach is, *e.g.*, to include at least one region per biome and biogeographic realm in the selection, as done for the Global 200 programme of the WWF (Olson & Dinerstein 1998).

On regional to continental scales increasingly more data have become available for complementarity analyses on the basis of detailed species list, *e.g.*, per 1° grid cells (Küper *et al.* 2004; Linder *et al.* 2005) or ecoregions (Krupnick & Kress 2003).

Kirkpatrick (1983) described the first systematic algorithm for area selection for nature conservation based on species distribution data (Pressey 2002), and such algorithms have since been further developed and, *e.g.*, incorporated in the now widely used WORLDMAP computer programme (Williams 1997).

It is quite clear that analyses with spatial resolutions of 1° or referring to large scale ecoregions are still far from applicable at the scales where most of the practical work of nature protection is done. However, analyses by Bibby *et al.* (1992), Davis *et al.* (1994-1997), Olson and Dinerstein (1998), Myers *et al.* (2000) and others have drawn attention not only to areas where biodiversity is most threatened, but also to the problems of conserving the biodiversity of our planet in general.

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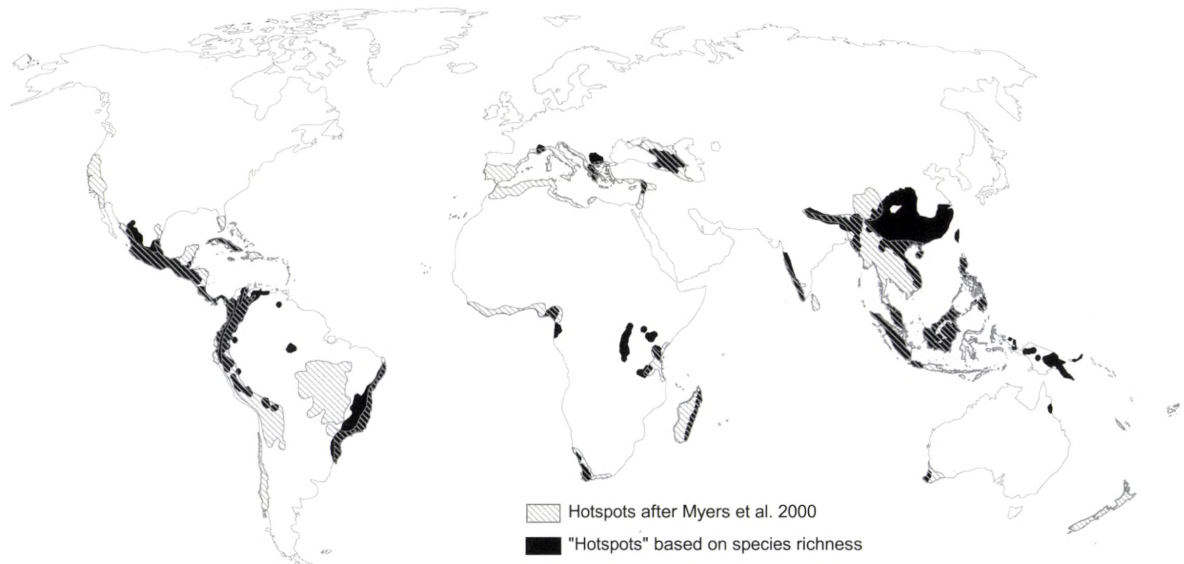


Fig. 9. Two versions of "hotspots": Biodiversity hotspots after Myers et al. (2000) compared to areas with at least 3000 species/10,000 km² (based on Fig. 3) and higher than mean human impact (based on the "human footprint index" after Sanderson et al. 2003).

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