Biodivers Conserv (2009) 18:3543–3561
DOI 10.1007/s10531-009-9659-6

ORIGINAL PAPER

Lichen diversity and composition in Araucaria forests and tree monocultures in southern Brazil

Márcia I. Käffer · Gislene Ganade · Marcelo P. Marcelli

Received: 1 September 2008 / Accepted: 13 May 2009 / Published online: 4 June 2009

Abstract Tree plantations for commercial use have been replacing native ecosystems all over the world. We investigated how forest conversion to plantations of exotic and native tree species may influence lichen diversity and composition in a southern Brazilian landscape. The lichen community from the National Forest of São Francisco de Paula was studied using three stands of each of the four vegetation types: native Araucaria forest and plantations of Araucaria, Pine and Eucalyptus trees. All plantation stands were surrounded by native Araucaria forest, were of smaller size and were allowed to endure longer than commercially managed plantations. Lichen species and their cover abundance were recorded on tree trunks from 30 to 150 cm above soil level in ten host-trees that were randomly selected in each replication. Seventy-eight lichen species, from 18 genera and 9 families, were registered. Conversion of native forest to plantations of exotic tree species altered species composition by reducing the occurrence of shade tolerant lichens. Plantations of *Araucaria angustifolia* sustained the highest lichen diversity measured, because this is an excellent host species. These results suggest that a greater diversity of lichens can be preserved in the landscape, if plantations of the exotic Pinus and Eucalyptus genera are replaced by plantations of this native species.

Keywords *Araucaria angustifolia* · *Eucalyptus* plantation · Landscape mosaic · Lichenized fungi · Native Araucaria forest · *Pinus* plantation

---

M. I. Käffer · G. Ganade
Laboratório de Ecologia da Restauração, Biologia, UNISINOS, C.P. 275, São Leopoldo,
RS CEP 93001-970, Brazil

G. Ganade (✉)
Departamento de Botânica Ecologia e Zoologia, Centro de Biociências, Universidade Federal do Rio
Grande do Norte, Natal, RS CEP 59072-970, Brazil
e-mail: gganade@cb.ufrn.br; gganade@gmail.com

M. P. Marcelli
Instituto de Botânica, C.P. 4005, São Paulo, SP CEP 01061-970, Brazil

Introduction

Anthropogenic influences on vegetation structure can substantially alter the communities of lichens (Will-Wolf et al. 2002; Goward and Spribille 2005; Martinez et al. 2006; Wolseley et al. 2006). This is because various lichen communities are susceptible to local species loss due to disturbance (Pharo et al. 2000; Uliczka and Angelstam 2000; Nordén and Appelqvist 2001). Additionally, lichen communities can also become dominated by species that are resistant to the effects of disruption or pollution (Jüriado et al. 2003; Humphrey et al. 2002; Will-Wolf et al. 2002; Brunialti and Giordani 2003; Nascimbene et al. 2007).

The conversion of native forest to tree plantations can influence lichen diversity (Humphrey et al. 2002; Wolseley et al. 2006). This is expected because community composition and diversity of epiphytic lichens can be determined by its host-trees characteristics (Jesberger and Sheard 1973; Lõhmus et al. 2007). Trees with bark that suffer shredding do not favor lichen colonization (Brodo 1973). Tree barks that produce resins and saps can also inhibit lichen growth (Topham 1977). The acidity and alkalinity of the bark can affect the lichen thallus, because pH can be critical for the reproduction of various species (Hale 1957; Brodo 1973). When forest environments are altered or transformed into different arboreal vegetation types, the availability of favorable host-trees can diminish, promoting changes in the lichen composition and decreases in species' diversity (Sillet et al. 2000; Hilmo and Sastad 2001; Kantvilas and Jarman 2004; Pykälä 2004).

Another important aspect of lichen community structure is the lichen vertical distribution along the host trunk. Changes in temperature and humidity are key factors defining spatial distribution of lichens along tree trunks (Harris 1971; Lang et al. 1980). Tree plantations present, in general, low microhabitat heterogeneity in respect to light penetration, and vegetation cover due to poor canopy stratification. Therefore, conversion of native forests to tree plantations can modify physical characteristics that may alter lichen vertical distribution.

The Araucaria forest from southern Brazil is a subtropical rain forest that contains around 222 species of lichens, 200 of them occurring on tree trunks (Spielmann 2006). This forest has been extensively damaged or converted into plantations of exotic tree species, especially from the genera *Pinus* and *Eucalyptus*. The impact of these forest transformations on lichen communities is still unknown. In the present study we evaluate how the corticolous and foliose lichen community respond to vegetation type alterations such as the conversion of native forest to plantations of tree monocultures. Our specific aims are: (1) to determine if the richness, abundance, diversity and species composition of lichen communities differ between tree plantations and native forest stands; (2) to investigate if there are differences between vegetation types in the way lichen richness is distributed along trunk heights; (3) to determine possible differences in structural characteristics and/or lichen strategies that could explain lichen community distribution throughout vegetation types.

Methods

Study area

This study was undertaken at the National Forest of São Francisco de Paula (FLONA), southern Brazil (29° 02′ S and 50° 23′ W). The reserve lies over a basaltic basin formed during Mesozoic lava extrusion events. The region is located 912 m above see level, with an average temperature of 14.5°C and average rainfall of 2,252 mm year^{-1}. The predominant vegetation type is Araucaria forest, characterized by the dominance of the species *Araucaria angustifolia* (Bert.) O. Ktze. (Araucariaceae, “Brazilian-pine”). The FLONA encompasses an area of 1,607 ha, which contains monoculture stands of tree species from the genera *Araucaria*, *Pinus* and *Eucalyptus*. This National Forest is classified as a Conservation Unit for Sustainable Use. Therefore, these stands differ from classical tree monoculture plantations in age (being older), in size (being smaller), and by surroundings (being of native forest). Additionally, disturbance of understory regeneration in these areas due to events of thinning occurred less frequently than in commercial tree plantations. All this “ecologically optimum management” provides an excellent scenario for the establishment of new lichen species in these tree plantation stands.

Sampling

The sampling was carried out in three stands of each vegetation type: native Araucaria forest (FO), Araucaria plantation (PA), Pine plantation (PP), and Eucalyptus plantation (PE); 12 stands total. Each stand was selected based on its availability and accessibility, but all stands were at least 1 ha in area and at least 100 m apart. For Eucalyptus plantations only three stands of minimum size of 1 ha were available. There was no standardization for stand distance from native forest but this vegetation type was reasonably spread around stands (Fig. 1). The three native Araucaria forest stands studied had been recorded as undisturbed forest until the end of the 19th century. Selective logging occurred in these stands from 1900 to 1950 and after that all three stands were left undisturbed. All plantation stands were established on old agricultural fields or pastures. The Araucaria plantations were between 44 and 56 years old, the Pine plantations between 35 and 38 years old and the Eucalyptus plantations between 15 and 31 years old. Different tree species were able to colonize naturally all stands studied from the beginning of their implementation, this management procedure allowed different types of host trees to be present in all plantations.

