The vegetation of granite rock outcrops in Rio de Janeiro, Brazil, and the need for its protection

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Summary

Rock outcrop communities usually receive very little attention from scientists and environmentalists. We examined the vegetation occurring in eight gneiss-granite rock outcrops at Rio de Janeiro State (Brazilian Atlantic coast) which exists in natural associations on soil islands. A total of 86 vascular plant species, belonging to 30 families, was found on 347 soil islands. Bromeliaceae, Asteraceae and Velloziaceae species were the most frequent plants, many of them endemic to these habitats. Ordination and cluster analyses using species frequency on each site made evident some major distinctions related to local influences, most probably the proximity to the sea. Each outcrop presented high values of the Shannon-Wiener index of species diversity. Species richness was very dependent on the total area, and high beta diversity was observed amongst sites. Similarities with the South American and African rock-outcrop communities were found. Despite their uniqueness as habitats, their possession of several endemic species and the fragility of the ecosystem involved, Brazilian rock outcrops are not protected by specific environmental legislation and we propose urgent actions for their protection.

Keywords: Brazil, rock outcrop, island vegetation, soil island, endemism, diversity

Introduction

Rock outcrops are a very attractive feature of the south-eastern Brazilian coast. Many of them adorn the famous scenery of the town of Rio de Janeiro, between forests and the Atlantic Ocean. The Sugar Loaf Mountain (Pão de Açúcar), a gneiss-granite outcrop and probably the most famous of them, is one of countless bell-shaped mountains that arise at the coast, in the Serra do Mar range, near Guanabara Bay. Some outcrops appear as mostly bald mountains with rainforest patches on the summit, or alternatively, at the base. Other outcrops seem to consist only of exposed rock rising from rainforest vegetation. Outcrops which appear bare at a distance, however, bear many vascular plant species, the most amazing feature of which is the ability to grow on a surface with almost no soil. These peculiarities fascinated the nine-teenth-century Scottish naturalist, George Gardner, on his visit to the Rio de Janeiro coast (Gardner 1846). After his visit, little attention was paid to these outcrops, although they constitute the primary habitat of some valuable ornamental species. Good examples are some famous ornamental gesner-iads, such as *Sinningia cardinalis* and *S. speciosa*, better known from their hybrids than from the wild species.

Besides its peculiarities, rock-outcrop vegetation shows interesting patterns of distribution and affinity to substratum. Distinctive species are usually installed on a thin soil layer, forming elliptical soil-islands varying in size from a few centimetres across to hundreds of square metres in area.

The best known soil-island plant communities worldwide are granite outcrops in the south-eastern United States (Winterringer & Vestal 1956) and those found by Barthlott *et al.* (1993), in Africa. North American rock outcrops have been the focus of very detailed studies, comprising the mapping of such soil-island communities and the analysis of species composition, of species-area relationships and of successional patterns (Burbanck & Platt 1964; Phillips 1981; Burbanck & Phillips 1983). On the other hand, tropical rock-outcrop soil islands, although mentioned in some studies, have never been explored in the same detail as those in temperate regions. The abundance of such gneiss rock formations in south-eastern Brazil provides a chance to study their species composition, richness and diversity, as well as trends in the community structure and distribution.

Soil islands can be regarded as mini-terrestrial ecosystems, to some extent liable to manipulation, and therefore an appropriate material for empirical model generation (Platt & McCormick 1964). They represent suitable material for island theory studies, as they retain some characteristics mentioned as desirable or obligatory in ecological islands. Amongst other features, these islands exhibit a clearly-defined border, enabling precise delimitation of area and species composition (Connor & McCoy 1979; Gilbert 1980).

The goal of this study was to call attention to the urgent need to protect this peculiar vegetation on the Rio de Janeiro coast, and to provide basic ecological information for further detailed studies and conservation proposals.

Methods

Study area

Plant mats in soil islands were investigated in eight gneiss-granite rock outcrops, on the coast of Rio de Janeiro State

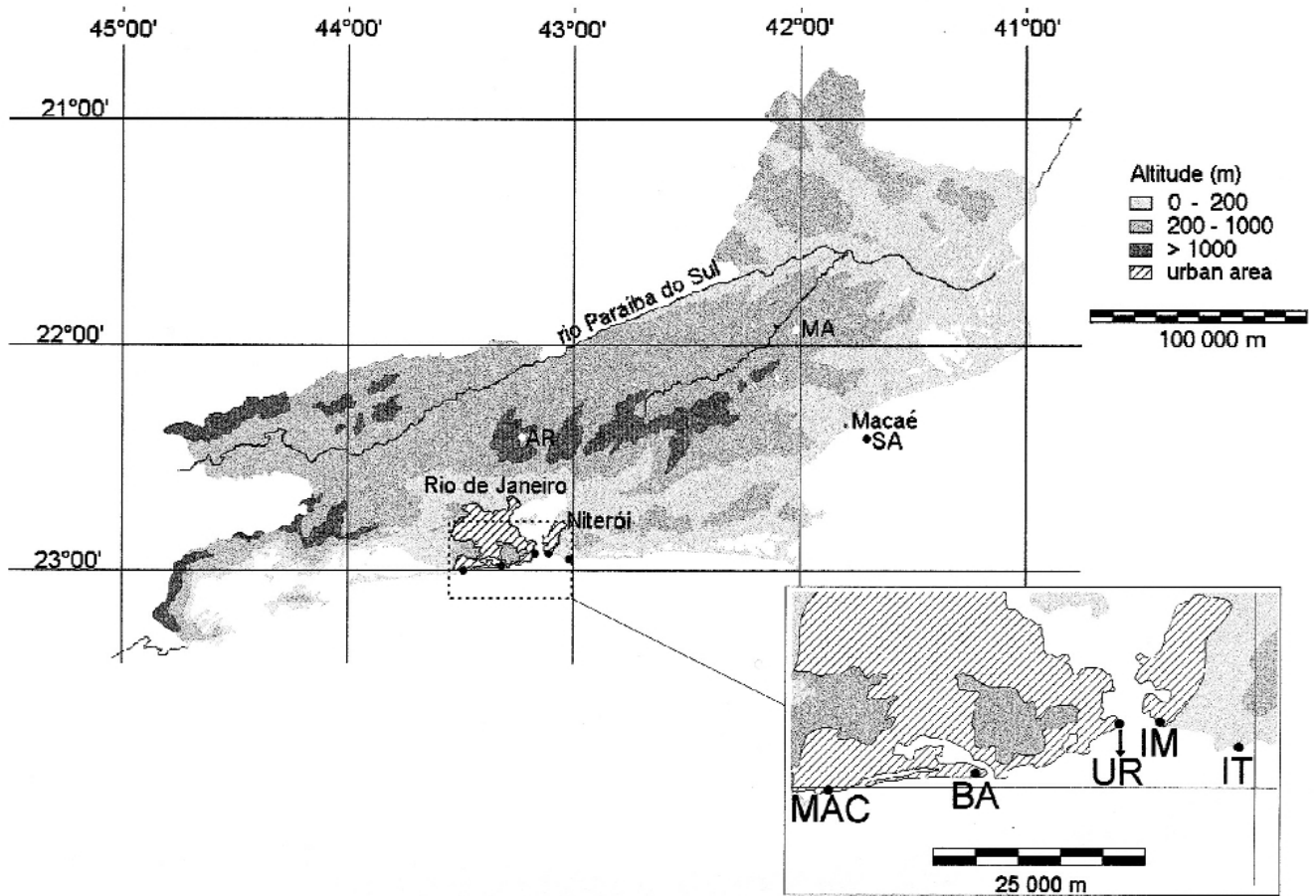*Correspondence: Dr Sergio Tadeu Meirelles Fax +55 11 813 4151 e-mail: stmeirel@ib.usp.br

