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GEOGRAPHIC PATTERNS OF VASCULAR PLANT DIVERSITY AT CONTINENTAL TO GLOBAL SCALES

With 4 figures, 2 tables and 1 supplement (III)

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Biodiversität, Geodiversität, Makroökologie, Artenreichtum, Hotspots, Naturschutzkonzepte

Zusammenfassung: Geographische Muster der Gefäßpflanzenvielfalt im kontinentalen und globalen Maßstab

Dokumentation und Verständnis der Muster der Diversität von Organismen sind zentrale Gegenstände der Biogeographie und Makroökologie. Kenntnisse über die Verteilung von Biodiversität sind ebenfalls eine wesentliche Voraussetzung für ihren Schutz und ihre nachhaltige Nutzung. In den letzten Jahren sind durch die Verfügbarkeit großer Verbreitungsdatensätze, methodische Fortschritte und die Entwicklung leistungsfähiger Software große Fortschritte in der Kartierung großräumiger geographischer Gradienten von Artenreichtum und Endemismus auf kontinentalem und globalem Maßstab erzielt worden. Im vorliegenden Beitrag werden Analysen zu globalen Verbreitungsmustern von Gefäßpflanzen, insbesondere auch von Gymnospermen vorgestellt. Anhand des Modellkontinents Afrika wird gezeigt, wie biogeographische Daten als Grundlage für die Erstellung kleinmaßstäbiger Karten zur Entwicklung überregionaler Schutzstrategien genutzt werden können.

Summary: Documenting and understanding patterns of biodiversity is a central issue in biogeography and macroecology. Knowledge about the distribution of biodiversity is also a central prerequisite for its sustainable use and conservation. Due to a greater availability of distribution data, methodological advances, and software tools, important progress has been made during the last decade to map broad-scale geographic gradients of plant species richness and endemism at continental to global scales. In this paper, we provide an overview about recent advances made in this field. We present studies that analyze global-scale diversity patterns of gymnosperms and all vascular plants. Exemplarily for the model continent Africa, we show how biogeographic data can be used to develop broad-scale conservation strategies.

1 *Introduction*

Geographic patterns of species richness are a focal issue in biogeography and macroecology. They have attracted enormous interest since the early nineteenth-century naturalists like Alexander von Humboldt or Alfred Russel Wallace set out to discover remote parts of the world. An important question in this context is why some places contain more species than others. Over the last decades, this question has led to a plethora of different causal hypotheses which try to explain the apparent differences in the spatial distribution of species richness and endemism across the globe (e.g. Pianka 1966; Schall a. Pianka 1978; Ricklefs 1987; Rohde 1992; Palmer 1994; Kerr a. Packer 1997; Kerr a. Currie 1999; Gaston 2000; Kerr 2001; Francis a. Currie 2003; Hawkins et al. 2003a; Ricklefs 2004; Wiens a. Donoghue 2004; Sarr et al. 2005; Mutke in press). Apart from being one of the fundamental questions in biogeography, macroecology, and biodiversity research, the answer to this question is also essential in order to understand and predict consequences of global change for the distribution of biological diversity and finally to halt the loss of biodiversity (e.g. Whittaker et al. 2005; Brooks et al. 2006). In the last decade, considerable progress has been made towards the documentation of continental to global patterns of plant species richness. In the present paper we give an overview about developments in this field. Furthermore, we show how these data can contribute to the development of broad-scale conservation strategies.

2 *Plant diversity: mapping approaches and data sources*

Generally, approaches to produce species richness maps fall under two different categories. First, in taxon-based approaches distributional information of single species or higher-order taxa is collected. Distributional information may be derived from gridded maps (Humphries et al. 1999; Kühn et al. 2003), from locality data of natural history collections (Linder 1998a; Crisp et al. 2001; Linder 2001; Küper et al. 2004; Küper et al. 2006), or from expert-drawn polygon maps (Kreft et al. 2006). Especially the latter data source has been extensively used in the last decade to document and analyze broad-scale patterns of vertebrate richness (Rahbek a. Graves 2001; Jetz a. Rahbek 2002; Hawkins et al. 2003b; Jetz et al. 2004; Stuart et al. 2004; Ceballos et al. 2005; Orme et al. 2005;

Lamoreux et al. 2006; Orme et al. 2006). Continental maps of vascular plant species richness using the taxon-based approach are available for Africa (Linder 1998a; Lovett et al. 2000; Linder 2001; Küper et al. 2006), Europe (Humphries et al. 1999), and Australia (Crisp et al. 2001). These studies use a portion of the flora of 10%, 20% and 50%, respectively. However, as pointed out further below, this approach inevitably involves issues of unequal sampling activity and taxonomic bias. The former inherently leads to an underestimation of species' geographic ranges. At a global scale, a taxon-based approach has currently not been used due to a lack of digital information from Natural History Collections. Secondly, inventory-based approaches use information about the diversity, in most cases numbers of species and endemics of a region that is documented in the literature (like, e.g., local and regional floras, checklists). To date, the inventory-based approach represents the only possible way to document and analyze plant diversity at a global scale (compare Kier et al. 2006 for a detailed discussion of different mapping approaches).