In each replicate, ten host—trees were randomly sampled, with 120 host-trees in total. In order to choose host trees we randomized ten points in each 1 ha stand, and the nearest tree (planted or naturally established) that was at least 8 cm in DBH was chosen for lichen sampling. In each one of the stands, for each host-tree, the corticolous and foliose lichens were recorded from 30 to 150 cm above the ground by placing a rubber band around the trunk every 10 cm (Marcelli 1992). All the species that touched the rubber band were identified in the field or collected for posterior identification. Each rubber band was divided into 100 units of equal size, thus the number of rubber band units covered by lichens were used as a measurement of lichen abundance.

The lichen identification was carried out by observing anatomical sections of the thallus and fructifications using stereoscopic and optical microscopes. The external characteristics of the lobes like color and thallus aspect, width and length of the lobes, presence of pycnidia, and the aspect of the rhizines, ciliates, and apothecia were also analyzed. Coloration tests were used to determine the presence of the acid substances in the cortex and medulla. Identified samples were incorporated into the Herbarium Prof. Dr. Alarich Schultz (HAS) of the Zoobotanical Fundation of Rio Grande do Sul State, Brazil.

Each sampled host-tree was identified to species, and its bark type, bark pH, diameter at breast height (DBH), and tree height were recorded. The host-trees were identified in the field, or in the Laboratory with the help of specialists. For each tree species, the following

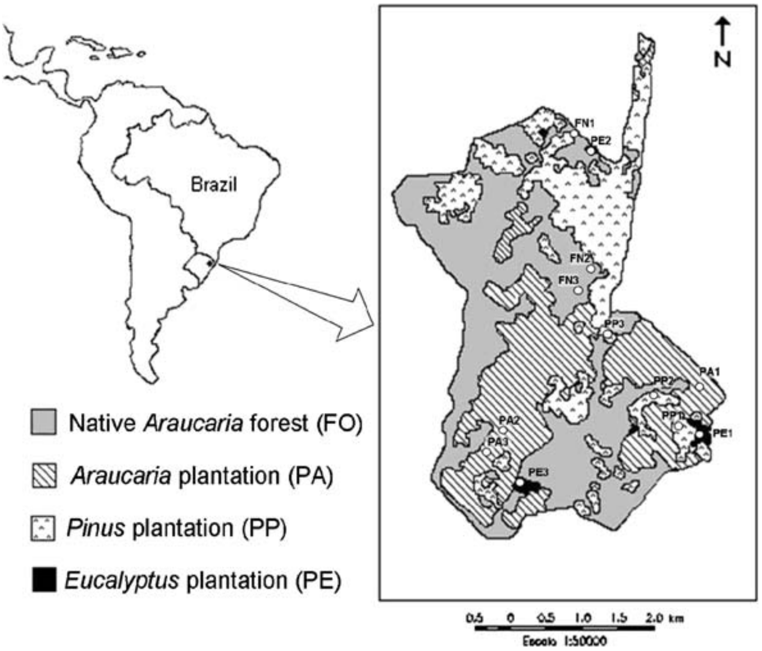


Fig. 1 Map of the study area representing the locations of different vegetation types studied at the National Forest of São Francisco de Paula, southern Brazil

bark types were identified: furrowed, fibrous, and smooth. The tree bark's pH was determined in the field, in a clean space of the tree trunk, free of lichens and bryophytes using a digital pH measurer model PH—1,700—Instrutherm.

Data analysis

Species richness was considered as the total number of lichen species occurring in the 10 host-trees analyzed in each stand. The lichen abundance was calculated by adding up the number of rubber band units covered by lichens for the 13 height levels and 10 host-trees studied in each stand (13 height levels, 100 units per level, 10 host-plants).

We calculated two types of lichen diversity indexes, one based on cover that has the assumption that large individuals are more abundant and another index based on occurrence that has the assumption that the most abundant individuals are the ones present in the largest number of trees, independent of lichen size. The indexes were calculated using the Shannon–Wiener Diversity Index (Krebs 1999). For the diversity index based on cover, the relative abundance of each species was represented by the number of elastic units in which the species was recorded on each host-tree, divided by the total number of units in which the lichens were recorded. For the diversity index based on occurrence, the relative abundance of each species was represented by the number of host-trees on which the species was present in each stand, this number varied from 1 to 10. Lichen richness, abundance and diversity were compared among vegetation types with an ANCOVA analysis using the sum of the DBHs for each host-tree as a covariant variable to correct for possible differences in sampling effort between stands. Analyses were performed using the General Linear Model procedure of Systat 10 (2000) package.

To investigate possible changes in species similarity between lichen communities present in plantations and native forest stands a cluster analyses based on the relative Sørensen coefficient of dissimilarity as classification method, flexible beta = 0.25 was used as the clustering algorithm (McCune et al. 2002). To understand how the different lichen species influenced differences in community composition between vegetation types, a non-metric multidimensional scaling (NMS) was performed as ordination method. This analysis used the relative Sørensen coefficient of dissimilarity as classification method. The statistical analyses were performed using the PC-ORD 4.0 statistical program (McCune and Mefford 1999).

All lichen species were characterized as shade tolerant or light demanding species according Marcelli et al. (1998) plus 32 published articles on species taxonomic description, as well as based on the authors' unpublished data. The lichen taxa were classified following their geographical distribution. The specimens listed as new records to science were referred to as having restricted distribution, whereas the others were classified as having tropical distribution (occurring only in tropical regions), temperate distribution (occurring only in temperate regions) and cosmopolitan distribution (spread in tropical and temperate regions).

Lichen species richness was compared between heights and vegetation types, using height, vegetation type, and the vegetation type x height interaction as independent variables. The analysis was performed using the GLM—General Linear Model procedures of SYSTAT 10.

To investigate possible differences between vegetation types in the availability of proper trees for lichen fixation, average measurements of tree DBH and bark pH, as well as measurements of host-tree richness were compared among vegetation types, by ANOVA, using the LSD a posteriori test. The availability of host tree bark types for lichen fixation was compared among vegetation types using a Chi-square test.

Results

Seventy-eight lichenized fungi, from 18 genera, were recorded. Among them, 81% were colonized by chlorophyceans and 19% by cyanobacteria (Table 1). In total, 27 species were found in the native Araucaria forests, 49 species in the Araucaria plantations, 27 species in the Pine plantations, and 30 species in the Eucalyptus plantations.

Species occurrence

There were differences in species distribution among vegetation types. Of the 44 species that were specific of a single vegetation type, 11 occurred in the native Araucaria forest, 15 occurred only in the Araucaria plantations, 5 only in the Pine plantations and 10 only in the Eucalyptus plantations. Four species occurred in all vegetation types: *Heterodermia leucomela* (L.) Poelt, *Heterodermia obscurata* (Nyl.) Trevis, *Leptogium azureum* (Sw.) Mont. and *Parmotrema rampoddense* (Nyl.) Hale (Table 1). Around 15% of the species found in the native Araucaria forest occurred also in the tree plantations: Of those species 10 (83.3%) were found in both forest and plantations. One (8.3%) was found in Araucaria forest and Pine plantation and 8.3% in the Eucalyptus plantations. About 25% of those species that were found in the Araucaria plantations were also found in the Pine and Eucalyptus plantations.

