

## Change in the woody floristic composition, diversity and structure from protected to unprotected savannahs in Pendjari Biosphere Reserve (Benin, West Africa)

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### Abstract

Savannahs are widespread vegetation type in Sudanian zone of Africa. As protected areas are often assumed to be the best way to conserve biodiversity, we assessed the effectiveness of the Pendjari Biosphere Reserve in Benin, for maintaining savannah woody species composition, diversity and structure. Square plots of 900 m<sup>2</sup> were randomly established in protected and surrounding unprotected savannahs, and all woody species (dbh  $\geq$  1 cm) were recorded and identified. Species composition, Importance Value Index, densities, basal area and diversity indexes were assessed in relation to conservation status. The results showed that DCA based on presence/absence species data did not separate clearly protected savannahs from unprotected ones. However, some species were prominent in unprotected savannahs while others showed the same scheme in protected ones. Diversity indexes indicated a good distribution of species in the two savannah types. The woody density showed a higher value in protected than unprotected savannah at shrub layer level. The basal area was significantly higher in the protected savannah than unprotected one at the two woody layer levels. It can be concluded that biodiversity conservation in surrounding unprotected areas should be of great importance to increase biodiversity conservation by protected area whether specific actions were implemented.

*Key words:* conservation, diversity, savannah, structure, woody species

### Résumé

Les savanes sont un type de végétation très répandu dans la zone soudanienne de l'Afrique. Étant donné que les aires protégées sont supposées être la meilleure façon de préserver la biodiversité, nous avons évalué l'efficacité de la Réserve de biosphère de la Pendjari, au Bénin, pour ce qui est du maintien de la composition des espèces ligneuses de la savane, leur diversité et leur structure. Des parcelles carrées de 900 m furent établies au hasard dans l'aire protégée et dans les savanes non protégées voisines, et toutes les espèces ligneuses (dbh 1 cm) furent enregistrées et identifiées. La composition des espèces, l'Indice de valeur d'importance, la densité, l'aire basale et les indices de diversité furent évalués par rapport au statut de conservation. Les résultats ont montré que la DCA basée sur des données portant sur la présence/absence d'espèces ne séparait pas clairement les savanes protégées de celles qui ne l'étaient pas. Cependant, certaines espèces étaient prédominantes dans les savanes non protégées alors que d'autres l'étaient dans les savanes protégées. Les indices de diversité indiquent une bonne distribution des espèces dans les deux types de savane. La densité ligneuse montrait une valeur supérieure dans la savane protégée que dans la savane non protégée au niveau de la strate arbustive. L'aire basale était significativement supérieure dans la savane protégée que dans la savane non protégées aux deux niveaux des strates ligneuses. On peut en conclure que la conservation de la biodiversité dans les aires voisines non protégées devrait être considérée comme très importante pour améliorer la conservation de la biodiversité d'une aire protégée où des mesures spécifiques ont été appliquées.

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## Introduction

All over the world, human survival depends on biodiversity (Singh, 2002) and therefore its conservation becomes fundamental. Several strategies such as the protected area setting, their effective management, the achievement of conservation measures outside the protected areas to restore biodiversity in degraded habitats, are fulfilled (Primack, 2008). Among these strategies, the most effective is probably the establishment of protected areas, due to the large amounts of biodiversity that it preserves (Maiorano, Falcucci & Boitani, 2008; Abellán *et al.*, 2011). However, this effectiveness is not always achieved. Moreover, many kinds of environmental changes influence or determine processes that can both increase and erode diversity (Sheil, 1999). Those changes mainly concern exploitation through selective harvest and commercial logging, seasonally set forest fires, fuel wood removal and charcoal production, grazing of cattle, pruning and land clearing for agricultural activities (Ramirez-Marcial, Gonzalez-Espinosa & Williams-Linera, 2001; Reyers, 2004; Banda, Schwartz & Caro, 2006). These disturbances are reported as influence factors of forest structure (Bhuyan, Khan & Tripathi, 2003; Sagar, Raghubanshi & Singh, 2003; Banda, Schwartz & Caro, 2006), its woody diversity (Sagar & Singh, 2005; Makana & Thomas, 2006) and woody species composition (Sagar, Raghubanshi & Singh, 2003) in tropical areas. In addition, quantification based on woody species is an important aspect when studying disturbance impact on forest structure. Indeed, woody species is a dominant life form which provides resources and habitat for many animal species and is easy to count (Condit *et al.*, 1996; Cannon, Peart & Leighton, 1998; Sagar, Raghubanshi & Singh, 2003).