Documenting the spatial distribution of biodiversity has a long tradition and is a central goal of biogeography. The first global vegetation maps such as the Berghaus Atlas (Berghaus 1837–1847) already used the Humboldtian statistics to show numbers of known species for different regions. To our knowledge, Wulff (1935) was the first scientist who published a map of species richness of vascular plants with a fully global coverage (Fig. 1). His map is based on species richness figures referring to ca. 140 geographic regions and recognizes five diversity zones. However, since these regions differ in size, super-regional comparisons of species numbers were hardly possible. Nevertheless, the map provided evidence for the extraordinary high diversity of several tropical regions. The map published in 1975 by the Russian botanist Malyshev represents an important advance in the documentation of global plant species richness since it is the first giving standardized species numbers with a global coverage. His data set consisted of ca. 400 species richness figures which were standardized at 100,000 km^2 using a species-area model. In 1996, we published a world map of global plant diversity based on a considerably larger data set and hence displaying diversity patterns in much higher detail in Vol. 50 of Erdkunde (Barthlott et al. 1996). The data basis for this map consisted of ca. 1,000 geographic regions and species number were standardized at 10,000 km^2 using the species-area model of Lebrun (1960). Final delineation of ten diversity zones between <100 and >5,000 spp./10,000 km^2 applied a semi-quantitative, expert-based approach, where data gaps were filled based on comparisons with data on putative co-variates of species richness, like, e.g., temperature, rainfall, or topography. All centres of plant richness (>5,000 spp. per 10,000 km^2) that were identified in this study are situated in spatially heterogeneous regions of the humid tropics and subtropics. The observation that topographically complex parts of the humid tropics carry the maximum of biodiversity is owed to Alexander von Humboldt. In 1845 he wrote in his Kosmos: "Die dem Äquator nahe Gebirgsgegend […] von Neugranada […] ist der Teil der Oberfläche unseres Planeten, wo im engsten Raum die Mannigfaltigkeit der Natureindrücke ihr Maximum erreicht." (The mountainous region of Neugranada [nowadays: Columbia] near the equator is the part of earth's surface where the variety of natural impressions [nowadays, one would say "biodiversity"] reaches its maximum on a very small area.) (Humboldt 1845–1858, 12). It was also von Humboldt who first described the increasing number of species with closer proximity to the equator (Hawkins 2001), a pattern that is today well documented for various kinds of organisms and well known as the 'latitudinal gradient of species richness', the underlying causes and mechanisms of which are still heavily debated (Rohde 1992; Hillebrand 2004).

Since the publication of our first world map in 1996 (Barthlott et al. 1996), we extensively expanded the underlying data set. It contains now more than 3,300 species richness figures derived from floras, local and regional checklist, and other literature sources referring to more than 1,800 suitable geographic regions. Because geographic regions differ in size, their species numbers were standardized using the species-area relationship by Arrhenius 1921 and empirically calculated z-values. Standardized richness estimates were then used to delineate diversity zones. Interpolation into unsampled areas was performed using additional geographic data like, e.g., temperature, rainfall, vegetation, and topography. For detailed discussion about the methodology compare Barthlott et al. 1999; Mutke 2002a, b; Barthlott et al. 2005; Kier et al. 2005; Mutke a. Barthlott 2005; Kier et al. 2006.

3 *Global patterns of plant species richness*

Due to the expanded data base and new GIS-based techniques, the map (Suppl. III) provides a much more detailed picture of the distribution of plant richness than all earlier attempts (Wulff 1935; Malyshev 1975; Barthlott et al. 1996; Kier 1998; Barthlott et al. 1999). A clear latitudinal increase of species numbers towards the equator is apparent. This broad trend is differentiated in all parts of the earth by mountainous regions which are characterized by generally higher species richness than the surrounding lowland areas when referring to the chosen standard area of 10,000 km^2. Interestingly, not all tropical regions are necessarily richer in plant species than subtropical or temperate ones. For instance, parts of Central Europe harbour higher species richness than tropical areas like, e.g., the Venezuelan Llanos, the Caatinga, or the West African rainforests. Regions with minimum species richness are found in desert regions and in high arctic tundra.

There are only 20 global centres where species richness of vascular plants is higher than 3,000 spp./10,000 km^2 (Fig. 2). Most of these centres are located in mountainous regions of the humid tropics. Only five centres surpass 5,000 species per 10,000 km^2 (Costa Rica-Chocó, Tropical Eastern Andes, Atlantic Brazil, Northern Borneo, New Guinea) (BARTHLOTT et al. 1996; BARTHLOTT et al. 1999; BARTHLOTT et al. 2005). Table 1 summarizes specific features of these regions. The five maxima cover only approximately 0.2% of the terrestrial surface of the world. Nevertheless, more than 6% of all vascular plant species are endemic to these centres.