Table 1 Composition and occurrence of lichen species in four vegetation types in south Brazil

Species	FO	PA	PP	PE	Algae	Habitat	Distribution	Family
Phyllopsora confusa Swinscow & Krog	168				Cl.	Shady	Trop	Biatorac.
Lobaria tenuis Vainio	120				Cl.	Shady	Trop	Lobariac.
Sticta sinuosa Pers.	134				Cl.	Shady	Temp	Stictac.
Sticta damaecornis (Sw.) Ach.	274				Cl.	Shady	Cosmopolitan	Stictac.
Sticta variabilis (Bory) Ach.	168				Cl.	Shady	Cosmopolitan	Stictac.
Coenogonium cf. *interplexum* Nyl.	35				Cl.	Shady	Cosmopolitan	Gyalectac.
Physcia sp. 1 •	25				Cl.	Shady	Restrict	Physciac.
Sticta sp. 6	74				Cl.	Shady	Restrict	Stictac.
Sticta sp. 1	11				Ci.	Shady	Restrict	Stictac.
Coenogonium linkii Ehrenb.	255				Cl.	Shady	Trop	Gyalectac.
Lobaria cf. *discolor* (Bory ex Delise) Hue	23				Cl.	Shady	Trop	Lobariac.
Canoparmelia sp. 1 ■		5			Cl.	Sunlight	Restrict	Parmeliac.
Lobaria cf. casarettiana (De Not.) Trev. •		5			Cl.	Shady	Trop	Lobariac.
Sticta sp. 4		4			Ci.	Shady	Restrict	Stictac.
Parmotrema melanothrix (Mont.) Hale		10			Cl.	Sunlight	Trop	Parmeliac.
Parmotrema hypomiltoides (Vainio) Fleig		29			Cl.	Sunlight	Trop	Parmeliac.
Parmotrema crinitum (Ach.) M. Choisy		22			Cl.	Sunlight	Cosmopolitan	Parmeliac.
Parmotrema aff. *subarnoldi* (Abb.) Hale ▲		17.5			Cl.	Shady	Trop	Parmeliac.
Coccocarpia pellita (Ach.) Müll. Arg. ex R. Sant.		7			Ci.	Shady	Trop	Coccocarpiac.
Parmotrema neosubcrinitum Ribeiro & Marcelli ▲		67			Cl.	Sunlight	Restrict	Parmeliac.
Parmotrema bangii (Vainio) Hale ▲		18			Cl.	Shady	Trop	Parmeliac.
Pseudocyphellaria clathrata (De Not.) Malme		15			Cl.	Shady	Trop	Stictac.
Lobaria sp. 1		40			Cl.	Shady	Restrict	Lobariac.
Lobaria intermedia (Nyl.) Vainio •		50			Cl.	Shady	Trop	Lobariac.
Heterodermia vulgaris (Vainio) Follmann & Redón		30			Cl.	Shady	Trop	Physciac.

Table 1 continued

Species	FO	PA	PP	PE	Algae	Habitat	Distribution	Family
Leptogium cf. *pichneum* (Ach.) Malme		40			Ci.	Shady	Trop	Collematac.
Hypotrachyna aff. *livida* (Taylor) Hale			5		Cl.	Sunlight	Cosmopolitan	Parmeliac.
Hypotrachyna steyemarkii (Hale) Hale ▲			7		Cl.	Sunlight	Trop	Parmeliac.
Parmelinopsis cf. *minarum* (Vainio) Elix & Hale			15		Cl.	Sunlight	Trop	Parmeliac.
Hypotrachyna croceopustulata (Kurok.) Hale •			6		Cl.	Sunlight	Cosmopolitan	Parmeliac.
Hypotrachyna cf. *peruviana* (Nyl.) Hale			11		Cl.	Sunlight	Trop	Parmeliac.
Heterodermia flabellata (Fée) Awasthi				10	Cl.	Sunlight	Trop	Physciac.
Rimelia homotoma (Nyl.) Hale & Fletcher				10	Cl.	Sunlight	Temp	Parmeliac.
Lobaria cuprea (Müll. Arg.) Zahlbr.				23	Cl.	Shady	Trop	Lobariac.
Leptogium marginellum (Swartz) S. Gray				10	Ci.	Shady	Trop	Collematac.
Leptogium isidiosellum (Riddle) Sierk ▲				10	Ci.	Shady	Cosmopolitan	Collematac.
Punctelia riograndensis (Lynge) Krog				20	Cl.	Sunlight	Trop	Parmeliac.
Canomaculina subcaperata (Kremp.) Elix				27	Cl.	Sunlight	Trop	Parmeliac.
Physcia sp. 2 •				15	Cl.	Sunlight	Restrict	Physciac.
Canomaculina uruguensis (Kremp.) Elix				10	Cl.	Sunlight	Restrict	Parmeliac.
Coccocarpia erythroxyli (Spreng.) Swinscow & Krog				22	Ci.	Shady	Cosmopolitan	Coccocarpiac.
Heterodemia galactophylla (Tuck.) W. L. Culb.	15	20			Cl.	Sunlight	Trop	Physciac.
Punctelia graminicola (W. L. Culb. & C. F. Culb.) Krog	35	75			Cl.	Sunlight	Cosmopolitan	Parmeliac.
Sticta sp. 2	7	13			Ci.	Shady	Restrict	Stictac.
Sticta weigelii (Ach.) Vainio	9	5			Ci.	Shady	Trop	Stictac.
Pannaria rubiginosa (Ach.) Bory	46	32			Ci.	Shady	Cosmopolitan	Pannariac.
Leptogium sp. 1	10	45			Ci.	Shady	Restrict	Collematac.
Lobaria sp. 2	10	123			Cl.	Shady	Restrict	Lobariac.
Cladonia ceratophylla (Sw.) Spreng.	5		39		Cl.	Shady	Trop	Cladoniac.
Leptogium cyanescens (Ach.) Körb.	30			13.3	Ci.	Shady	Cosmopolitan	Collematac.

Table 1 continued

Species	FO	PA	PP	PE	Algae	Habitat	Distribution	Family
Hypotrachyna singularis (Hale) Hale •		15	12		Cl.	Sunlight	Trop	Parmeliac.
Parmotrema sp. 1 ■		20	5		Cl.	Sunlight	Restrict	Parmeliac.
Rimelia reticulata (Taylor) Hale & Fletcher		255	6		Cl.	Sunlight	Cosmopolitan	Parmeliac.
Rimelia simulans (Hale) Hale & Fletcher		114	3		Cl.	Sunlight	Cosmopolitan	Parmeliac.
Punctelia reddenda (Sirt.) Krog		5	18		Cl.	Sunlight	Cosmopolitan	Parmeliac.
Hypotrachyna sp. 1		1	6		Cl.	Sunlight	Restrict	Parmeliac.
Sticta sp. 3		10	5		Ci.	Shady	Restrict	Stictac.
Parmelinopsis horrescens (Taylor) Elix & Hale		41	17		Cl.	Shady	Cosmopolitan	Parmeliac.
Heterodermia japonica (Sato) Swinscow & Krog		172		10	Cl.	Sunlight	Cosmopolitan	Physciac.
Lobaria erosa (Eschw.) Nyl.		172.5		35	Cl.	Shady	Cosmopolitan	Lobariac.
Rimelia cetrata (Ach.) Hale & Fletcher		45		66	Cl.	Sunlight	Cosmopolitan	Parmeliac.
Hypotrachyna livida (Taylor) Hale		25		30	Cl.	Sunlight	Cosmopolitan	Parmeliac.
Pseudocyphellaria aurata (Ach.) Vainio		5		20	Cl.	Shady	Cosmopolitan	Stictac.
Hypotrachyna sp. 2			26	18	Cl.	Sunlight	Restrict	Parmeliac.
Leptogium austroamericanum (Malme) Dodge	8	15	15		Ci.	Shady	Trop	Collematac.
Heterodermia speciosa (Wulf.) Trev.	5	62		15	Cl.	Sunlight	Cosmopolitan	Physciac.
Lobaria patinifera (Taylor) Hue	4	5		69	Cl.	Shady	Trop	Lobariac.
Parmotrema mellissii (Dodge) Hale		63	130	15	Cl.	Sunlight	Trop	Parmeliac.
Parmotrema gardneri (Dodge) Sérusiaux ▲		21	22	10	Cl.	Shady	Cosmopolitan	Parmeliac.
Parmotrema robustum (Degel.) Hale		41	11	5	Cl.	Sunlight	Trop	Parmeliac.
Parmotrema eciliatum (Nyl.) Hale		96	5	10	Cl.	Sunlight	Cosmopolitan	Parmeliac.
Rimelia macrocarpa (Pers.) Hale & Fletcher		7	10	5	Cl.	Sunlight	Trop	Parmeliac.
Parmotrema rigidum (Lynge) Hale		5	5	5	Cl.	Sunlight	Cosmopolitan	Parmeliac.
Canoparmelia caroliniana (Nyl.) Elix & Hale		41	70	9	Cl.	Shady	Cosmopolitan	Parmeliac.
Heterodermia leucomela (L.) Poelt.	10	18	11	17	Cl.	Shady	Trop	Physciac.