Pendjari Biosphere Reserve in Benin like other National Parks in Africa was set up primarily to protect wildlife mainly the big mammals as these latter maximize the financial return of reserves. It is also assumed that protecting large mammals is an appropriate surrogate for conserving all biodiversity, including plants (Banda, Schwartz & Caro, 2006). Therefore, it might be necessary to test whether such protected area contributes effectively to conserve the forest attributes such as structure, woody species composition and diversity. Indeed, from some past studies (Vermeulen, 1996; Shackleton, 2000; Banda, Schwartz & Caro, 2006; Paré *et al.*, 2009), protected areas

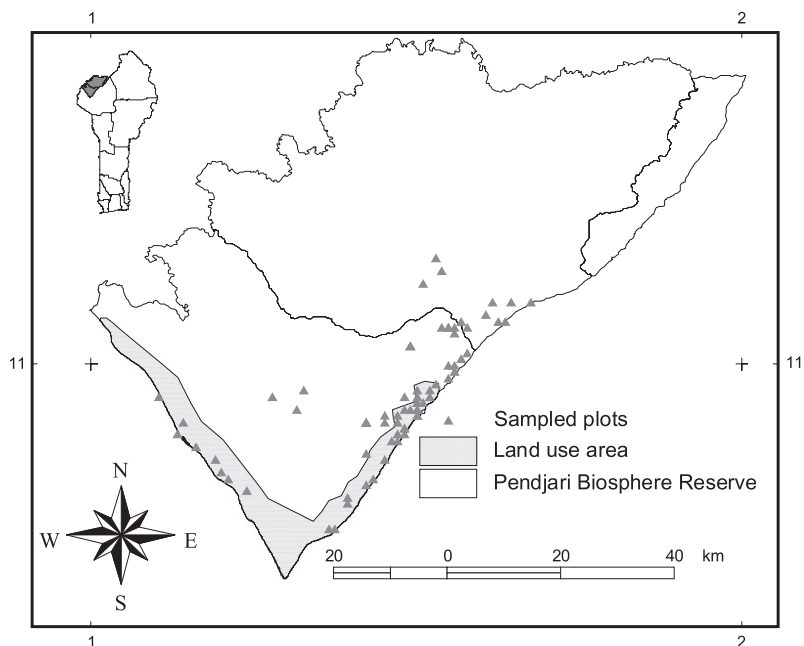
do not necessarily conserve the greatest diversity of plant species. While other studies (Bhuyan, Khan & Tripathi, 2003; Sagar, Raghubanshi & Singh, 2003; Sahu, Sagar & Singh, 2008) have proved the opposite.

In addition, savannahs constitute one of the largest biomes of the world, comprising about 20 per cent of the land surface and most of them occur in Africa (Shorrocks, 2007). Savannahs are a resource for food, medicine, timber and livestock breeding (Bellefontaine, Gaston & Petrucci, 1997). Thus, they are subjected to much degradation, and their conservation is important in the process of biodiversity conservation. To conserve them, it is required to know how its attributes such as woody species composition, diversity and structure behave facing degradation. Therefore, this study was carried out in order to check whether Pendjari Biosphere Reserve contributes to conserve effectively woody structural characteristics, diversity and species composition of savannahs.

## Materials and methods

### Study system

The study was carried out in the Pendjari Biosphere Reserve (10°30'–11°30'N and 0°50'–2°00'E), a protected area located in the extreme north-western part of Benin (West Africa) and in its surrounding land-use areas (Fig. 1). It was established since 1986 and covers 4666.4 km<sup>2</sup> including Pendjari National Park (2660.4 km<sup>2</sup>), Pendjari hunting zone (1750 km<sup>2</sup>) and Konkombri hunting zone (251 km<sup>2</sup>). The climate is tropical with an average annual, unimodal rainfall of 1100 mm. The rainy season starts in April or May, followed by a dry season from November to March. In the PBR, savannahs are the widespread vegetation type, and anthropogenic activities are prohibited. However, savannahs, in surrounding open access land, are set up sometimes on unfit land for agriculture and are subjected highly to human disturbance such as selective logging and cutting; pruning and firewood extraction. Inside and outside the protected area, the soils are mainly ferruginous. The reserve is set up on a peneplain with a flat relief with the presence of large isolated hills and floodplains. The Atakora mountain chain (400–513 m above sea level) occupies its southern part, with stones and unfitted land for agriculture. Several large mammals are encountered in the PBR and benefited some particular attention. The main species are *Syncerus caffer planiceros*, *Hippotragus equines*,