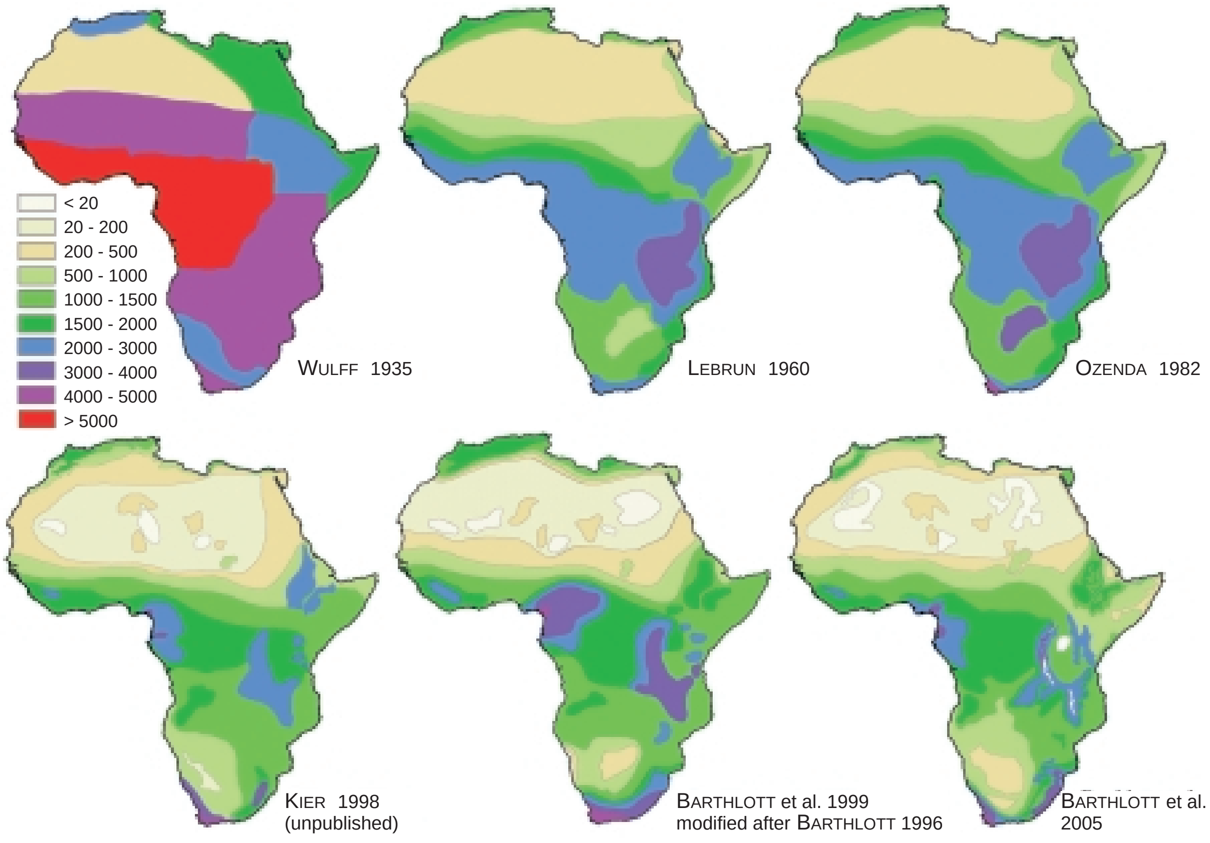


Fig. 1: Historical evolution of maps displaying plant species richness patterns in Africa. Apart from the map of WULFF (1935), which indicates the total species richness of the displayed areas, the maps show species richness per standard area of 10,000 km^2. All maps are inventory-based and to a varying degree rely on expert-opinion. The same legend of ten classes as displayed was applied to all maps

Historische Entwicklung der Kartierung großräumiger Muster der Phytodiversität Afrikas. Mit Ausnahme der Karte von WULFF (1935), welche Angaben zu den Gesamtartenzahlen unterschiedlich großer Regionen enthält, zeigen die anderen Karten Artenzahlen pro 10.000 km^2. Alle Karten beruhen auf dem inventarbasierten Ansatz und beziehen in unterschiedlichem Maß Experten-Schätzungen als Datengrundlage mit ein

Table 1: The five global centres of plant diversity with >5,000 spp. per 10,000 km^2

Die fünf globalen Megadiversitätszentren mit >5.000 Arten pro 10.000 km^2

	Centre	Area (km^2)	Total spp.[1]	Endemism spp.	Endemism %	Elevation (m a.s.l.)	WWF Biomes[2]	% protected[3]
1	Costa Rica-Chocó	78,000	≥12,500[a]	5,500[a]	44%	0–3,800	1; 2; 14	18.8%
2	Tropical Eastern Andes	62,000	10,000[b]	3,000[b]	30%	250–3,500	1; 10	19.1%
3	Atlantic Brazil	50,000	≥ 6,000[c]	4,500[c]	75%	0–2,8000	1; 7	6.3%
4	Northern Borneo	57,000	9,000[d]	3,500[d]	39%	0–4,100	1; 10;14	7.7%
5	New Guinea	87,000	≥ 6,000[e]	2,000[e]	33%	0–4,500	1; 10	1.8%
	Total	**334,000**		**18,500**				
	% of world's total	**0.2%**		**6.2%**				

[1] Figures for total species number and endemism represent conservative estimates after various sources (Myers 1988; Groombridge 1992; Davis et al. 1997; Jørgensen a. León-Yánez 1999):

[a] La Amistad Biosphere Reserve = 10,000 spp., 3,000 endemic spp. (Davis et al. 1997), plus endemic species of the Chocó Department: 2,500 spp. (Myers 1988).

[b] Baseline Ecuadorian Andes >1,000 m = 9,865 spp. (Jørgensen a. León-Yánez 1999); 3,040 national endemic plants in the Ecuadorian Andes (Valencia et al. 2000): minus W-Andes endemics, plus narrow endemics of Peru and Colombia.

[c] Mountain ranges of Rio de Janeiro: 5,000–6,000 spp., 75% endemism (Davis et al. 1997).

[d] Northern Borneo 9,000 spp., 3,510 endemic spp. (Myers 1988).

[e] Bismarck Falls, Ramu, Mt. Otto, Mt. Wilhelm: 5,000–6,000 spp. (Groombridge 1992), 30 % endemism estimated (considering that estimated endemism for whole New Guinea ranges between 55 and 90% (Myers 1988; Groombridge 1992).

[2] WWF Biomes (after Olson et al. 2001): (1) Tropical moist broadleaf forest; (2) Tropical and subtropical dry broadleaf forest; (7) Tropical and subtropical grasslands, savannas and shrub lands; (10) Montane grasslands and savannas; (14) Mangroves.

[3] Portion of the centre which is protected according to IUCN categories I–IV (after *World database on protected areas* (*UNEP and IUCN* 2003)).