Table 1 continued

Species	FO	PA	PP	PE	Algae	Habitat	Distribution	Family
Heterodermia obscurata (Nyl.) Trev.	15	106	10	40	Cl.	Sunlight	Trop	Physciac.
Leptogium azureum (Sw.) Mont.	38	42	63	62	Ci.	Shady	Trop	Collematac.
Parmotrema rampoddense (Nyl.) Hale	25	54	18	15	Cl.	Sunlight	Trop	Parmeliac.

FO native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation. *Legend*: • new report for Brazil, ■ new species, ▲ new report for RS state, *cl* chlorophycean, *ci* cyanobacteria, *trop* tropical, *temp* temperate. Numbers represent the total abundance values for each lichen species at the four vegetation types

Richness, diversity, and abundance

Lichen richness, abundance and diversity tended to be greater in the Araucaria plantations (Fig. 2a–d). However, this pattern was only significant for lichen richness (Table 2, Fig. 2a). The sampling effort (sums of tree DBH) did not show any significant effect on the lichen richness and diversity (Table 2).

Species composition

Cluster analysis yielded three distinct groups revealing differences in species composition among vegetation types. The vegetation type which showed the most distinct species composition was the Araucaria forest (Fig. 3a). The NMS (non-metric multidimensional scalling) ordination revealed that Araucaria forests formed a distinct group strongly related to shade tolerant species. The analysis produced 6 axes and the percentage of variance explained by the first two axes added up 62.9, 43.5% in the first axis and 19.4% in the second. Axis 1 showed positive correlation with shade tolerant species characteristics of native Araucaria forest such as *Phyllopsora confusa* Swinsc & Krog, *Lobaria tenuis* Vain

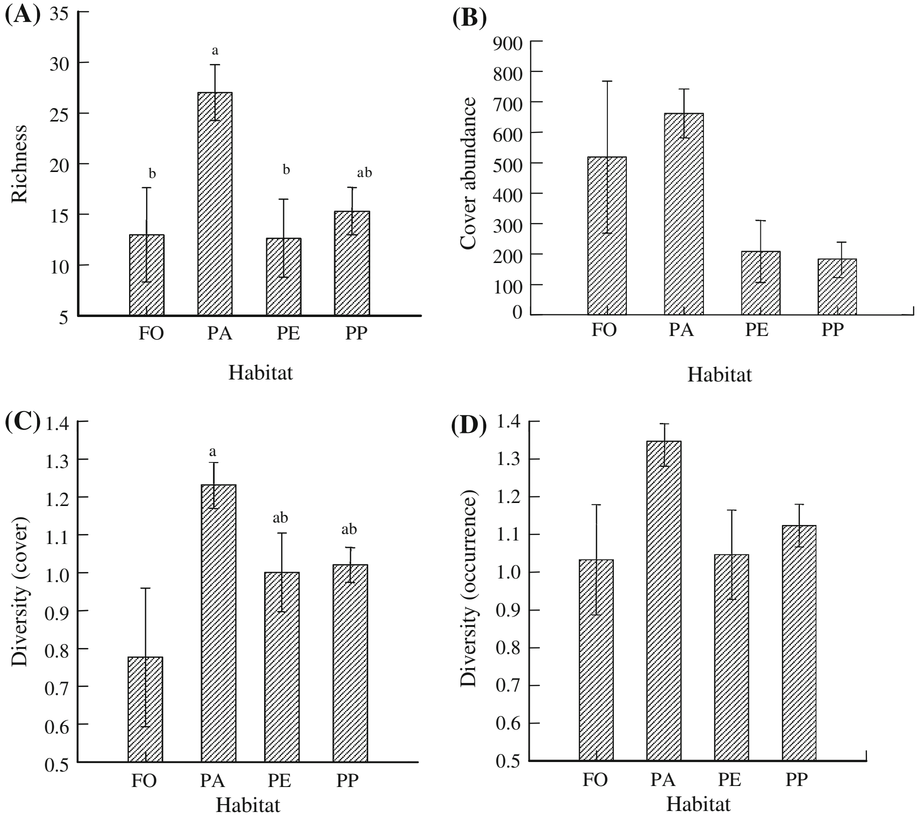


Fig. 2 Lichen species richness (**a**) Cover abundance (**b**), Shannon's Diversity Index based on lichen cover (**c**) and Shannon's Diversity index based on lichen occurrence in host-trees (**d**). Vegetation types represent: *FO* native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation

Table 2 *F* values and probability (*P*) for richness, abundance, diversity based on cover, and diversity based on occurrence of lichen species

Sources	*df*	Richness		Cover abundance		Diversity (cover)		Diversity (occurrence)	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Habitat	3	5.71	0.027	3.60	0.07	4.1	0.05	3.27	0.09
Sampling effort	1	0.05	0.83	0.19	0.67	0.1	0.91	0.02	0.89
Error	7								

Sources of variation represent vegetation types (native Araucaria forest, Araucaria plantation, Pine plantation, and Eucalyptus plantation) and sampling effort

and species of the genus *Sticta*. The second axis showed negative correlation with light demanding species such as species of the genus *Heterodermia* and family Parmeliaceae (Fig. 3b).

Distribution of shade and light demanding species

The contingency table showed that there were differences among vegetation types in relation to the abundance of shade and light demanding species. In the native Araucaria forest there was a greater observed frequency of shade tolerant lichens in relation to the expected frequency, however, in the Pine and Eucalyptus vegetation type the inverse was true, a greater percentage of light demanding lichens was encountered ($\chi^2 = 16.4$, $df = 3$, $P = 0.001$, Fig. 4). In the Araucaria plantations, however, there was no difference in the occurrence of these two lichen groups. There was no significant relationship between the lichen species' geographical distribution and the vegetation type they occurred ($\chi^2 = 0.38$, $df = 3$, $P > 0.05$), thus, species with wide or restrict distributions occurred in all vegetation types studied.