**Fig 1** Localization of study area and sampled plots

*Alcelaphus buselaphus major*, *Kobus kob*, *Sylvicapra grimmia*, *Ourebia ourebi*, *Tragelaphus scriptus*, *Phacochoerus aethiopicus*, *Papio anubis*, *Cercopithecus aethiops*, *Hippopotamus amphibius*, *Panthera leo*, *Acinonyx jubatus*, *Panthera pardus*, *Loxodonta africana* etc. Some of these species could be encountered sometimes in surrounding unprotected zone. In this latter area, conservation activities focused on wildlife are implemented and aimed at controlling the small hunting.

#### Sampling and data collection

Thirty five square plots of 900 m<sup>2</sup> were established randomly in each savannah type (protected and unprotected). Within each plot, every woody individual with a diameter at breast height (dbh)  $\geq 1$  cm was measured for dbh and identified. Plant names and authorities were checked in database of the International Plant Name Index (IPNI) through the link: [www.ipni.org](http://www.ipni.org). Data were collected during the period from July to September.

#### Data analyses

For each plot, the number of species, stem density, basal area and diversity indexes were calculated. These indices were Shannon–Wiener's diversity index, Shannon's measure of evenness and Margalef's index (Magurran, 2004).

As surveys based solely on large and medium-sized tree species were not able to always reflect the overall woody diversity (Tchouto *et al.*, 2006), we considered two woody layers (tree layer dbh  $\geq 10$  cm and shrub layer 10 cm  $>$  dbh  $\geq 1$  cm) when calculating the above-mentioned parameters. In the shrub layer, tree and shrub species were also recorded.

Two-way ANOVA was performed to examine whether the computed vegetation attributes vary in relation to savannah conservation status and vegetation layer. Thus, the number of species, the stem density and the basal area per plot were log-transformed before the analysis. The combinations of savannah conservation status variants (protected and unprotected) and those of vegetation layer (shrub and tree layer) were compared by a Tukey test. Univariate statistical analyses were performed with Statview.

Multivariate Detrended Correspondence Analysis (DCA) was used to explore the variation of woody floristic composition across savannah types in PCORD.5. From output of DCA, we calculated the Importance Value Index (IVI) for each inventoried species in each of group defined by DCA. IVI was calculated as the sum of relative dominance, relative density and relative frequency. The matrix obtained was subjected to Principal Component Analysis (PCA) using Community Analysis Package (CAP). Jaccard's similarity index was used for assessing

$\beta$ -diversity among the two savannahs (protected and unprotected).

## Results

### Woody species composition

The two savannah types yielded a total of 58 species representing 44 genera and 23 families. A complete list of species and their code are provided in appendix 1. The most abundant families are Combretaceae (17%), Mimosoideae (10%), Caesalpinioideae (10%), Rubiaceae (10%), Meliaceae (7%) and Anacardiaceae (7%). The two savannah types shared most of their common woody species, and the pattern of DCA (Fig. 2) indicated three groups of plots score (one group composed exclusively of plots from protected savannahs, one group composed exclusively of plots from unprotected savannahs and mixed group composed of plots from the two savannah types). The similarity in woody species composition between the two savannah types was 67%. Using IVI values of species, the first two axes of principal component analysis (Fig. 3) saved 95% (63.27% with axis 1 and 31.73% with axis 2) of variation in species composition. The projection of the

