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THE ROLE OF FOREST STRUCTURE AS A DETERMINANT OF EPIPHYTIC LICHENS WITHIN MANAGED TEMPERATE DECIDUOUS FORESTS (SOUTHERN ROMANIA)

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Abstract

This study shows the impact of tree- and forest-level variables on epiphytic lichens within four managed forest fragments. Additionally, the impact of human activities, such as pastoral activities and timber harvesting, on epiphytic lichens is taken into account. At the tree level, a pertinent ecological pattern with regard to lichen abundance could not be supported by the obtained results because the effect of tree and forest variables (aspect and shrub cover) was significant only on a few lichens. The lichen richness was related to tree (algae cover) and forest structure (semi-open canopies) variables. At the forest level, lichen abundance was influenced by forest structure (canopy variation and shrub cover). Timber harvesting significantly acted on forest structure components, such as shrub cover and tree canopies. Thus, shrub coverage increased and tree canopies became rare depending on the intensity of timber harvesting. Furthermore, timber harvesting, shrub cover, and closed canopies have led to significant differences in lichen composition in the four investigated forests.

Key words: canopy variation, pastoral activity, shrub cover, timber harvesting

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1. Introduction

European deciduous forests are under intensive anthropogenic pressure (Tomićević-Dubljević et al., 2017), which is represented by the clear-cutting of large woodland areas in favour of the development of urban and agricultural landscapes (Csolti et al., 2017; Nascimbene et al., 2013). Furthermore, forestry management affects both forest structure and as a consequence, epiphytic lichens (Bolliger et al., 2007).

The scientific literature includes several valuable papers that provide findings about the influence of tree- and forest-level drivers on epiphytic lichens in an integrated context (Nascimbene et al., 2012; Ranius et al., 2008). Great importance is attributed to quantifying the availability of sunlight required for epiphytic lichen growth (Gauslaa et al., 2007; Marmor et al., 2012). Thus, within temperate forests, shaded microhabitats caused by canopy closure are a limiting factor for lichens (Nascimbene et al., 2012); therefore, an improvement in forest management that is related to an understanding of lichen requirements is needed (Gauslaa et al., 2007; Marmor et al., 2011). The changes in canopy cover caused by human activities affect temperature, humidity and water availability and disturb the suitability of lichen substrata (Vitt et al., 2019). A long rotation cycle represents a more satisfactory forest management approach that ensures better ecological conditions for epiphytic lichens (Hauck, 2011; Nascimbene et al., 2013). In addition, large trees and their retention are significant for epiphytic lichen growth (Gustafsson et al., 1992). Epiphytic lichens also depend on old trees and their bark texture (Jüriado and Liira, 2009; Mistry and Berardi, 2005; Thor et al., 2010). Tree removal contributes to the loss of adequate substrata for epiphytes; therefore, it is preferable to retain a mixed structure represented by young and old trees for epiphytic lichen conservation (Fritz et al., 2008). Some forest management strategies are based on the retention of structure during forest regeneration and the creation of a characteristic structural pattern (Lindenmayer and Franklin, 2002).

Considerable importance has been ascribed to environmental factors that influence the abundance of epiphytic lichens. Thus, light is a controlling factor of the distribution of lichens over the height of tree trunks, with lower parts of trees insufficiently illuminated, resulting in epiphytic lichens occurring less often at this level (Benesperi et al., 2018; Hauck, 2011; Merinero et al., 2014). Epiphytic lichens are influenced by the water regime, pH and nutrients (Hauck, 2011).

The diversity of epiphytic lichens is of great importance for forest ecology (Pike, 1978) and conservation (Pipp et al., 2001; Westerberg et al., 2017). The diversity of forest stands, which is well conserved with trees of different ages, is represented by a great diversity of tree species (Hauck, 2011; Jüriado and Liira, 2009; Thor et al., 2010), and importantly, its ecological continuity offers optimum environmental conditions for epiphytic lichens (Hauck, 2011).