In the native Araucaria forest, shade tolerant genera such us *Sticta*, *Phyllopsora,* and *Coenogonium* occurred in 66.7% of all trees sampled. The abundance of these shade tolerant genera was also very high in the Araucaria forest, the only vegetation type where *Phyllopsora,* and *Coenogonium* were encountered (Table 1). *Leptogium* is also another genus characteristic of shady and humid environments, however, its species are very adaptable to different vegetation types (Wolseley 1991), especially *Leptogium azureum* (Sw.) Mont., which was present in the four vegetation types studied. Like most Brazilian vegetation were Parmeliaceae is by far the most important family (Marcelli 1998), all tree plantations support a great number of species from this light-demanding group. This family was quite frequent in our samples and was responsible for 44.8% of the species recorded in all vegetation types. However, only 2.6% of these Parmeliaceae species were reported in the native Araucaria forest at the height levels sampled. The most common genus of this family, *Parmotrema* encompasses 33.3% of the lichen species sampled in plantations.

Vertical distribution of species richness

In all vegetation types, lichen species richness was significantly larger at the highest trunk height measurements (Table 3, Fig. 5). Richness was consistently greater in Araucaria plantations followed by native Araucaria forests. Nevertheless, the interaction among height and vegetation types was not significant (Table 3, Fig. 5).

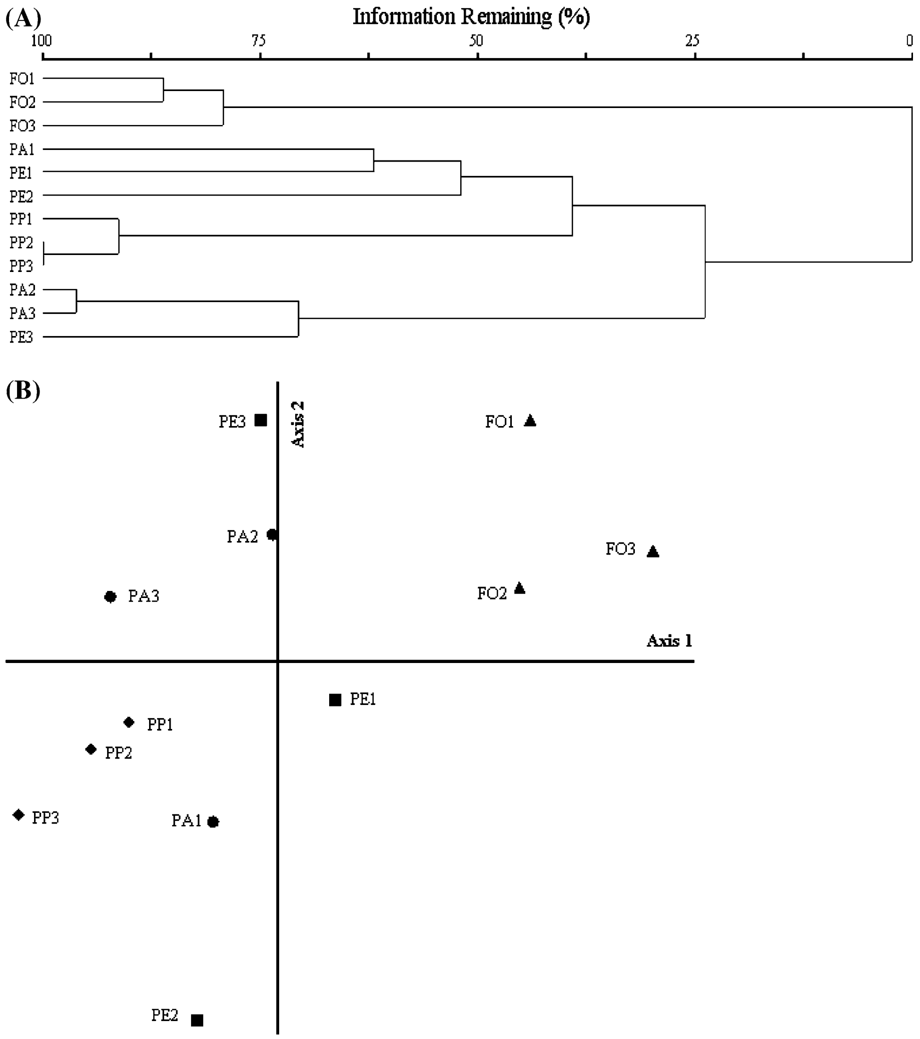


Fig. 3 Cluster of similarity in community composition based on the relative Sørensen coefficient of dissimilarity (**a**); and ordination of community composition using the Non-Metric Multidimensional Scaling (*NMS*) method based on the relative Sørensen coefficient of dissimilarity (**b**). Vegetation types represent: *FO* native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation

Host-tree composition

In terms of composition and occurrence of the 120 host-trees sampled, the following species presented the highest frequency of individuals: *Araucaria angustifolia* (Bert.) O. Ktze (23.3%), followed by *Pinus* spp. (20%) and *Eucalyptus* spp. (19.2%). Tree species dominance differed among vegetation types. In the native Araucaria forest host-tree dominance was low (Fig. 6a), however, 73.3% of the trees sampled in Araucaria plantations were *A. angustifolia* trees (Fig. 6b). In the Pine plantations, the *Pinus* species stood out, representing 80% of the analyzed host-trees (Fig. 6c), and in the Eucalyptus plantation, the *Eucalyptus* species represented 76.7% of the sampled host-trees (Fig. 6d).

Fig. 4 Frequency of shade tolerant and light demanding lichen species, in four vegetation types: *FO* native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation

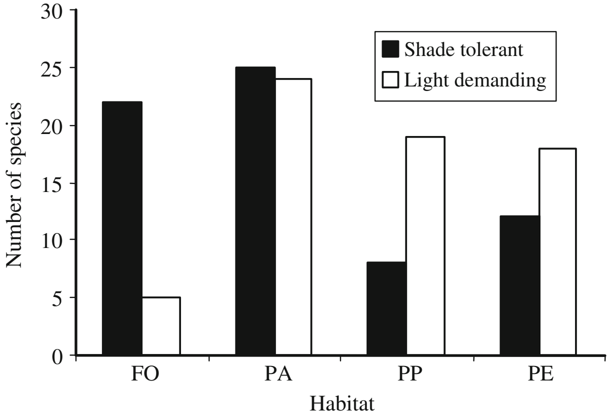
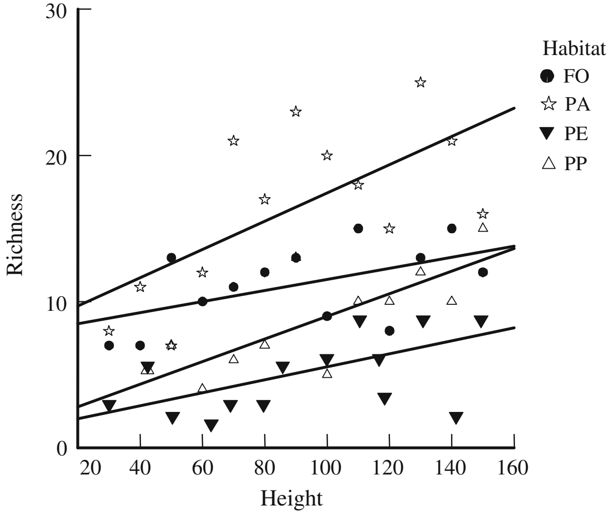