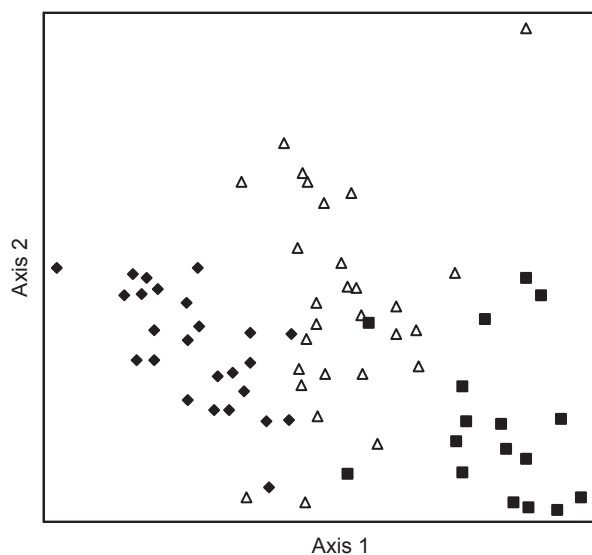


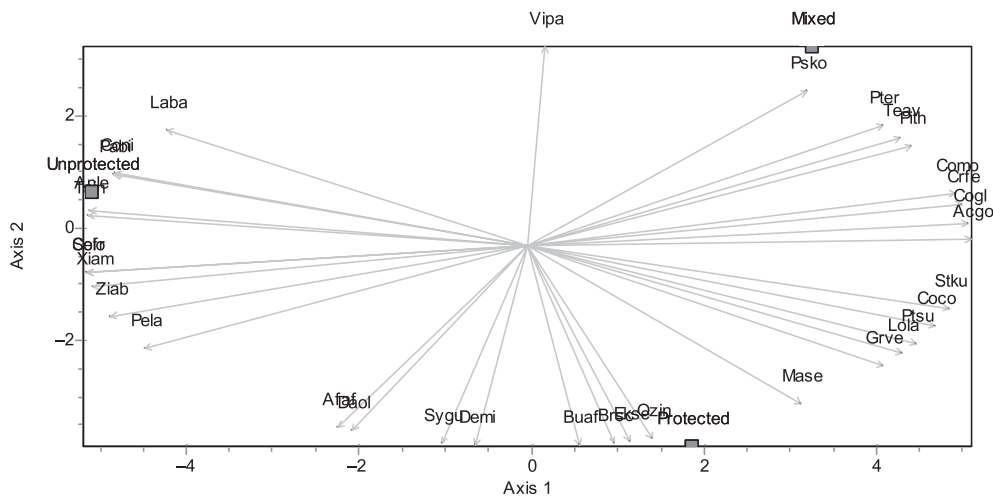
Fig 2 Plot scores projection onto axes 1 and 2 of Detrended Correspondence Analysis on woody species composition (from left to right : exclusive plots of unprotected savannas, plots of mixed group and exclusive plots of protected savannas). Total inertia: 3.3; Eigenvalue of Axis 1: 0.30; Eigenvalue of Axis 2: 0.18

three precedent groups defined by the DCA, in the axes system obtained from PCA showed that the first axis discriminated the groups of species with high IVI values from those of low ones in unprotected savannah. Thus, species such as *Parkia biglobosa* (Jacq.) R.Br. ex G. Don, *Lannea barteri* Engl., *Anogeissus leiocarpa* Guill. & Perr., *Securidaca longepedunculata* Fresen., *Tamarindus indica* L., *Ximenia americana* L., *Ziziphus abyssinica* Hochst. ex A. Rich. and *Combretum nigricans* Leprieur ex Guill. & Perr. had high IVI values in unprotected savannahs, while *Acacia gourmaensis* A. Chev., *Pteleopsis suberosa* Engl. & Diels, *Lonchocarpus laxiflorus* Guill. & Perr., *Stereospermum kunthianum* Cham., *Grewia villosa* Willd. and *Maytenus senegalensis* (Lam.) Exell showed the opposite scheme in the same habitat. The second axis separated the group composed exclusively of plots of protected savannahs, from one mixed group. These plot groups are linked with species that had high IVI values in each of them. Thus, *Vitellaria paradoxa* C.F. Gaertn., *Bridelia scleroneura* Müll. Arg., most of *Combretum* species, *Crossopteryx febrifuga* Benth., *Piliostigma thonningii* (Schumacher) Milne-Redh, *Pseudocedrela kotschyii* Harms, *Terminalia avicennioides* Guill. & Perr. and *Pterocarpus erinaceus* Poir. had high IVI values in mixed plot group. However, *Azelia africana* Sm., *Burkea africana* Hook., *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, *Detarium microcarpum* Guill. & Perr., *Ekebergia senegalensis* Fuss., *Lannea barteri* Engl., *Ozoroa insignis* Delile, *Pericopsis laxiflora* (Benth. ex Baker) Meeuwen and *Syzygium guineense* Guill. & Perr. had high IVI values in protected savannahs.