Figure 1 Location of the surveyed rock outcrops in Rio de Janeiro State, Brazil. Codes according to Table 1.

Table 1 General characteristics of the studied areas and the number of soil islands in each rock outcrop.

Sites	Codes	Lat. & Long.	Elevation	No. of islands	Total island area (m^2)
Macumba	MAC	23°02′S 43°29′W	0–10 m (shore)	29	67.02
Intanhangá	ITN	22°59′S 43°19′W	0–40 m (coastal land)	25	5.74
Urca	URC	22°57′S 43°09′W	10–50 m (shore)	42	97.58
Imbuí	IMB	22°56′S 43°07′W	120 m (coastal land)	41	184.18
Itacoatiara	ITA	22°58′S 43°01′W	120 m (coastal land)	41	160.75
Araras	ARA	22°25′S 43°14′W	1000–1050 m (inland mountains)	91	567.25
Santana	SAN	22°25′S 41°42′W	40 m (coastal island)	20	50.55
Madalena	MAD	21°56′S 42°01′W	1400 m (inland mountains)	58	130.60

Figure 2 View of the vegetation associated with a rock outcrop in the vicinity of the Itacoatiara site. Note soil islands scattered over the rock contrasting with the dense rainforest at the rock base.

(south-eastern Brazil). Two outcrops (Araras and Madalena) were located in the Serra do Mar range, at altitudes of 1000–1400 m. A third outcrop was on the oceanic island of Santana, near the town of Macaé. The remaining sites were located within the urban perimeters of the town of Rio de Janeiro (Macumba, Itanhangá and Urca) and the town of Niterói (Imbuí and Itacoatiara) (Fig. 1, Table 1). Soil islands could easily be distinguished as plant mats surrounded by exposed rock (Fig. 2).

Meteorological data showed that there were slightly different climatic conditions amongst the studied sites. Those at Serra do Mar (Araras and Madalena) and near Macaé (Santana) usually have more than four months per year with monthly rainfall below 50 mm. Lower temperatures were found at the Araras and Madalena sites, at altitudes of 1000 m or more. In contrast, rainfall on the sites near the towns of Rio de Janeiro and Niterói (Macumba, Itanhangá, Urca, Imbuí and Itacoatiara) was never below 50 mm per month in the dry winter period and temperatures were higher.

On each site, every accessible soil island was examined. Data collected for each island consisted of surface area,

species composition and the life forms present. The surface area was calculated considering each island as an ellipsis and multiplying the two perpendicular radii by 3.1415 (Table 1).

Species composition of each soil island was determined by collecting fertile individuals, which were identified by specialists. Species names follow the Gray Card Index (Harvard University Herbaria 1998). Voucher specimens are lodged in the State University of Campinas (Campinas, S.P.) herbarium (code UEC). Life form categories were identified according to Raunkiaer (Ellenberg & Mueller-Dombois 1967). Despite their relative importance on the studied sites, mosses, green algae and lichens were omitted.

Distribution patterns of species on a geographical scale were assessed by examining the herbarium records of: Herbário Maria Eneyda Kaufman Fidalgo (Instituto Botânico de São Paulo [SP]), Herbário do Departamento de Botânica (Universidade de São Paulo [SPF]), Herbário do Departamento de Botânica (Universidade Estadual de Campinas – SP [UEC]), Jardim Botânico do Rio de Janeiro (RB), Museu Nacional – RJ (R), Herbário Leopoldo Krieger (Universidade Federal de Juiz de Fora – MG [CESJ]), Herbário do Departamento de Botânica da Universidade Federal de Minas Gerais (BHCB), Herbário Alexandre Leal Costa, Instituto de Biologia (Universidade Federal da Bahia [ALCB]). These names and codes are according to the Index Herbariorum (Holmgren 1990). The endemic character was also verified through published revisions of genera and families: Bromeliaceae – Smith (1943); Cyperaceae – Koyama and Maguirre (1965), Koyama (1969); Velloziaceae – Ayensu (1973*a*, *b*), Menezes (1980*a*, *b*, *c*) and phytogeographic surveys (Pereira & Pereira 1972; Martinelli & Vaz 1986; Fontoura *et al.* 1991).