Table 3 ANOVA table for lichen richness

Sources	*df*	SS	MS	*F*	*P*
Height	2	299.57	29.957	3.72	0.03
Habitat	1	83.111	2.770	34.10	0.00
Habitat × height	3	4.207	1.402	1.59	0.20
Error	44	38.651	8.78		

Sources of variation represent: Height (lichen fixation height on host-trees) and vegetation types (native Araucaria forest, Araucaria plantation, Pine plantation, and Eucalyptus plantation)

Fig. 5 Distribution of lichen richness in relation to trunk height in four vegetation types at the National Forest of São Francisco de Paula, southern Brazil: *FO* native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation



There were differences among vegetation types for various host-tree characteristics such us DBH, bark pH and bark structure (Table 4). In terms of bark structure, there were significant differences in their occurrence among vegetation types ($\chi^2 = 24.51$, $df = 6$, $P < 0.01$). Fissured barks occurred at a higher frequency than expected in the native

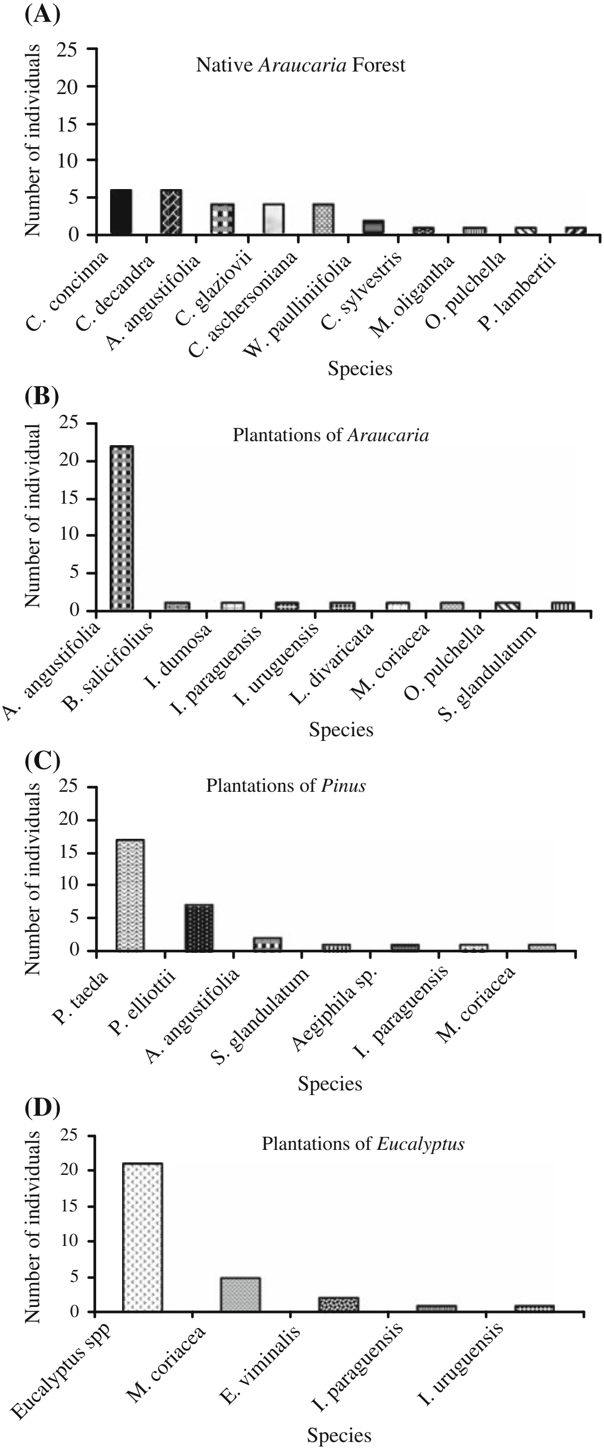


Fig. 6 Host-tree frequency distribution sampled in four vegetation types at the National Forest of São Francisco de Paula, southern Brazil: *FO* native Araucaria forest (**a**), *PA* Araucaria plantation (**b**), *PP* Pine plantation (**c**) and *PE* Eucalyptus plantation (**d**)

Araucaria forest (15.8%) and in the Pine plantation (11.7%), being less frequent in the Araucaria and Eucalyptus plantations. There was a higher frequency of smooth bark than expected in the Eucalyptus plantation (1.7%), compared to the other vegetation types. Furrowed barks were more frequently found in the Araucaria (20.8%) and Eucalyptus (18.3%) plantations while in the Pine plantation and in the native Araucaria forest, this frequency was lower than expected. For all tree species sampled DBH varied between 8 and 63.7 cm. DBH of sampled host trees was significantly higher in the Pine plantations ($F = 12.65$, $df = 3,8$, $P < 0.05$). For all vegetation types bark pH varied between 5.9 and 8.7. *Eucalyptus* species presented the lowest values of bark pH (Table 4), and host-tree bark pH was on average, lower in the Eucalyptus plantation ($F = 18.62$, $df = 3,8$, $P < 0.05$).

Table 4 Host-tree characteristics and occurrence in four vegetation types at the National Forest of São Francisco de Paula

Species	Number of individuals	DBH	Bark pH	Habitat	Structure bark	Height
Araucaria angustifolia (Bert.) O. Ktze.	28	8.4–52.9	7.8	FO, PA, PP	Furrowed	10.0
Ilex paraguensis St. Hil.	3	8.0–16.9	7.7	PA, PP, PE	Fissured	5.7
Ilex dumosa Reissek	1	8.3	7.1	PA, PP	Fissured	5.0
Myrsine coriacea	7	8.4–13.1	7.0	PA, PP, PE	Fissured	7.5
Sapium glandulatum (Vell.) Pax	2	8.1–11	7.3	PA, PP	Fissured	6.5
Blepharocalyx salicifolius (Kunth) O. Berg	1	8.4	8.4	PA	Furrowed	13.5
Ocotea pulchella Mart.	2	8.6–15.1	8.1	FO, PA	Fissured	12.0
Inga uruguensis Hook. et Arn.	2	9.5–11.1	7.9	PA, PE	Furrowed	6.0
Luehea divaricata Mart. et Zucc.	1	18.2	7.8	PA	Furrowed	10.0
Calyptranthes concinna DC.	6	8.6–16.2	8.1	FO	Furrowed	9.2
Cryptocarya aschersoniana Mez	4	14–63.7	7.8	FO	Fissured	14.0
Myrcia oligantha Berg	1	16.6	8.7	FO	Furrowed	14.0
Casearia decandra Jacq.	6	8.4–20.2	7.2	FO	Fissured	10.3
Cinnamomum glaziovii (Mez) Kasten	4	8.8–34.4	7.0	FO	Fissured	8.7
Podocarpus lambertii Klotzsch	1	32.8	8.0	FO	Fissured	20.0
Casearia sylvestris	1	44.5	7.0	FO	Fissured	8.0
Weinmannia paulliniifolia Pohl ex Seringe	2	9.1–19.4	7.7	FO	Fissured	9.5
Pinus elliottii Engelm	7	35.5–54.1	8.3	PP	Fissured	13.4
Aegiphila sp.	1	13.4	7.8	PP	Fissured	6.0
Pinus taeda L.	17	38.8–55.7	7.7	PP	Fissured	15.1
Eucalyptus viminalis Labill.	2	8.9–11.3	6.3	PE	Smooth	7.0
Eucalyptus spp.	21	9.4–38.8	5.9	PE	Furrowed	9.8