### Species diversity and structural characteristics

Species richness per plot did not differ significantly between savannah types while the difference was significant at layer level of each savannah type (Table 1). Diversity indexes indicated a good distribution of species in the two savannah types. However, in unprotected savannahs, the diversity was higher at shrub layer level than at tree one.

A total of 1106 and 916 woody individuals were recorded, respectively, in protected and unprotected savannahs. The woody density per plot was significantly higher in protected savannahs at shrub layer level while the difference was not significant at tree layer. As far as, the basal area is concerned significant higher values were found in the protected savannah compared with the unprotected one at the two layer levels (Table 1).



**Fig 3** Projection of woody species and plot score group in the system axes of Principal Correspondence Analysis using Importance Value Index values of species. The plot score groups were defined previously by the DCA and were unprotected, mixed and protected groups. The meaning of abbreviations and species list are provided by appendix 1

**Table 1** Structural characteristics and diversity of savannahs (protected and unprotected) in relation to layer (tree and shrub) in Pendjari Biosphere Reserve. Values of a line, followed by a same letter (a or b), are not significantly different while those followed by different letters are significantly different. (in bracket, we are the number of plots)

	Protected savannahs (35)		Unprotected savannahs (35)		P-value		
	Shrub layer : dbh < 10 cm	Tree layer (dbh ≥ 10 cm)	Shrub layer : dbh < 10 cm	Tree layer (dbh ≥ 10 cm)	Savannah status (SS)	Vegetation layer (VL)	SS*VL
Species richness (S) per plot	8a	4b	8a	4b	0.771	<0.001	0.895
Shannon–Wiener's diversity index ( $H' = -\sum \pi_i \log_2 \pi_i$ )	4.33a	4.30a	4.67a	2.87b	0.853	<0.001	0.313
Shannon's measure of evenness ( $J' = H'/\ln S$ )	0.79a	0.82a	0.87a	0.74a	0.780	0.441	0.107
Margalef's index ( $D_{Mg} = (S-1)/\ln N$ )	7.18a	8.22a	8.10a	5.77b	0.663	<0.001	0.761
Density (plant/ha)	253.65a	95.87b	193.65ab	96.50b	0.129	<0.001	0.040
Basal area (m <sup>2</sup> /ha)	2.03a	19.2b	1.3ba	16.60c	0.215	<0.001	0.883

## Discussion and conclusion

The study revealed that the woody species richness was higher at shrub than tree layer level of each savannah type. However, the woody diversity showed the same trend in solely unprotected savannahs. This suggests disturbance effect on woody diversity at tree layer level. Such effect should be mostly linked to the firewood use that selects adult's tree individuals of some woody species and consequently decreases woody species rich-

ness and diversity. Similar results were reported elsewhere (Bhuyan, Khan & Tripathi, 2003; Sagar, Raghubanshi & Singh, 2003; Sagar & Singh, 2005; Makana & Thomas, 2006) where a significant decrease in woody diversity with the disturbance intensity were reported on various tropical ecosystems. However, we found that diversity indexes indicated a good distribution of species in the two savannah types at shrub layer level. This finding agrees with those one of Banda, Schwartz & Caro (2006) and Paré *et al.* (2009) and suggesting that

surrounding unprotected areas should be of great importance in biodiversity conservation.

The finding according to which, the mean density of woody was higher in conserved savannahs than in the unprotected ones at shrub layer level is consistent with others researches (Bhuyan, Khan & Tripathi, 2003; Sagar, Raghubanshi & Singh, 2003; Makana & Thomas, 2006) undertaken elsewhere. These authors found that the mean stem density of woody was higher in the least disturbed site than in the highly disturbed one. These disturbances concerned mostly the selective cutting of woody for fuel use in the case of our study area. If woody selective cutting have induced shrub density decreasing, this meant also that this activity (i.e. woody extraction for fuel use) threatens seriously biodiversity conservation in this open access land. Therefore, conservation strategies in this latter area must be oriented towards a sustainable use of firewood trees.