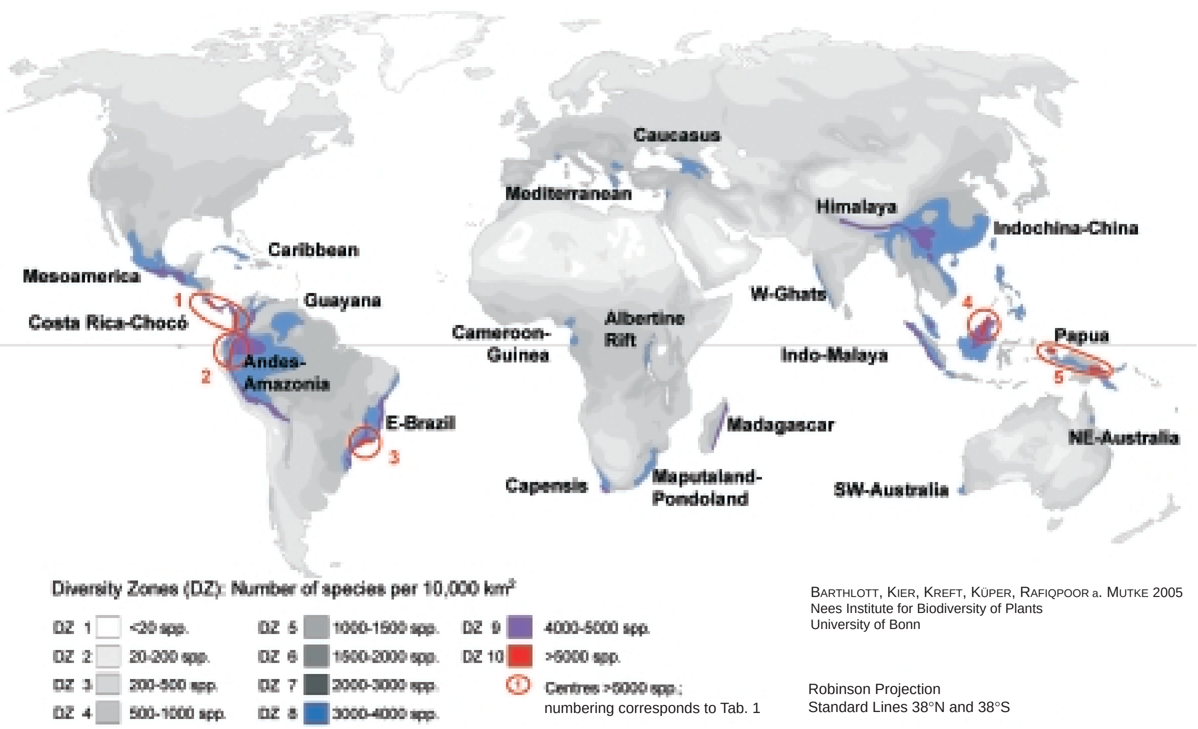
[4] Baselines for world's total: terrestrial earth's surface = 144.5*10^6 km^2; global species number of vascular plants = 300,000 spp.

4 Geodiversity – the diversity of the abiotic environment

As a driving factor of the patterns described above, 'geodiversity' as the diversity of abiotic factors within an area is of particular relevance (Barthlott et al. 1996; Barthlott et al. 1999). Many of the metrics belonging to the standard repertoire of biodiversity research (e.g. alpha, beta, gamma diversity; rarity, evenness) could be applied to analyze geodiversity. Furthermore, they could be used to provide a conceptual framework to understand biodiversity–geodiversity–ecodiversity relationships (Barthlott et al. 1999). Geodiversity as the heterogeneity of topography, geology, soils, or climate is a driving mechanism for habitat differentiation of communities and might therefore explain the higher biodiversity in geodiverse regions. For instance, all top five maxima of plant diversity cover altitudinal gradients of at least 2,800 meters (cf. Tab. 1). Furthermore, contemporary climate is a strong predictor of species richness (Kreft a. Jetz 2007). Energy-related variables such as potential evapotranspiration, the number of frost days or mean annual temperature show particularly high correlations with plant richness at higher latitudes (Mutke a. Barthlott 2005; Mutke et al. 2005; Kreft a. Jetz 2007). In the thermally more suitable tropics, on the other hand, factors like mean annual precipitation, actual evapotranspiration or the number of days per year with rainfall show much a closer relationship with species richness (Mutke a. Barthlott 2005; Kreft et al. 2006; Kreft a. Jetz 2007).