A total of 347 soil islands, ranging from 0.1 to 10 000.0 dm² in area were surveyed. The number of soil islands varied between sites, with the lowest number being 20 islands at the Santana site.

A multivariate ordination analysis was performed and, for that, the entire data matrix was randomly resampled to obtain subsets of 20 islands for each site, to allow comparisons both amongst subsets and with the site containing the smallest number of islands. For ordination, species frequency was taken as the total occurrence divided by 20.

Comparisons and descriptions

A cluster analysis technique was applied for comparison amongst sites of soil-island species composition, based on a binary presence-absence matrix of sites and species. The squared Euclidean distance was used to produce a similarity matrix. The centroid clustering method was used and the hierarchical cluster analysis was performed using the SPSS package, version 7.5 (SPSS Incorporated 1996). Ordination was via Detrended Correspondence Analysis (DCA) on species frequency data in order to reveal possible intrinsic patterns in site subsets. These calculations were performed using the CANOCO programme (Ter Braak 1987–92).

Diversity was estimated based on the proportional contribution of each species in the community, where F_i/F_t; F_i = frequency of species i; F_t = frequency of all species.

The sampling of every element in the community allowed the use of species number (E) as a reliable richness measure. The Shannon-Wiener index (H') was used to estimate species diversity (with the natural base logarithm) and Pielou's J' index used to estimate evenness (calculations were performed on the original matrix, following Krebs 1989). As surveys consisted of exhaustive sampling of every natural unit, making up complete censuses, the diversity values were directly compared.

Results

Species recorded

Monocotyledons prevailed in most island plant communities and these were mainly Velloziaceae species. In larger islands, a shrubby cover on a thin soil could also be found. A total of 85 species and 30 families of vascular plants were found. Monocotyledonous species comprised half of the total (43 species in 10 families), while the remainder consisted of 36 dicotyledonous species (16 families) and 6 pteridophytes (4 families) (Table 2). The family with the highest number of species was Bromeliaceae, with 16 species, followed by Asteraceae and Velloziaceae, respectively with 8 and 7 species.

The most frequent species was *Trilepis lhotzkiana*, which occurred in 45% of all soil islands (the value would be higher if obtained from the original matrix), followed by *Nanuza plicata* (27% of total) and *Vellozia candida* (26%) (Fig. 3). A small group of species, with frequencies between 15 and 20%, consisted of *Cephalocereus fluminensis*, *Selaginella sellowii*, *S. convoluta*, *Pleurostima purpurea* and *Epidendrum elongatum*. Hemicryptophytes were the predominant life form in number of species (37), followed by nanophanerophytes (27) (Table 2).

At least 80% of the species with frequencies higher than 5% were restricted to gneiss-granite outcrops. All species occurring in more than 15% of the islands could only be found in this kind of habitat. Rock outcrops also sheltered some species, which are native to surrounding communities, most frequently coming from the *restinga* (lowland) forest and coastal vegetation. Invasive alien species were rarely found, although being very abundant in the nearby vegetation, especially *Melinis minutiflora* Beauv. and *Panicum maximum* Jacq., both grasses of African origin (Table 2). It was observed that these species tended to colonize recently-burned sites.

Cluster and ordination analysis

A strong similarity between the Araras and Madalena sites was observed (Fig. 4). Sites close to the town of Rio de Janeiro differed according to the position relative to seashore, and the most dissimilar sites were those directly influenced by sea spray. Macumba, the lowest site and nearest to the sea

was markedly dissimilar from the others (Fig. 4). Species composition in the Macumba site was the most influenced by the neighbouring restinga vegetation, possessing as it did species such as *Neoregelia cruenta*, *Pilocereus arrabidae*, *Selenicereus* sp., *Pereskia* sp. and *Bromelia antiacantha*, but Velloziaceae and Selaginellaceae species, which are very common at the other sites, were not recorded in Macumba (Table 2). Urca was also very dissimilar, probably also due to the sea influence but this site differed mostly from Macumba (Fig. 4) in being surrounded not by sand dunes, but by rainforest and buildings, and thus did not show a great influence from restinga vegetation.

The detrended correspondence analysis showed that subsets of the same site appeared in distinct 'clouds', allowing confidence in identifying each outcrop. The first three axes' eigenvalues (0.77; 0.49; 0.21) accounted for 49% of the variation. The first axis accounted mainly for the differentiation in species composition influenced by elements typical of sand dune vegetation (Fig. 5). The second axis reflected the surf-zone influence on the exclusion of the main soil island constituents, such as *Trilepis lhotzkiana* and *Selaginella* species (Fig. 5). The increase in the ordination score along the third axis (Fig. 6) seems to express the sea influence on the typical composition of rock outcrop vegetation, by the exclusion of particular species in outcrops 50 m above the region of intense salt-spray action. The strong segregation of the Macumba site is therefore attributable both to the direct effect of salt spray and the proximity of the restinga vegetation. Urca was probably under the influence of a mild salt spray action, which may have caused the very low frequency of *Trilepis lhotzkiana* and the exclusion of *Selaginella sellowii*, which are apparently sensitive to salinity. Besides being under the sea influence like the Macumba site, Urca is not surrounded by sand dune vegetation. This situation creates an intermediary pattern of species composition, inbetween Macumba and the other sites influenced by sea (Table 2).

Diversity

Species diversity, evenness and richness tended to differ amongst sites (Table 3). A linear regression between diversity and richness values showed that differences in species number were responsible for most of the variation in H' ($r^2 = 0.76$, $p < 0.01$; F = 21.7, $p < 0.01$). The number of species (E) was influenced by the total island area (Table 1); the sites with lower total area (Itanhangá and Santana) having the least species, while Araras (the site with highest total area) was the richest site (Fig. 7). An exponential association model was the best fit between richness and island area (Fig. 7). Overall, sites with more islands had higher species diversity. However, evenness rank did not follow that of diversity values; the Araras site, for example, was the lowest in evenness and fourth in diversity terms. Evenness was also little influenced by the number of species ($r^2 = 0.08$, $p > 0.05$; F = 0.61, $p > 0.05$). When considering the islands altogether, evenness was lower than for some of the sites in isolation.