As far as the basal area is concerned, we found higher values in the protected savannahs than in the unprotected ones at the two vegetation layers level. This difference of basal area between the two savannah types can be explained by the combined effect of selective logging and cutting. Large size class diameters of some valuable trees are targeted for logging. At the same time, smaller individuals are cut for firewood use. This result is consistent with that of Banda, Schwartz & Caro (2006) who obtained higher value of basal area in Katavi National park (Tanzania) compared with the one in the human-inhabited area. Also Assogbadjo *et al.* (2010) found in Wari Maro forest reserve (centre of Bénin) a significantly higher basal area in woodlands of low anthropogenic pressure than in ones of high pressure.

The woody species richness recorded globally in the study showed the dominance of the Combretaceae, Mimosoideae, Caesalpiniodeae and Rubiaceae families. This floristic trend has been reported by Paré *et al.* (2009) in Burkina and is characteristic of African sudanian savannahs. Considering IVI values as indicator of species dominance, *A. africana*, *B. africana*, *D. oliveri*, *D. microcarpum*, *E. senegalensis*, *L. acida*, *O. insignis*, *P. laxiflora*, and *S. guineense* would be less prominent in unprotected savannahs. This may be explained by the fact that human pressure mostly threatens those woody species and prevent their prominence in unprotected area. Consequently, they should retain particular attention in biodiversity conservation process in this area. This result agrees partially with the finding of Paré *et al.* (2009) who found in Burkina Faso that *O. insignis* was rare in the unprotected dry forest.

*A. africana*, *B. africana* and *D. microcarpum* have been also reported as prominent in woodland stands of low human pressure (Assogbadjo *et al.*, 2010). Other species have high IVI values in unprotected savannahs and may suggest that they are not mostly valued by local people (case of *S. longepedunculata*, *Z. abyssinica* and *C.*) or that these species support mostly human pressure despite their valorization (case of *P. biglobosa*, *L. barteri*, *A. leiocarpa*, *T. indica* and *X. americana*).

Analysis of change of woody species composition in relation with protection status of savannah showed that with increasing demographic pressure and consequently pressure on savannahs, their woody species composition may change. Similarly, Sagar, Raghubanshi & Singh (2003) indicated a variation of woody species composition in relation to disturbance gradient of a tropical dry forest in India.

In conclusion, this study showed that effectiveness of this protected area to conserve savannah structure and woody diversity depends on the woody layer. Woody species composition change in relation to savannah conservation status may be also evident according to interrelation specific-use-species. Thus, implementation of some specific actions could help woody vegetation conservation in surrounding unprotected areas. The main could be the introduction in unprotected area, rapid growth tree species that can be used by local communities for fuel use. Also, local communities could be encouraged to diversify their agroforestry parklands with woody species that are less prominent in unprotected areas.

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## References

- ABELLÁN M.D., MARTÍNEZ J.E., PALAZÓN J.A., ESTEVE M.Á. & CALVO J.F. (2011) Efficiency of a protected-area network in a mediterranean region: a multispecies assessment with raptors. *Environ. Manage.* **47**, 983–991.
- ASSOGBADJO, A.E., GLELE KAKAÏ, R.L., SINSIN, B. & PELZ, D. (2010) Structure of *Anogeissus leiocarpa* Guill., Perr. natural stands in relation to anthropogenic pressure within Wari-Maró Forest Reserve in Benin. *Afr. J. Ecol.*, **48**, 644–653.
- BANDA T., SCHWARTZ M.W. & CARO T. (2006) Woody vegetation structure and composition along a protection gradient in a