5 Patterns of gymnosperm diversity

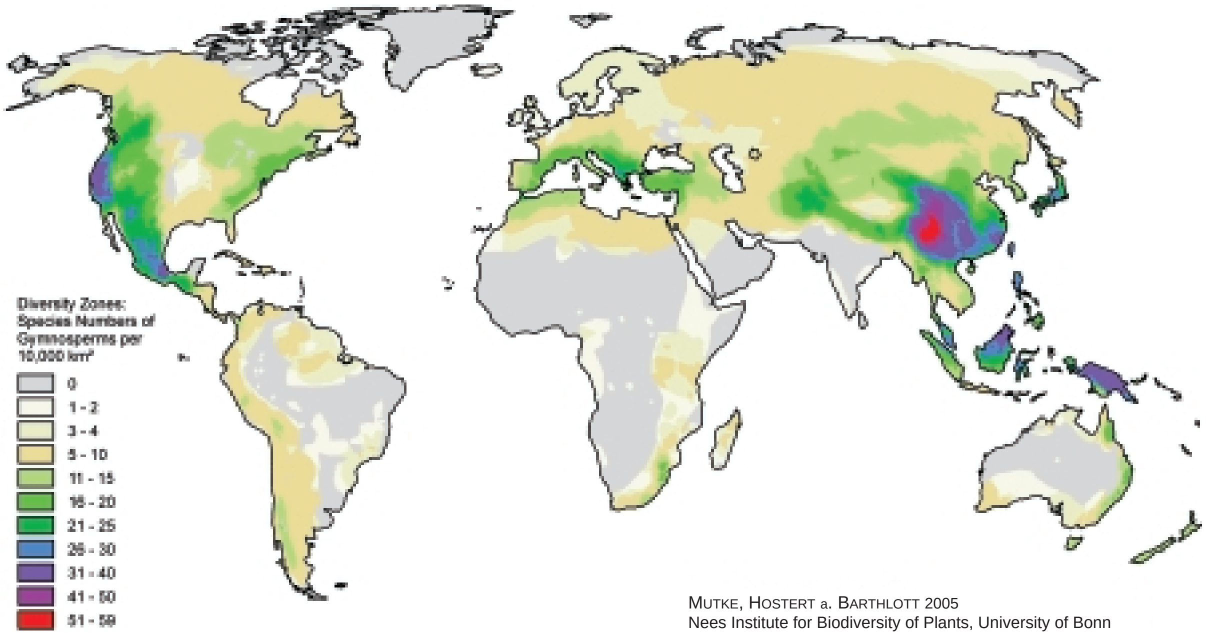
For the analysis of the factors that drive species richness of plants it might be rewarding to map the diversity of different ecological (e.g., epiphytes, carnivorous plants) or taxonomic groups (e.g., ferns, gymnosperms, monocots). In this context, we (Hostert 2002; Mutke a. Barthlott 2005) mapped and analyzed the spatial distribution of gymnosperm diversity (Fig. 3). Distribution data for 862 extant species were collected from the literature and digitized in a geographical information system. Compared to overall vascular plant diversity interesting similarities but also striking differences emerge. The most important diversity centres of this ancient group of seed plants are located in SE Asia.



BARTHLOTT, KIER, KREFT, KÜPER, RAFIQPOOR a. MUTKE 2005
Nees Institute for Biodiversity of Plants
University of Bonn

Fig. 2: Global centres of vascular plant diversity. The five centres of megadiversity are highlighted

Globale Zentren der Artenvielfalt von Gefäßpflanzen. Die fünf Megadiversitätszentren sind besonders hervorgehoben



MUTKE, HOSTERT a. BARTHLOTT 2005
Nees Institute for Biodiversity of Plants, University of Bonn

Fig. 3: Global map of gymnosperm diversity based on the distributional ranges of 862 species (number of species per 10,000 km²)

Weltkarte der Gymnospermen-Diversität auf der Basis der Verbreitungsgebiete von 862 Arten (Arten pro 10.000 km²)

This area shows a very high overall diversity of vascular plants at species level as well as at higher taxonomical levels and is an important centre for various subgroups of land plants (MUTKE a. BARTHLOTT 2005). These patterns suggest an important role of historical influences for the high biodiversity of this region (cf. e.g., QIAN a. RICKLEFS 2000; RICKLEFS et al. 2004). Within SE Asia, the region of Yunan and Sichuan with its great topographical and climatic heterogeneity exhibits the highest species density with more than 50 gymnosperm species per 10,000 km^2. Mount Kinabalu in Northern Borneo harbours almost 30 gymnosperm species within an area of only 1,200 km^2 (compare http://herbarium.lsa.umich.edu/kinabalu and BEAMAN 2005) – with half of them only documented for Borneo in our dataset. With up to almost 40 gymnosperm species per 10,000 km^2, New Caledonia and New Guinea also exhibit impressive gymnosperm diversity. Another region with high species richness is situated in the New World in parts of California and Mexico where more than 30 species occur per 10,000 km^2. Within the Mediterranean basin, parts of the Balkans are important local centres of European gymnosperm diversity with more than ca. 20 species per unit area. Furthermore, regions with up to 20 gymnosperm species per 10,000 km^2 are found in East Australia, Tasmania, in the South African Drakensberg Mountains and in some parts of the Andes. Tropical parts of Africa and South America seem to have an impoverished gymnosperm flora. The whole African continent has slightly more than 100 species, which are mainly concentrated in Southern Africa and the Mediterranean parts of North Africa. Especially dry regions like, e.g., in India, Saudi Arabia, the Sahara, and Central Australia, as well as tropical humid parts of West Africa and the Amazon basin, are free of gymnosperm species. Boreal conifer forests of Eurasia and North America are structurally dominated by gymnosperms. Nevertheless, the gymnosperm diversity is relatively poor and only reaches ca. 5–10 species per 10,000 km^2 (MUTKE a. BARTHLOTT 2005).

6 Continental patterns of plant diversity – Africa as model continent

In many respects, Africa suits as a model continent for macroecological and biogeographical approaches. First of all, it is a continent for which, compared to other (sub-)tropical regions, good floristic data are available. Moreover, the continent covers a wide range of climatic gradients between the Mediterranean parts in the North and South and the core tropics. Climatic gradients follow a North-South direction and vegetation belts are thus broadly latitudinally arranged. The East African tropical mountains provide an opportunity to analyze the effect of geodiversity on biodiversity, and, together with the Western African lowland rainforests, the influence of isolation and their potential as refuge areas under historically shifting climate regimes. Analyses of continental patterns of African plant diversity have been carried out in the framework of the BMBF BIOTA Programme (www.biota-africa.org) and are another example for a taxon-based biodiversity mapping approach. In contrast to the inventory-based approach used for the analysis of global biodiversity patterns, this approach is based on distribution records of individual species that allow more in-depth analyses of various diversity aspects. Building upon species collection data derived from taxonomic revisions, herbarium specimens, or field collections, the BIOTA Information System on African Plant Diversity (BISAP) has been established and consolidated for the sub-Saharan Africa jointly with cooperation partners (LINDER 1998b; LOVETT et al. 2000; LINDER 2001; LA FERLA et al. 2002; KÜPER et al. 2004; LINDER et al. 2005; KÜPER et al. 2006). It currently comprises distribution data for more than 6,500 vascular plant species, which is 10–15% of the African Flora. Linked to environmental and land cover data bases of regional to global extent such as described, for example, by MITCHELL et al. (2004) or MAYAUX et al. (2004) it facilitates a wide range of analyses related to species distributions, centres of diversity and endemism, and their determinants.