Although forests from the Bucharest metropolitan area are intensively managed, their structure currently includes remnant patches with very old oak trees as a part of the former ''Codrii Vlăsiei'', which are renowned forests that represent a relic of the continuity that is important for epiphytic lichen survival (Carcea and Seceleanu, 2011; Duduman, 2011). The forests situated around Bucharest are still represented by remarkable tree diversity, which harbours a relatively large diversity of lichens (Ardelean et al., 2013; Bălteanu et al., 2006; Sanda et al., 2008).

The aims of the present study performed within four forests from the areas surrounding Bucharest were (a) identifying an ecological pattern based on macro- and micro-variables of the forest structure that have a significant importance for lichens and (b) revealing how this pattern is affected by anthropogenic pressure, such as pastoral activities and timber harvesting. In this regard, the following questions were addressed:

(i) Which forest- and tree-level variables are most closely related to the abundance and richness of lichen species?

(ii) Have grazing and timber harvesting had a significant impact on shrub cover? How does timber harvesting affect canopy cover? As a consequence of feeding domestic animals with shrub leaves and clear-cutting, shrub cover becomes either reduced or very dense. Furthermore, have pastoral activities and the intensity of timber harvesting had a significant impact on the abundance and richness of lichen species?

(iii) Does lichen composition differ in the four investigated forests with regard to the intensity of timber harvesting and grazing? Do environmental factors determine the significant differences in lichen composition?

(iv) Do the different tests reveal not only particular ecological groups of lichen species but also different patterns in their microhabitats?

As a target for the present research, it is important to highlight the major forest drivers that characterised the ecological pattern observed.

2. Material and methods

2.1. Study area

The woodland vegetation is dominated by thermophilous and xerophilous oaks such as *Quercus cerris* L., *Q. pedunculiflora* K. Koch, *Q. robur* Pall. and *Q. pubescens* Willd. Climatic conditions are characterised by average annual temperatures ranging between 9 and 10°C and relatively low amounts of precipitation, which range between 450 and 600 mm (Doniță et al., 1992). Soils are represented by kastanozems, chernozems, phaeozems and luvisols (Bălteanu et al., 2006; FAO-Unesco, 1974; FAO-Unesco, 1981).

The research activity was performed within the following 4 remnant forest fragments: Pustnicul Forest, Golășei Forest, Brânzeasca Forest, and Snagov Forest, situated in southern Romania (Fig. 1; Table 1). The area of each investigated forest is presented in Table 1. In the studied area, the environmental quality is affected by different industrial activities, such as power plants, vehicular traffic, and domestic heating (Iojă, 2008; Velea et al., 2009; Vicol, 2014).

2.2. Sampling procedure

Within the forest fragments, a total of 82 plots, each 10 × 10 m, were randomly placed (Table 2). The number of plots selected within each of the four forests depended on the forest area (Table 1).

Thus, the larger the forest, the higher the number of plots except Snagov Forest where timber harvesting was intensive (a large part of the forest was cut). The sampling method (the size of the plot) was established according to Prigodina-Lukošienė and Naujalis (2006).

Table 1. Geographical coordinates and the area of the studied forests

Investigated forests	*Geographical coordinates*	*Area (ha)*
Pustnicul	44.46847°N; 26.30519°E	918
Golășei	44.56514°N; 26.26692°E	161
Brânzeasca	44.62622°N; 25.25533°E	1095
Snagov	44.71481°N; 26.21086°E	1455