Table 2 Species recorded from soil islands at eight studied sites, as absolute frequency (codes according to Table 1). Lf = life form; Hem = hemicryptophytes; Nfan = nanophanerophytes; Cam = chamaephytes; Geo = geophytes; Ter = terophytes; Epf = epiphytes; Hepf = hemiepiphytes; Suc = Succulent. Microendemic species in bold.

Family	Species	Lf	MAD	ARA	SAN	ITA	ITN	URC	IMB	MAC
Agavaceae	*Furcraea gigantea* Vent.	Hem	0	0	0	0	0	0	0	3
Amaryllidaceae	*Hippeastrum aviflorum* (Ravenna) Dutilh	Geo	22	0	0	2	0	0	0	0
Araceae	**Anthurium sucrii Barroso**	Hepf	0	2	0	10	0	0	0	7
Asteraceae	*Bacharis* sp.	Nfan	0	0	0	0	0	7	0	0
	Emilia sagitata (Vahl)	Ter	0	0	0	0	0	0	0	21
	Eupatorium viridiflorum Baker	Nfan	0	0	5	12	0	0	2	45
	Vanillosmopsis erithropappa Sch.Bip.	Nfan	0	1	0	0	0	0	0	0
	Vernonia longo-angustata Barroso	Nfan	0	4	0	0	0	0	0	0
	Vernonia muricata Less.	Nfan	0	5	0	0	0	0	0	0
	Vernonia rupestris Gardner	Nfan	0	0	5	7	0	7	2	7
	Vernonia sp.	Nfan	3	0	0	0	0	0	0	0
Begoniaceae	*Begonia* sp.	Nfan	0	0	0	0	0	0	0	3
Bombacaceae	*Ceiba erianthos* K. Schum.	Nfan	3	2	0	0	0	0	0	0
Bromeliaceae	*Achmaea nudicaulis* Griseb.	Hem	0	0	0	2	0	0	0	0
	Bromelia antiacantha Mez	Hem	0	0	0	0	0	0	0	3
	Neoregelia cruenta (R. Graham) L.B. Smith	Hem	0	0	0	0	0	0	0	34
	Pitcairnia albiflos Herb.	Hem	0	0	0	0	0	55	0	0
	Pitcairnia flammea Lindl.	Hem	0	0	0	0	0	0	0	72
	Pitcairnia sp.	Hem	0	2	0	0	0	0	0	0
	Pitcairnia staminea Lodd.	Hem	0	0	0	15	16	0	7	0
	Tillandsia araujei Mez	Hem	0	0	0	51	0	0	0	0
	Tillandsia gardnerii Lindl.	Epf	0	5	0	0	0	0	0	0
	Tillandsia mallemontii Glaz.	Epf	0	1	0	0	0	0	0	0
	Tillandsia stricta Soland.	Epf	0	0	0	0	0	0	10	0
	Tillandsia tricholepis Baker	Epf	0	0	0	0	0	0	2	0
	Alcantarea geniculata (Wawra) J.R. Grant	Hem	0	0	0	17	0	29	2	0
	Alcantarea imperialis (Carriere) J.R. Grant	Hem	10	27	10	0	0	0	0	0
	Vriesea neoglutinosa Mez	Hem	7	0	10	10	0	0	10	0
	Alcantarea sp.	Hem	0	3	0	0	0	0	0	0
Cactaceae	**Cephalocereus fluminensis (Miq.) Br.Rose**	Suc	3	0	65	15	0	0	10	52
	Cereus obtusus Haw.	Suc	0	0	0	0	0	0	32	69
	Opuntia sp.	Suc	0	0	0	0	0	0	12	0
	Pereskya aculeata Pfeiff.	Nfan	0	0	0	0	0	0	0	7
	Cereus pernanbucensis Lemaire	Suc	0	0	0	0	0	0	0	31
	Rhipsalis cereoides Backeb. &Voll	Suc	0	0	0	29	0	0	0	0
Commelinaceae	*Commelina* sp.	Cam	0	0	0	0	0	0	0	45
Convolvulaceae	*Evolvulus glomeratus* Nees & Mart.	Nfan	0	0	0	12	0	0	0	0
Crassulaceae	*Kalanchoe brasiliensis* Camb.	Nfan	0	0	0	0	0	0	63	0
Cyperaceae	*Cyperus coriifolius* Boeck.	Hem	0	0	40	20	4	2	0	38
	Cyperus sp.	Hem	7	0	0	0	0	0	0	0
	Trilepis ciliatifolia Koyama	Hem	53	0	0	0	0	0	0	0
	Trilepis lhotzkiana Nees	Hem	72	97	0	71	88	5	10	0
Euphorbiaceae	*Croton compressus* Lam.	Nfan	0	0	5	2	0	7	12	0
	Euphorbia comosa Vell.	Nfan	0	0	0	0	0	0	0	72
	Manihot leptopoda (Muell. Arg.) Rogers	Geo	0	0	0	0	0	5	0	0
	Phyllanthus subemarginatus Muell. Arg.	Nfan	0	0	0	15	0	0	0	0
	Stillingia dichotoma Muell. Arg.	Nfan	33	0	0	22	0	10	24	0
Gesneraceae	**Sinningia bulbosa (Mart.) H.E. Moore**	Geo	0	0	0	0	4	7	0	38
	Paliavana racemosa Fritsh	Geo	0	7	0	0	0	0	0	0
Guttiferae	*Clusia fluminensis* Tr. & Pl.	Nfan	0	0	0	0	0	2	2	0
	Kielmeyera membranaceae Casar.	Nfan	3	0	0	0	0	0	0	0
Leguminosae	*Cassia* sp.	Nfan	0	1	0	0	0	0	0	0
	Chamaecrista nictitans L.	Nfan	0	1	0	0	0	0	5	0
Malvaceae	*Sida* sp.	Ter	0	0	0	0	0	0	5	0
Marantaceae	*Calathea brasiliensis* Körn	Hem	0	0	0	0	0	0	0	7
Melastomataceae	*Tibouchina corymbosa* Cogn.	Nfan	0	0	0	5	0	7	0	0