Vegetation types represent: *FO* native Araucaria forest, *PA* Araucaria plantation, *PP* Pine plantation and *PE* Eucalyptus plantation. DBH stands for “diameter at breast height”

Discussion

Various lichen species of native Araucaria forest did not find difficulties to establish in Araucaria, Pine, and Eucalyptus plantations. This pattern was probably due to the management procedures applied in these plantations. All monoculture stands were surrounded by native forest, had smaller size and were allowed to last longer than commercially managed plantations. These factors improved the chances of species migration from the forests to monoculture stands (Sillet et al. 2000; Pykälä 2004). These findings highlight the importance of maintaining stands that are "ecologically managed" in commercial tree plantations (Fonseca et al. 2009). Such stands could function as corridors promoting establishment, reproduction and lichen species translocation between forest areas.

Conversion of native forest to plantations, nonetheless, altered lichen community composition. The greatest occurrence of shade tolerant species was recorded in the native Araucaria forest while an increase in light demanding lichen species was found in tree plantations. These results may be explained by the well-established fact that disturbance has a negative effect on shade species from forest understorey whereas canopy species tend to increase in abundance. This pattern has been shown for many organisms including bryophytes and insects (Lesica et al. 1991; Kantvilas and Jarman 2004; Gunnarsson et al. 2004; Martinez et al. 2006; Lõhmus et al. 2007), and has been widely registered for lichens from neotropical regions (Lücking 1999; Sipman 1997, 2006; Komposch and Hafellner 2000, 2003; Cáceres et al. 2008; Rivas Plata et al. 2008). Our results show that few light demanding species of Parmeliaceae were reported for the native Araucaria forest at the height levels sampled. However, species of this family are dominant in the canopy of humid tropical forests (Sipman and Harris 1989; Fleig and Grüninger 2008). Indeed, various light demanding species were encountered on branches that fell from the native Araucaria forest canopy (Käffer unpublished data). These results suggest that this native Araucaria forest may be able to maintain a greater diversity of light demanding lichen species at its upper strata and that these species may have been able to establish themselves in the understory of plantations due to the greater light penetration therein. This study emphasizes that converting native forests into exotic tree plantations may not affect light demanding lichen species but can cause the loss of species typical to shady and humid environments. This pattern occurs even when plantations are surrounded by native forest and less intensively managed.

Lichen community structure in terms of species richness, and diversity was also affected by the conversion of native forest to monoculture plantations. The greatest diversity of lichens was encountered in the Araucaria plantations when compared to all other vegetation types studied. The more advanced age of these stands, compared to the exotic tree plantations, may partially explain these results. Nonetheless, Araucaria plantations were younger than native Araucaria forest stands, and still sustained greater lichen diversity in its understorey. In Araucaria plantations, we found the largest frequency of *A. angustifolia* a native host-tree. Araucaria has a wide range of lichen species adapted to it and is an excellent host-tree for lichen establishment, because the fibrous structure of its bark is able to retain water thus increasing bark humidity levels. Studies undertaken in woody vegetation confirm that alterations in lichen community structure could be attributed to host-tree composition and their bark characteristics (Hawksworth 1975; Hale 1983; Ferry and Lodge 1996). Therefore, a greater diversity of lichens can be preserved in the landscape, if plantations of exotic Pine and Eucalyptus trees are replaced by plantations of the native species *A. angustifolia*.

Lichen richness increased with trunk height at the same rate for all vegetation types. Changes in trunk height may cause microclimate changes in humidity and light that in general modify lichen species composition and its vertical distribution (Harris 1972; Lang et al. 1980; Hilmo and Sastad 2001). With increases in trunk height, light becomes increasingly available and new species became better able to colonize tree trunks. These results demonstrate that light can be a limiting factor for lichen establishment in the understorey of all vegetation types studied.

Our results show that the conversion of rain forests to monoculture plantations of exotic tree species decreases lichen species diversity and alters lichen community composition. Even when the best options of management for conserving biodiversity are applied, exotic tree plantations suffer from losses of lichen species that reach up to 42% of the species available for colonization. We conclude that the use of native tree species with bark structure favorable to lichen establishment, such as *A. angustifolia*, would be the best option for the maintenance of lichen diversity in commercially altered landscapes. The large scale implementation of native tree vegetation type may not only lead to increases in lichen diversity but can also favor the great variety of organisms that use lichens for food and shelter.

Acknowledgments We thank Leomar Paese for helping with the field work, the Floresta Nacional de São Francisco de Paula (IBAMA) for providing the study area and the Museu de Historia Natural da Fundação Zoobotânica do Rio Grande do Sul for providing structure for the laboratorial analysis. We thank Edward G.F. Benya for kindly revising the English. Gislene Ganade was funded by CNPq with a PQ grant. This work was supported by the Brazilian National Research Council (CNPq) and the Universidade do Vale do Rio dos Sinos, UNISINOS, Brazil.

References

Brodo IM (1973) Substrate ecology. In: Hale ME (ed) The lichens. Academic Press, New York, pp 401–436

Brunialti G, Giordani P (2003) Variability of lichen diversity in a climatically heterogeneous area (Liguria, NW Italy). Lichenologist 35:55–69. doi:10.1006/lich.2002.0417

Cáceres MES, Lücking R, Rambold G (2008) Corticolous microlichens in northeastern Brazil: habitat differentiation between coastal Mata Atlântica, Caatinga and Brejos de Altitude. Bryologist 111:98–117. doi:10.1639/0007-2745(2008)111[98:CMINBH]2.0.CO;2

Ferry BW, Lodge E (1996) Distribution and succession of lichens associated with *Prunus spinosa* at Dungeness, England. Lichenologist 28:129–143

Fleig M, Grüninger W (2008) Liquens da Floresta com Araucária no Rio Grande do Sul. Pró-Mata: Guia de Campo 3. University of Tübingen, Germany

Fonseca CR, Ganade G, Baldissera R, Becker CG, Boelter CR, Brescovit AD, Campos LM, Fleck T, Fonseca VS, Hartz SM, Joner F, Käffer MI, Leal-Zanchet AM, Marcelli MP, Mesquita AS, Mondin CA, Paz CP, Petry MV, Piovensan FN, Putzke J, Stranz A, Vergara M, Vieira EM (2009) Towards and ecologically-sustainable forestry in the Atlantic Forest. Biol Conserv 142:1209–1219

Goward T, Spribille T (2005) Lichenological evidence for the recognition of inland rain forest in western North America. J Biogeogr 32:1209–1219. doi:10.1111/j.1365-2699.2005.01282.x

Gunnarsson B, Hake M, Hultengren S (2004) A functional relationship between species richness of spiders and lichen in spruce. Biodivers Conserv 13:685–693. doi:10.1023/B:BIOC.0000011720.18889.f7

Hale ME (1957) Lectures notes lichenology. West Virginia University, Morgantown

Hale ME (1983) The biology of lichens. In: Arnold E (ed) 3rd edn. London

Harris GP (1971) The ecology of corticolous lichens. J Ecol 59:431–439. doi:10.2307/2258323