- miombo ecosystem of western Tanzania. *For. Ecol. Manage.* **230**, 179–185.
- BELLEFONTAINE, R., GASTON, A. & PETRUCCI, Y. (1997) Aménagement des forêts naturelles des zones tropicales sèches. Cash FAO Conservation 32.
- BHUYAN, P., KHAN, M.L. & TRIPATHI, R.S. (2003) Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodivers. Conserv.* **12**, 1753–1773.
- CANNON C.H., PEART D.R. & LEIGHTON M. (1998) Tree species diversity in commercially logged Bornean rain forest. *Science* **28**, 1366–1368.
- CONDIT R., HUBBELL S.P., LA FRANKIE J.V., SUKUMAR R., MANOKARAN N., FOSTER R.B. & ASHTON P.S. (1996) Species–area and species–individual relationships for tropical trees a comparison of three 50 ha plots. *J. Ecol.* **84**, 549–562.
- MAGURRAN A.E. (2004) Measurement Biological Diversity. Blackwell Science Ltd, London.
- MAIORANO L., FALCUCCI A. & BOITANI L. (2008) Size-dependent resistance of protected areas to land-use change. *Proc. R. Soc. B* **275**, 1297–1304.
- MAKANA J.R. & THOMAS S.C. (2006) Impacts of selective logging and agricultural clearing on forest structure, floristic composition and diversity, and timber tree regeneration in the Ituri Forest, Democratic Republic of Congo. *Biodivers. Conserv.* **15**, 1375–1397.
- PARÉ S., TIGABU M., SAVADOGO P., ODEN P.C. & OUADBA J.M. (2009) Does designation of protected areas ensure conservation of tree diversity in the Sudanian dry forest of Burkina Faso? *Afr. J. Ecol.* **48**, 347–360.
- PRIMACK R.B. (2008) A Primer Of Conservation Biology, 4th edn. Sinauer, Sunderland.
- RAMIREZ-MARCIAL N., GONZALEZ-ESPINOSA M. & WILLIAMS-LINERA G. (2001) Anthropogenic disturbance and tree density in Montane Rain Forests in Chiapas, Mexico. *For. Ecol. Manage.* **154**, 311–326.
- REYERS B. (2004) Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. *Biol. Conserv.* **118**, 521–531.
- SAGAR R., RAGHUBANSHI A.S. & SINGH J.S. (2003) Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *For. Ecol. Manage.* **186**, 61–71.
- SAGAR R. & SINGH J.S. (2005) Structure, diversity, and regeneration of tropical dry deciduous forest of northern India. *Biodivers. Conserv.* **14**, 935–959.
- SAHU P.K., SAGAR R. & SINGH J.S. (2008) Tropical forest structure and diversity in relation to altitude and disturbance in a Biosphere Reserve in central India. *Appl. Veg. Sci.* **11**, 461–470.
- SHACKLETON C.M. (2000) Comparison of plant diversity in protected and communal lands in the Bushbuckridge lowveld savanna, South Africa. *Biol. Conserv.* **94**, 273–285.
- SHEIL D. (1999) Tropical forest diversity, environmental change and species augmentation: after intermediate disturbance hypothesis. *J. Veg. Sci.* **10**, 851–860.
- SHORROCKS, B. (2007) The Biology of African Savannahs. Oxford University Press Inc., New York. 268.
- SINGH J.S. (2002) The biodiversity crisis: a multifaceted review. *Curr. Sci.* **82**, 638–647.
- TCHOUTO M.G.P., DE BOER W.F., DE WILDE J.J.F.E. & VAN DER MAESEN L. J.G. (2006) Diversity patterns in the flora of the Campo-Maan rain forest, Cameroon: do tree species tell it all? *Biodivers. Conserv.* **15**, 1353–1374.
- VERMEULEN S.J. (1996) Cutting of trees by local residents in a communal area and an adjacent state forest in Zimbabwe. *For. Ecol. Manage.* **81**, 101–111.

## Appendix 1

A complete list of woody species with dbh >1 cm recorded in the all inventoried plots with their families and codes used in the PCA ordination.

Species	Family	Code
<i>Acacia dudgeoni</i> Craib	Leg-Mimosoideae	Acdu
<i>Acacia erhembergiana</i> A	Leg-Mimosoideae	Acer
<i>Acacia gourmaensis</i> A. Chev	Leg-Mimosoideae	Acgo
<i>Acacia mellifera</i> Benth	Leg-Mimosoideae	Acme
<i>Azelia africana</i> Sm.	Leg-Caeslpinioideae	Afaf
<i>Annona senegalensis</i> Pers.	Annonaceae	Anse
<i>Anogeissus leiocarpa</i> Guill. & Perr.	Combretaceae	Anle
<i>Balanites aegyptiacus</i> Delile	Balanitaceae	Baae
<i>Bombax costatum</i> Pellegr. & Vuillet	Bombacaceae	Boco
<i>Bridelia scleroneura</i> Müll. Arg.	Euphorbiaceae	Brsc