Distribution data can be used to display documented diversity patterns simply by counting species occurrences per unit area. However, they suffer from data inconsistencies, and the available data provide an incomplete impression of the existing patterns due to taxonomical and geographical bias in the data set (KÜPER et al. 2006). To mitigate effects of incomplete representation of the geographic ranges by the available species locality data, environmental niche models and geostatistical approaches are used to estimate the potential overall distribution ranges of species (e.g. MCCLEAN et al. 2005). For this purpose, the environmental parameters at the documented species occurrence localities are measured. The relevance of the different environmental parameters as determinants for the occurrence of individual species is then geostatistically tested to identify the combination of abiotic parameters (a so called bioclimatic envelope) that statistically explains best the environmental conditions within a species' range. Prominent parameters for plant species distribution at a broad scale are, amongst others, factors related to moisture and solar energy, as, e.g., precipitation and

Table 2: Comparative performances of three area sets of equal size to cover the sub-Saharan African centres of plant diversity (after Küper et al. 2004)

Vergleichende Darstellung von drei verschiedenen Gebietsauswahlen mit insgesamt gleicher Flächengröße, die die subsaharischen Zentren der Artenvielfalt abdecken (nach Küper et al. 2004)

	Sub-Saharan Africa	Myers Hotspots		Redefined Hotspots		Near-minimum-cost set	
	Total	Total	%	Total	%	Total	%
One-degree cells	1,713	125	7.3	125,0	7.3	125,0	7.3
All species	5,985	3,841	64.2	4,759	79.5	5,196	86.8
Restricted-range	1,540	802,0	52.1	1,011	65.6	1,155	75.0
Range-size rarity (sum)	5,985	2,354	39.3	2,955	49.4	2,603	43.5
Human footprint (sum)	33,965	3,040	–	3,420	–	2,215	–
Human footprint (average)	19.8	24.3	–	27.4	–	17.7	–

The following sets are compared: the hotspots as defined by Myers et al. (2000), a redefined set of hotspots identified on the basis of distribution data for 5,985 plant species, and a near-minimum-cost area set on the basis of the same data. In order to compare the sets, all have been rescaled to a one-degree based grid of 1,713 cells covering Africa south of 17° N latitude. The comparison is based on four criteria: (i) overall number of species covered; (ii) number of restricted range species covered; (iii) cumulative range-size rarity for the included cells; and (iv) human footprint (sum and average for the included cells, based on Sanderson et al. 2002). Note that the aim of hotspot sets is to cover the most threatened centres of plant diversity (represented by high values for both plant diversity and human footprint). In contrast, the near-minimum-cost area set is based on a heuristic algorithm (Williams et al. 1996) that seeks to cover all species in cells with a human footprint as low as possible. Percentages indicate the proportion of the respective total values for sub-Saharan Africa. The plant data stem from the Biogeographic Information System on African Plant Diversity (BISAP) representing 10%–15% of the species of the sub-Saharan African flora.

potential evapotranspiration. The envelope is then projected on maps with environmental conditions across the continent, showing potential geographic ranges for species. This method allows giving estimates of potential species richness even for areas with scarce or no available distribution data. The resulting maps of documented and potential species richness show areas with high documented species richness, while others which have similar climate, as in the central Congo Basin, do not appear rich in species mainly due to insufficient data availability. These data gaps can be closed when potential species richness is mapped (Küper et al. 2006).

Apparently, when compared to patterns of vertebrate diversity (see Balmford et al. 2001; Brooks et al. 2001; Burgess et al. 2002; Jetz a. Rahbek 2002; de Klerk et al. 2004; Fjeldså et al. 2004; Jetz et al. 2004; Küper 2005; Burgess et al. 2006), centres of plant diversity coincide with those for other groups in the afrotropical mountains and the West African lowland rainforests. All of them are characterized by high humidity with no distinct dry period, pronounced historical climate stability, and highly structured vegetation. In addition, each taxonomic group has specific needs and peculiarities and its own evolutionary history. For this reason, centres of diversity for some groups do not necessarily correspond with those of other groups. Most apparent in this context is the extraordinarily high plant species richness in the South African Cape region where it forms its own floristic kingdom (Küper 2005).

The description of patterns and distribution of biodiversity are the indispensable prerequisite for the development and evaluation of concepts for its conservation. The hotspot analysis of Norman Myers and Conservation International (Myers et al. 2000; Mittermeier et al. 2005) has drawn much attention in the last years and has increased the focus of conservation efforts towards hotspot areas, using expert opinions as a data basis. Accordingly, we tested the hotspots on the basis of empirical plant distribution data for sub-Saharan Africa, identifying areas with extraordinary high human impact that are as well centres of plant species richness (Küper et al. 2004). On a grid-cell basis, it can be clearly shown that many areas in the West African tropics, the East African tropical mountains, and in southern Africa are in fact hotspots under this definition (Tab. 2, Fig. 4). However, several equally suitable areas had not been included in the Myers hotspots published in 2000. A revised version of the hotspots includes all of the proposed areas (Mittermeier et al. 2005).