Harris GP (1972) The ecology of corticolous lichens. J Ecol 60:19–40. doi:10.2307/2258038

Hawksworth DL (1975) Lichens—new introductory, matter and supplementary. The Richmond Publishing Co., Cambridge [index by Smith AL (1921)]

Hilmo O, Sastad SM (2001) Colonization of old-forest lichens in a young and old boreal *Picea abies* forest: an experimental approach. Biol Conserv 102:251–259. doi:10.1016/S0006-3207(01)00100-8

Humphrey JW, Davey S, Peace AJ, Ferris R, Harding K (2002) Lichens and bryophyte communities of planted and semi-natural forests in Britain: the influence of stand type, stand structure and deadwood. Biol Conserv 107:165–180. doi:10.1016/S0006-3207(02)00057-5

Jesberger JA, Sheard JW (1973) A quantitative study and multivariate analysis of corticolous lichen communities in the southern boreal forest of Saskatchewan. Can J Bot 51:185–201. doi:10.1139/b73-026

Jüriado I, Paal J, Liira J (2003) Epiphytic and epixylic lichen species diversity in Estonian natural forests. Biodivers Conserv 12:1587–1607. doi:10.1023/A:1023645730446

Kantvilas G, Jarman SJ (2004) Lichens and bryophytes on *Eucalyptus obliqua* in Tasmania: management implications in production forests. Biol Conserv 117:359–373. doi:10.1016/j.biocon.2003.08.001

Komposch H, Hafellner J (2000) Diversity and vertical distribution of lichens in a Venezuela tropical lowland rain forest. Selbyana 21:11–24

Komposch H, Hafellner J (2003) Species composition of lichen dominated corticolous communities: a lowland rain forest canopy compared to an adjacent shrubland in Venezuela. Bibl Lichenol 86:351–367

Krebs CJ (1999) Ecological methodology. Menlo Park, Benjamin/Cummings

Lang GE, Reiners WA, Pike LH (1980) Structure and biomass dynamics of epiphytic lichen communities of balsam fir forest in New Hampshire. Ecology 61:541–550. doi:10.2307/1937420

Lesica P, McCune B, Cooper SV, Hong WS (1991) Differences in lichen and bryophyte communities between old-growth and managed second-growth forests in the Swan Valley, Montana. Can J Bot 69:1745–1755. doi:10.1139/b91-222

Lõhmus A, Lõhmus P, Vellak K (2007) Substratum diversity explains landscape-scale co-variation in the species-richness of bryophytes and lichens. Biol Conserv 135:405–414. doi:10.1016/j.biocon.2006.10.015

Lücking R (1999) Ecology of foliicolous lichens at the ‘Botarrama’ trail (Costa Rica), a neotropical rainforest. IV. Species associations, their salient features and their dependence on environmental variables. Lichenologist 31:269–289

Marcelli MP (1992) Ecologia liquenica nos manguezais do sul-sudeste brasileiro. Bibl Lichenol 47:1–310

Marcelli MP (1998) History and current knowledge of the Brazilian lichenology. In: Marcelli MP, Seaward MRD (eds) Lichenology in Latin America: history, current knowledge and applications. CETESB, São Paulo, pp 25–45

Marcelli MP, Pereira EC, Iacomini M (1998) A bibliography on brazilian lichenology. In: Marcelli MP, Seaward MRD (eds) Lichenology in Latin America: history, current knowledge and applications. CETESB, São Paulo, pp 47–63

Martinez I, Carreño F, Escudero A, Rubio A (2006) Are threatened lichen species well-protected in Spain? Effectiveness of a protected areas network. Biol Conserv 133:500–511. doi:10.1016/j.biocon.2006.08.003

McCune B, Mefford MJ (1999) PC-ORD. Multivariate analysis of ecological data, Version 4.0. MjM Software, Gleneden Beach, OR

McCune B, Grace JB, Urban DL (2002) Analysis of ecological communities. MjM Software, Gleneden Beach, OR

Nascimbene J, Nimis PN, Marini L (2007) Testing indicators of epiphytic lichen diversity: a case study in N Italy. Biodivers Conserv 16:3377–3383. doi:10.1007/s10531-006-9084-z

Nordén B, Appelqvist T (2001) Conceptual problems of ecological continuity and its bioindicators. Biodivers Conserv 10:779–791. doi:10.1023/A:1016675103935

Pharo EJ, Beattie AJ, Pressey RL (2000) Effectiveness of using vascular plants to select reserves for bryophytes and lichens. Biol Conserv 96:371–378. doi:10.1016/S0006-3207(00)00080-X

Pykälä J (2004) Effects of new forestry practices on rare epiphytic macrolichens. Conserv Biol 18:831–838. doi:10.1111/j.1523-1739.2004.00210.x

Rivas Plata E, Lücking R, Lumbsch HT (2008) When family matters: an analysis of Thelotremataceae (Lichenized Ascomycota: Ostropales) as bioindicators of ecological continuity in tropical forests. Biodivers Conserv 17:1319–1351. doi:10.1007/s10531-007-9289-9

Sillet SC, McCune B, Peck JE, Rambo TR, Ruchty A (2000) Dispersal limitations of epiphytic lichens result in species dependent on old-growth forests. Ecol Appl 10(3):789–799. doi:10.1890/1051-0761(2000)010[0789:DLOELR]2.0.CO;2

Sipman HJM (1997) Additions to the lichen flora of Araracuara (Colombian Amazonia. Caldasia 19(1–2):247–255

Sipman HJM (2006) Diversity and biogeography of lichens in neotropical montane oak forests. Ecol Stud 185:69–81. doi:10.1007/3-540-28909-7_6

Sipman H, Harris RC (1989) Lichens. In: Lieth H, Werger MJA (eds) Tropical rain forest ecosystems. Elsevier, Amsterdam, pp 88–135

Spielmann AA (2006) Checklist of lichens and lichenicolous fungi of Rio Grande do Sul (Brazil), Caderno de Pesquisa, Sér. Bio 18(2):7–25

SYSTAT 10 (2000) Statistics I. SSPS Inc., Chicago

Topham P (1977) Colonization, growth, succession and competition. In: Seaward MRD (ed) Lichen ecology. Academic Press, London, pp 32–68

Uliczka H, Angelstam P (2000) Assessing conservation values of forest stands based on specialised lichens and birds. Biol Conserv 95:343–351. doi:10.1016/S0006-3207(00)00022-7

Will-Wolf S, Esseen PA, Neitlich P (2002) Monitoring biodiversity and ecosystem function: forests. In: Nimis PL, Scheidegger C, Wolseley PA (eds) Monitoring with lichens–monitoring lichens, vol 7, 4th edn. Kluwer, Dordrecht, pp 203–222

Wolseley PA (1991) Observations on the composition and distribution of the '*Lobarion*' in forests of south east Asia. In: Galloway DJ (ed) Tropical lichens: their systematics, conservation and ecology, Systematics Association special. Clarendon Press, Oxford, pp 217–243

Wolseley PA, Stofer S, Mitchell R, Truscott AM, Vanbergen A, Chimonides J, Scheidegger C (2006) Variation of lichen communities with landuse in Aberdeenshire, UK. Lichenologist 38(4):307–322. doi:10.1017/S0024282906006190