Family	Species	Lf	MAD	ARA	SAN	ITA	ITN	URC	IMB	MAC
	Tibouchina heteromalla Cogn.	Nfan	9	4	0	0	0	5	0	0
Orchidaceae	*Brassavola tuberculata* Hooker	Epf	0	0	0	24	0	0	0	0
	Cyrtopodim andersonii Cogn.	Hem	0	1	0	0	0	0	0	0
	Epidendrum elongatum Sesse & Moc.	Hem	3	27	0	5	12	38	24	3
	Prescottia colorans Lindl.	Hem	0	1	0	10	4	14	7	0
	Pseudolaelia vellozicola (Hoene) C.Porto & Brade	Epf	14	34	0	0	0	0	0	0
	Zygopetalum sp.	Hem	0	1	0	0	0	0	0	0
Piperaceae	*Peperomia incana* (How.) Hook	Hem	0	0	0	0	0	0	0	28
Poaceae	*Cenchrus* sp.	Hem	0	0	0	0	0	0	0	10
	Melinis minutiflora Beauv.	Hem	0	2	0	0	0	0	0	0
	Panicum maximum Jacq.	Hem	0	0	0	0	0	0	0	14
	Paspalum notatum Hook.	Hem	0	0	0	0	0	0	0	17
	Paspalum sp.	Hem	0	5	0	0	0	0	0	0
Polypodiaceae	*Polypodium loriceum* L.	Hem	0	0	0	2	0	0	0	0
Portulacaceae	*Portulaca hirsutissima* Camb.	Cam	0	0	0	7	0	0	0	45
Pteridaceae	*Doryopteris collina* (Raddi) J.Sm.	Hem	0	21	5	24	0	2	12	3
	Microgramma sp.	Epf	0	1	0	0	0	0	5	0
Schizaeaceae	*Anemia villosa* Humb. & Bonpl. ex Wild.	Hem	2	4	0	0	0	2	5	21
Scrophulariaceae	*Scoparia dulcis* L.	Nfan	0	0	0	0	0	0	0	24
Selaginellaceae	*Selaginella convoluta* (Arn.) Spring.	Hem	3	0	0	0	48	0	88	0
	Selaginella sellowii Hieron.	Hem	0	0	10	49	16	0	76	0
Sterculiaceae	*Walteria indica* Linn.	Nfan	0	0	0	5	0	0	0	0
Velloziaceae	*Nanuza plicata* (Spreng.) Ayensu	Nfan	69	60	85	0	0	0	0	0
	Pleurostima fanniae Menezes	Hem	43	0	0	0	0	0	0	0
	Pleurostima purpurea (Hook.) Raf.	Hem	0	0	0	0	0	93	37	0
	Pleurostima seubertiana (Goeth. & Henr.)Menezes	Hem	0	11	0	0	0	0	0	0
	Vellozia candida Mikan	Nfan	38	0	0	37	80	0	44	0
	Vellozia crassicaulis Mart. ex Schult.	Hem	0	9	0	0	0	0	0	0
	Vellozia variegata Goeth. & Reniard	Nfan	0	1	0	0	0	0	0	0

These results testify to the presence of distinct dominance patterns in the studied sites, because high overall evenness would have been caused by similarity in island species composition amongst the sites.

The highest diversity value was obtained for all islands combined. This result was expected and it should be regarded as an effect of beta (amongst site) diversity, since most species were confined to a single outcrop or to a small range.

Discussion

The results obtained here suggest a typical and distinctive species composition pattern and high levels of endemism in rock outcrop vegetation. This floristic distinctness was in accordance with surveys on other tropical outcrops and it extends from species to families. Some plant groups such as Velloziaceae were confined to rock outcrops and did not establish on the neighbouring forests and sand dunes. This is typical with this family (Ayensu 1973*a, b*) all over the tropics. Cactaceae, Orchidaceae and Amaryllidaceae were other families with many of their Brazilian representatives occurring on rock outcrops. Typical genera included *Trilepis* (Cyperaceae) and *Pitcairnia* (Bromeliaceae) species; *Trilepis ciliatifolia*, *T. microstachia*, *Pitcairnia albiflos* and *P. staminea*, for example, occur in small numbers on rock outcrops (Koyama & Maguirre 1965; Koyama 1969; Smith 1974).

Generally speaking, a greater tolerance of Monocotyledons than Dicotyledons to stressful conditions would explain their preponderance in rock outcrops. Species of the best-represented family in this study, the Bromeliaceae, also showed a great ability to colonize bare surfaces, making some *Tillandsia* species such as *T. araujei* important pioneers of the studied sites. *Tillandsia*, *Vriesea* and *Alcantarea* species were the only inhabitants of vertical wall surfaces. Bromeliaceae is also an important family in many vegetation types surrounding the outcrops, including the Atlantic rainforest, where they prevail as epiphytes. Pteridophytes were also significant elements in the soil island communities, especially *Selaginella* spp; *S. sellowii* was the only component of islands with a very thin soil layer, and *S. convoluta* was also important on small soil islands.

Most of the main features of the studied outcrops correspond with Barthlott and his co-workers' (Barthlott *et al*. 1993) findings and descriptions. When compared to this study, their descriptions indicate that tropical outcrop soil islands exhibit the same basic structure as those of temperate countries, where the bulk of plants is also composed of perennial Monocotyledons. The high frequency of *Pitcairnia* and *Vellozia* species in the examined sites may be considered an important similarity to other South American outcrops, such as those in Bolivia and Venezuela (Ibisch *et al*. 1995).