(continued)

<i>Burkea africana</i> Hook.	Leg-Caesalpinioideae	Buaf
<i>Combretum collinum</i> Fresen.	Combretaceae	Coco
<i>Combretum fragrans</i> F. Hoffm.	Combretaceae	Cofr
<i>Combretum glutinosum</i> Perr. ex DC.	Combretaceae	Cogl
<i>Combretum molle</i> R. Br. ex G. Don	Combretaceae	Como
<i>Combretum nigricans</i> Leprieur ex Guill. & Perr.	Combretaceae	Coni
<i>Crossopteryx febrifuga</i> Benth.	Rubiaceae	Crfe
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Leg-Caesalpinioideae	Daol
<i>Detarium microcarpum</i> Guill. & Perr.	Leg-Caesalpinioideae	Demi
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Leg-Caesalpinioideae	Dici
<i>Dombeya quinqueseta</i> (Delile) Exell	Sterculiaceae	Doqu
<i>Ekebergia senegalensis</i> Fuss.	Meliaceae	Ekse
<i>Gardenia aqualla</i> Stapf & Hutch.	Rubiaceae	Gaaq
<i>Gardenia erubescens</i> Stapf & Hutch.	Rubiaceae	Gaer
<i>Gardenia ternifolia</i> Schumach.	Rubiaceae	Gate
<i>Grewia lasiodiscus</i> K. Schum.	Tiliaceae	Grla
<i>Grewia villosa</i> Willd.	Tiliaceae	Grvi
<i>Hamnoa undulata</i> Planch.	Simaroubaceae	Haun
<i>Khaya senegalensis</i> A.Juss.	Meliaceae	Khse
<i>Lannea acida</i> A.Rich.	Anacardiaceae	Laac
<i>Lannea barteri</i> Engl.	Anacardiaceae	Laba
<i>Lannea velutina</i> A. Rich.	Anacardiaceae	Lave
<i>Lonchocarpus laxiflorus</i> Guill. & Perr.	Leg-Papilionoideae	Lola
<i>Maytenus senegalensis</i> (Lam.) Exell	Celastraceae	Mase
<i>Mitragyna inermis</i> (Willd.) Kuntze	Rubiaceae	Miin
<i>Ozoroa insignis</i> Delile	Anacardiaceae	Ozin
<i>Parkia biglobosa</i> (Jacq.) R.Br. ex G. Don	Leg-Mimosoideae	Pabi
<i>Pericopsis laxiflora</i> (Benth. ex Baker) Meeuwen	Leg-Papilionoideae	Pela
<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh	Leg-Caesalpinioideae	Pith
<i>Pseudocedrela kotschyi</i> Harms	Meliaceae	Psko
<i>Pteleopsis suberosa</i> Engl. & Diels	Combretaceae	Ptsu
<i>Pterocarpus erinaceus</i> Poir.	Leg-Caesalpinioideae	Pter
<i>Rhus natalensis</i> Bernh. ex Krauss	Anacardiaceae	Rhna
<i>Sarcocephalus latifolius</i> (Sm.) E. A.Bruce	Rubiaceae	Sala
<i>Securidaca longepedunculata</i> Fresen.	Polygonaceae	Selo
<i>Sterculia setigera</i> Delile	Sterculiaceae	Stse
<i>Stereospermum kunthianum</i> Cham.	Bignoniaceae	Stku
<i>Strychnos spinosa</i> Lam.	Loganiaceae	Stsp
<i>Syzygium guineense</i> Guill. & Perr.	Myrtaceae	Sygu
<i>Tamarindus indica</i> L.	Leg-Caesalpinioideae	Tain
<i>Terminalia albida</i> Scott-Elliot	Combretaceae	Teal
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	Teav
<i>Terminalia macroptera</i> Guill. & Perr.	Combretaceae	Tema
<i>Tricalysia okelensis</i> Hiern	Rubiaceae	Trok
<i>Vitellaria paradoxa</i> C.F.Gaertn.	Sapotaceae	Vipa
<i>Vitex doniana</i> Sweet	Verbenaceae	Vido
<i>Ximenia americana</i> L.	Olacaceae	Xiam
<i>Ziziphus abyssinica</i> Hochst. ex A. Rich.	Rhamnaceae	Ziab

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