The development and evaluation of conservation concepts have to account for the fact that an increasingly large proportion of the natural habitats is being anthropogenically converted, and that global climate

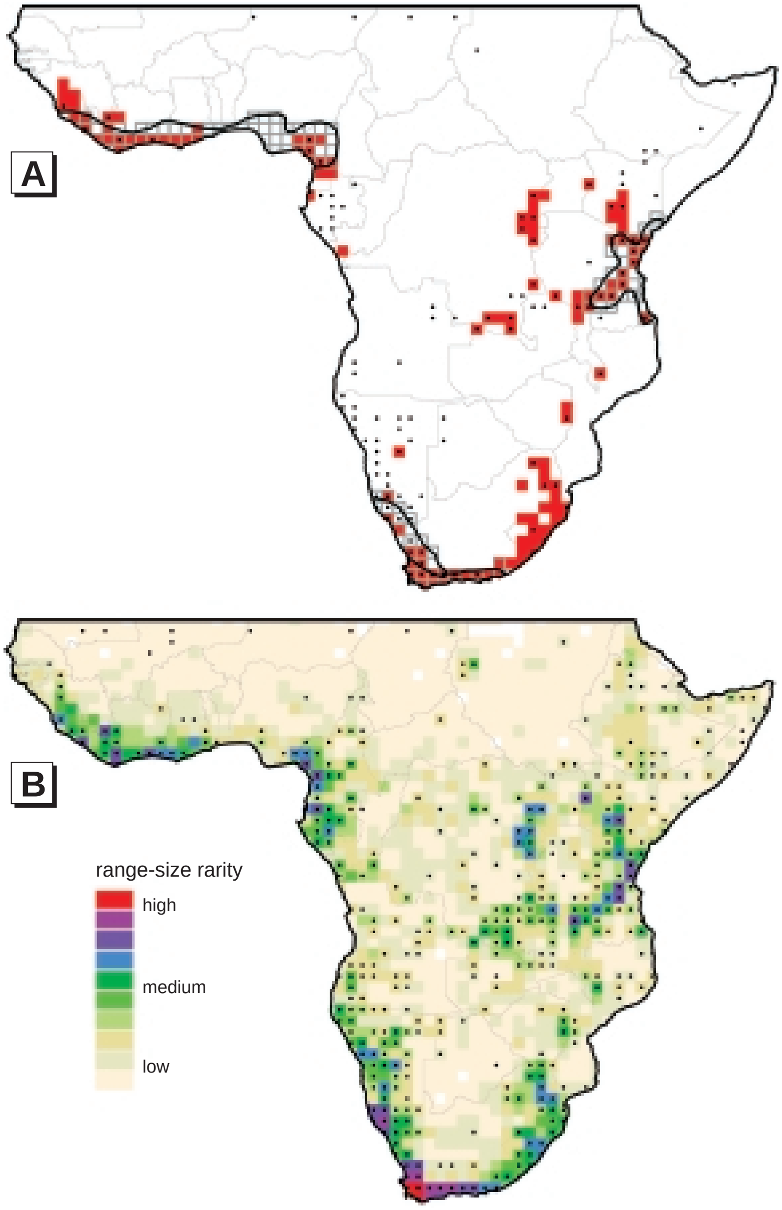


Fig. 4: **A:** Map of the set of redefined hotspots for the Sub-Saharan Africa identified by KÜPER et al. (2004), contrasted with the hotspots as delineated by MYERS et al. (2000). The original Myers hotspots (125 one-degree grid cells) are delineated by grey open squares. Red squares: 125 cells covered by the redefined hotspots of KÜPER et al. (2004) (cells with highest product of range-size rarity and human footprint (SANDERSON et al. 2002) per cell). Black dots represent areas (compare Tab. 2) that together cover a maximum total number of species on an area that is restricted to exactly 125 cells in total (near minimum-area set); compare Tab. 2). **B:** Map of range-size rarity per one-degree grid cell after KÜPER et al. (2004). This measure combines the values for richness and the range sizes of the species occurring in each cell. It is calculated as the sum of the inverse range sizes per cell (WILLIAMS et al. 1996). Black dots mark 422 cells that form the near-minimum-cost area set for sub-Saharan plant diversity in the data set. These cells represent all 5,985 plant species in a set with a total human footprint as low as possible. The figure shows Africa south of 17° N latitude with grey background lines indicating national boundaries

A: Karte der neu definierten Hotspots für das sub-saharische Afrika (nach KÜPER et al. 2004), überlagert mit den Hotspots (graue offene Rasterzellen) von MYERS et al. (2000). Die 125 ausgefüllten roten Rasterzellen sind von KÜPER et al. als Gebiete mit höchstem Endemitenanteil und gleichzeitig stärkstem anthropogenen Einfluss identifiziert worden. Schwarze Punkte markieren die Kombination von 125 Zellen (vgl. Tab. 2), die zusammen eine maximale Gesamtzahl von Pflanzenarten repräsentieren (*near-minimum-area set* (vgl. Tab. 2)). **B:** Karte der *range-size rarity* (Index der Seltenheit und Artenzahlen kombiniert) pro 1°-Raster nach KÜPER et al. (2004). Die 422 schwarzen Punkte repräsentieren die Kombination von Rasterzellen, die alle 5.985 Pflanzenarten repräsentieren und gleichzeitig von Menschen so wenig wie möglich beeinflusst sind. Die Karte gibt Afrika südlich des 17. Breitengrades wieder. Die Ländergrenzen sind grau dargestellt change will further increase the pressure on species and their geographic ranges. Within the next century, severe shifts in the distribution of species are predicted, leading to a decrease of biodiversity in the majority of areas (McClean et al. 2005).