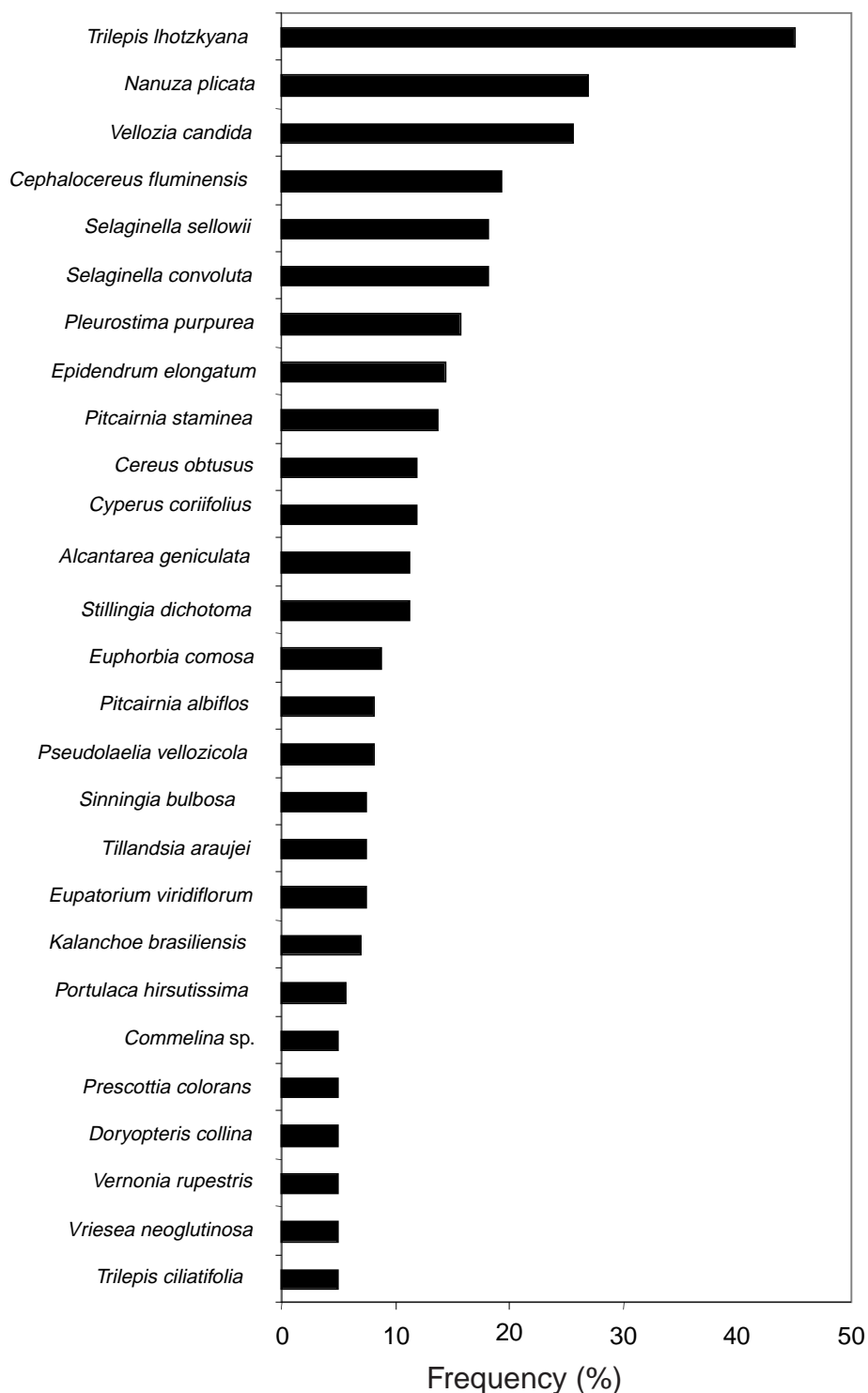The importance of *Trilepis* sedges is perhaps the most re-

Figure 3 The most frequent species occurring on the soil islands studied. Values refer to percentages of the total (347) islands surveyed.

markable similarity between south-eastern Brazil and Africa, where *Afrotrilepis* spp. (formerly from the same genus) are very frequent and abundant (Richards 1957; Hambler 1964; Porembski *et al.* 1996). Mats combining species of Velloziaceae and Cyperaceae can also be found in Africa (Owoseye & Sanford 1972; Barthlott *et al.* 1993; Porembski &

Barthlott 1993), as well as in Brazil. On the other hand, the Brazilian sites examined here were rich in rock-substratum species, and therophytes (ephemeral) were poorly represented, unlike in the African outcrops. The absence of epilithics in African outcrops could be responsible for dissimilar patterns of plant surface occupation.
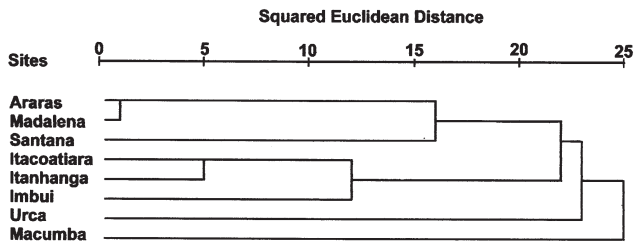
Figure 4 Dendrogram of similarity amongst the sites analysed.

Despite the lack of detailed surveys of other Brazilian rock outcrops, we can say that there is a high degree of endemism in the analysed sites. Based on herbarium investigation, we verified that several species recorded here were found only in the sites examined, as was also the case for *Rhipsalis cereoides* (Cactaceae).

Such endemic species occurring at sight distances from each other highlights the insular character of the rock outcrops. The species are subject to constraints including those of dispersal, habitat availability and community exposure to salinity, similar to those of other truly insular biota. Because they grow in peculiar habitats, high community dissimilarity between nearby sites was also attributable to local environmental variations. Salt spray action, for example, was considered one reason for major differences between sites, since salinity requires particular plant adaptations (Salisbury & Ross 1992), and distance from the sea can therefore be regarded as an important governing variable. The overall

heterogeneity arises when local differences are amplified by the extreme environmental conditions of rock outcrops, mostly because the lack of soil makes any thin layer of dust a more suitable condition for plant establishment than the bare rock surface itself.

Species diversity values found here for the small island communities can be considered high. Species richness and diversity were proportional to the number of islands on a site and their total area. Such findings corroborate the view that a dynamic equilibrium underlies species/area relationships (Barthlott *et al*. 1993). Nevertheless we cannot rule out a passive sampling effect on elective species from contributing to this relationship. The total diversity being higher than the highest value for each site individually suggests the existence of a measurable beta-diversity (Magurran 1988). High evenness values and their independence from species richness indicate that dominance was almost absent.

Disturbance agents may considerably modify rock outcrop species composition. The Macumba site, for example, besides being the most exposed to salinity effects, was also the most accessible site and hence is the most vulnerable to human actions. Its dissimilar floristic composition, with no Velloziaceae and Selaginellaceae species and a high frequency of Poaceae species (Table 2), may in part be explained by disturbing factors. Fire is a considerable disturbing element in rock outcrops, usually caused by lightning or fire coming from garbage burning by local people. Fire is a very destructive agent in such sites, causing the complete destruction of
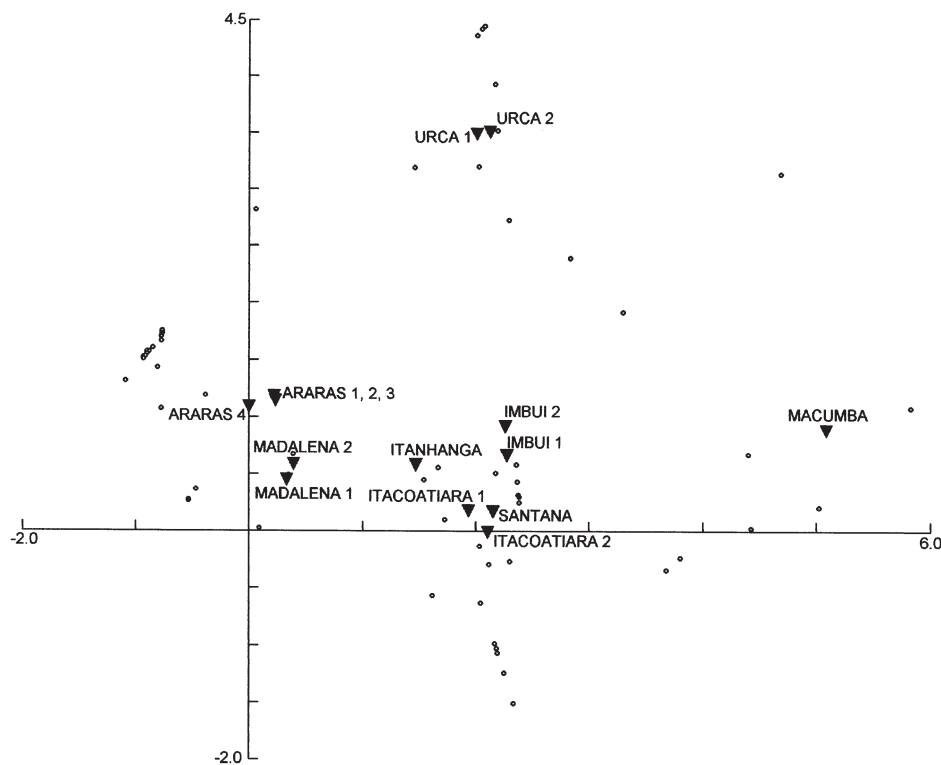

Figure 5 Results of detrended correspondence analysis (DCA) ordination: plot of axis 1 vs axis 2 eigenvalues for sites and species. Gradient lengths are respectively 5.09 and 3.52. Site subsets are represented by the site name followed by a number.
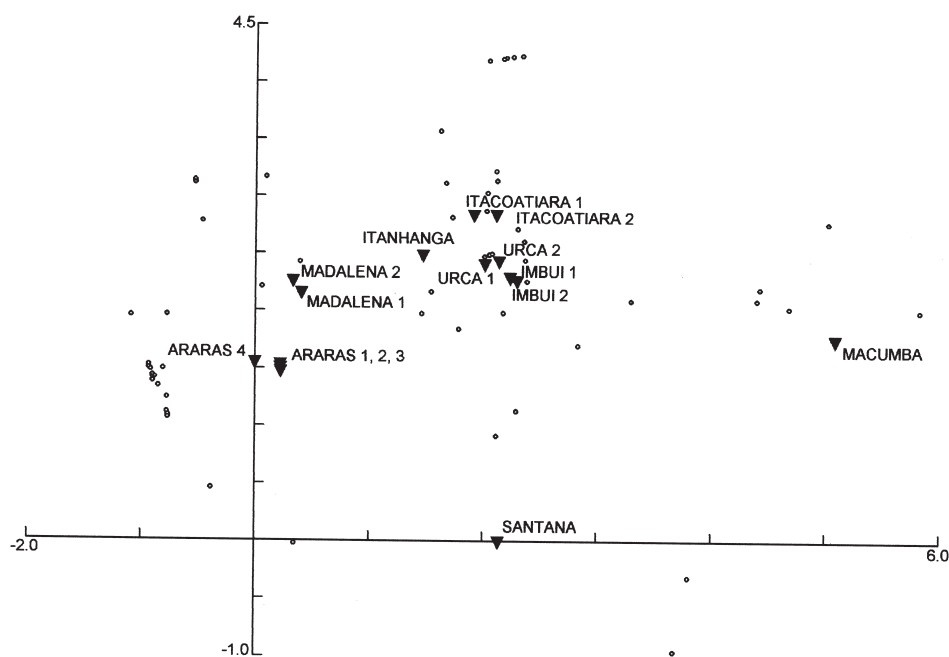
Figure 6 Results of DCA ordination: plot of axis 1 vs axis 3 eigenvalues for sites and species. Gradient lengths are respectively 5.09 and 2.87. Site subsets are represented by the site name followed by a number.

Table 3 Values of species diversity (H'), evenness (J') and richness (E) for the rock outcrop vegetation. The Shannon index was calculated using the natural logarithm basis.