7 Concluding remark

The progress of the last decade towards a better documentation and understanding of broad-scale patterns of plant diversity is evident. Much of the progress is due to the greater availability of distribution data, new statistical and computational tools and, importantly, due to the awareness that knowledge about spatial diversity patterns is central for the sustainable use and conservation strategies under scenarios of impending global change. The Global Strategy for Plant Conservation (GSPC) under the UN Convention on Biological Diversity (UNCBD) explicitly asks as one of its 16 targets to protect 50% of the most important areas for plant diversity by 2010. The great challenge for biogeographers now is to provide biodiversity information that is detailed and comprehensive enough to understand the historical and contemporary processes and parameters shaping current patterns of plant diversity, and to support sustainable conservation planning at broad scale.

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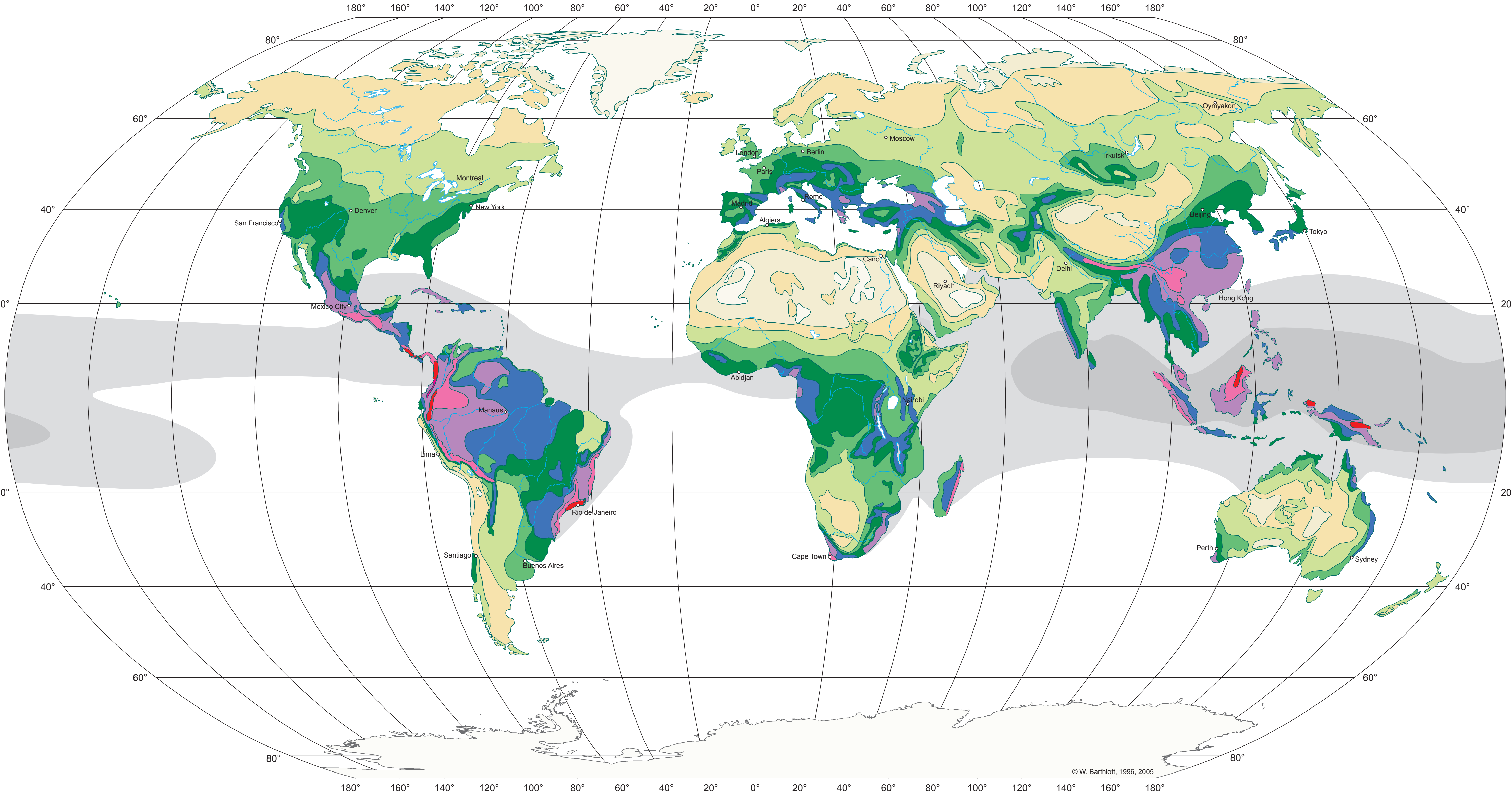
Supplement III to ERDKUNDE 61, 4 Article Barthlott, Hostert, Kier, Kreft, Küper, Rafiqpoor, Mutke, Sommer

GLOBAL BIODIVERSITY: SPECIES NUMBER OF VASCULAR PLANTS



Robinson Projection
Standard Lines 38°N and 38°S

Diversity Zones (DZ): Number of species per 10 000 km^2

⬜ DZ 1 (<100)
⬜ DZ 2 (100 - 200)
🟨 DZ 3 (200 - 500)
🟩 DZ 4 (500 - 1000)
🟩 DZ 5 (1000 - 1500)
🟩 DZ 6 (1500 - 2000)
🟦 DZ 7 (2000 - 3000)
🟪 DZ 8 (3000 - 3500)
🟪 DZ 9 (4000 - 5000)
🟥 DZ 10 (>5000)

sea surface temperature

⬜ > 27°C
⬜ > 29°C

W. Barthlott, G. Kier, H. Kreft, W. Küper,
D. Rafiqpoor & J. Mutke 2005
modified after
W. Barthlott, W. Lauer & A. Placke 1996
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