Site	E	H'	J'
Madalena	19	2.414	0.820
Araras	29	2.445	0.726
Santana	10	1.740	0.756
Itacoatiara	27	2.930	0.889
Itanhangá	9	1.688	0.768
Urca	18	2.219	0.768
Imbuí	26	2.708	0.831
Macumba	27	2.959	0.898
All sites	85	3.698	0.832

the soil island. After strong rain, the substratum of a burned island can be completely removed, leaving a bald rock surface, as observed by the authors during field visits. Where soil has not been removed by the heavy rain, some invasive species, especially the African grasses *Panicum maximum* Jacq. and *Melinis minutiflora* Beauv, are able to colonize the burned surface, either on the moister parts of the island or until the dry season comes, when they dry out. Fortunately, only the native soil-island species are able to withstand the dry period in such thin soil layers, making the problem of invasive plants less worrying in these habitats.

Case for conservation

The peculiar habitat conditions of rock outcrops select for highly distinct species, making the soil island communities unique. These communities present several of the criteria in-

dicated for conservation priority (Mackinnon *et al.* 1986). Rarity, uniqueness and fragility are perhaps the most meaningful of such criteria and sufficient to justify their protection.

Species such as *Worsleya raineiri* (Amaryllidaceae) and *Laelia lobata* (Orchidaceae), which were present in the studied area, are in the Brazilian official list of endangered species (Portaria IBAMA 37–N, 03/April/1992). *Manihot leptopoda*, which is another species occurring in that area, is suggested by the International Center for Tropical Agriculture (C.I.A.T.) as a germplasm source for the genetic improvement of *Manihot esculenta*, the edible cassava. In addition, the ecological processes that permit the survival of typical species under stressful conditions are not completely understood by science and this emphasizes the scientific value of the present communities.

At the population level, several other reasons point to fragility (according to Nilsson's & Grelsson's [1995] definition), as the inhabitant species form small and aggregated populations which are confined to small sites with specialized niche requirements. Also, pollination is difficult, completed by very specific agents, and vegetative reproduction through bulbs is ineffective in the substratum involved.

Subtle variations over a few metres of altitude are sufficient to change the floristic composition, generating high diversity at the habitat level (beta diversity). This supports a claim for protecting the outcrops in their entirety.

Besides their natural fragility, rock habitat islands are also greatly vulnerable to human actions. Most of the studied sites are very close to, or even within, urban centres and are constantly threatened by pollution, vandalism and fires. Therefore, local extinctions are imminent, and effective actions should be taken to protect the habitats concerned.
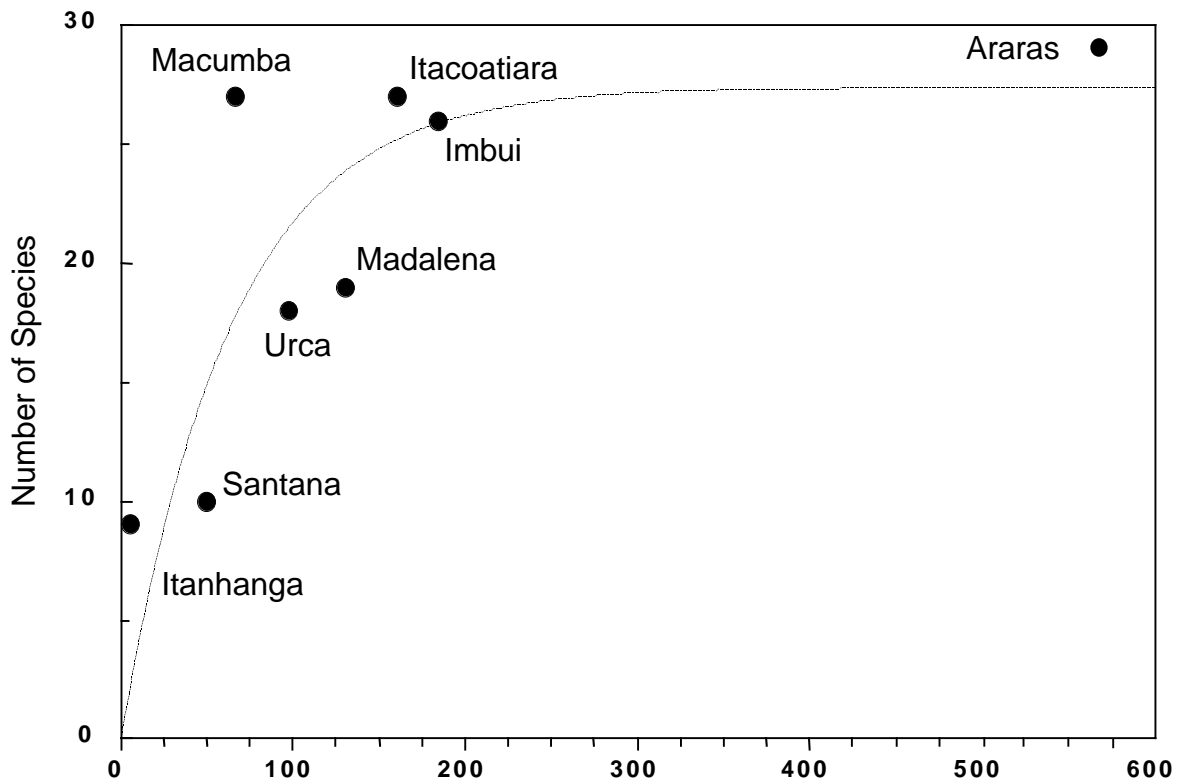
Figure 7 Relationship between species richness and the total island area (m²) in each site. Best fitting equation is given by the model: $y = 27.412 \, (1\text{-exp} \, (0.016))$, $r = 0.872$, SE = 5.4%.

Although the rock-outcrop communities studied are indirectly protected by the Brazilian environmental legislation, in that they occur scattered within the Atlantic biome which is preserved, and also because they shelter several endemic species which should be preserved, specific laws to protect this type of habitat do not exist. People usually consider this vegetation as marginal, and it does not receive much attention. It is necessary to emphasize that such communities in fact demand urgent conservation action.

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