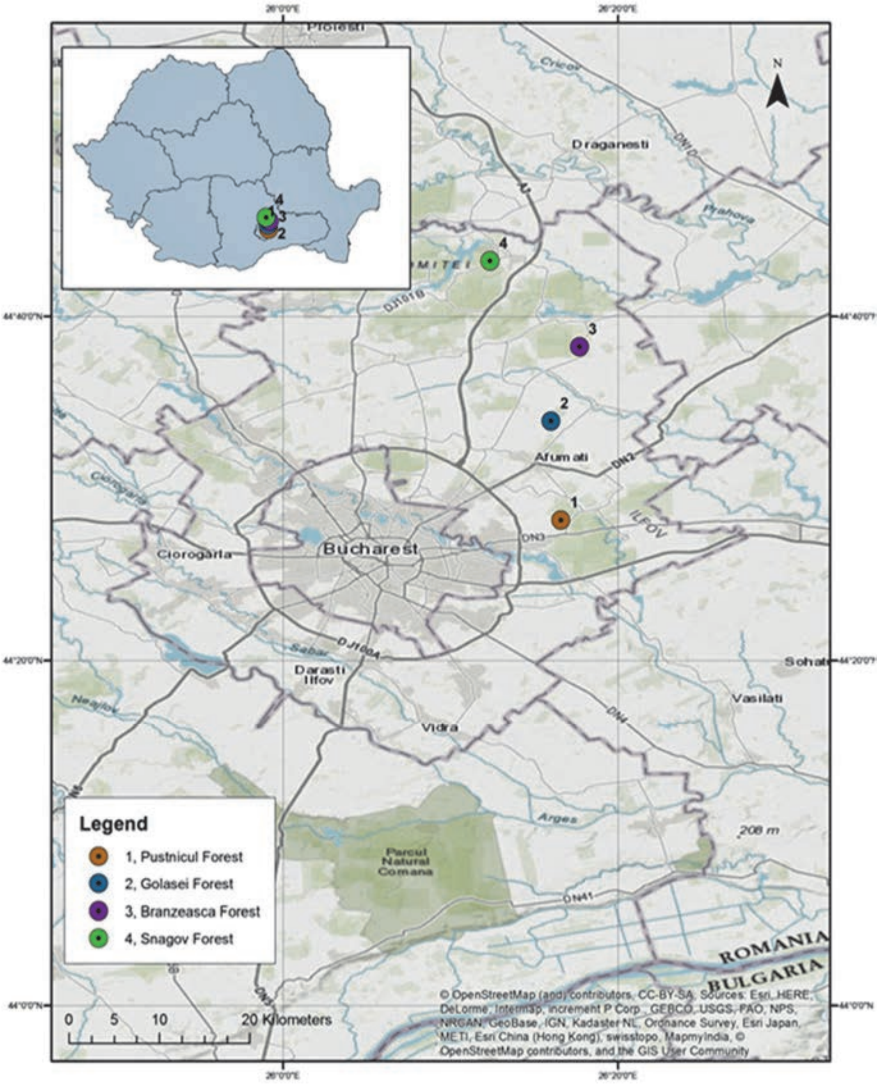

Fig. 1. The location of the studied forests situated in the southern part of Romania

Table 2. Information regarding the sampling design at the tree and plot levels

Sampling design	*PF*	*GF*	*BF*	*SF*	*Total number of plots and sampling units*
Total number of plots (10 × 10 m) in each forest	23	13	28	18	**82**
Total number of sampling units (30 × 30 cm) in each forest	88	56	103	56	**303**

Legend: PF-Pustnicul Forest, GF-Golășei Forest, BF-Brânzeasca Forest, SF–Snagov Forest

Thus, in each 10 × 10 m plot, all suitable trees, *i.e.*, those with unbranched trunks under 1 m above the ground, a circumference of more than 70 cm, upright trunks, trunks with entire bark and without knobs and holes, were sampled. Within each 10 × 10 m plot, only one tree was suitable, except one of the plots from Golășei Forest, where the two oldest oaks were both suitable for sampling.

It was not possible to have more than one sampled tree per plot because younger trees (i.e., less than 70 cm in circumference) were predominant and the 30 × 30 cm sampling frame overlapped the parts of the trunk that corresponded to the cardinal points. In total, 77 trees were sampled: 66 oak trees, 1 pear tree, 1 poplar tree, 3 linden trees and 6 ash trees (Table 3). Of the 82 sampling units (Table 2), six were inadequate for sampling.

At the level of each selected tree, a 30 × 30 cm frame was positioned at a height of 1 m above the ground on each cardinal face of the trunk, at which height, the circumference of each tree was measured (Table 4). A total of 303 sampling units of 30 × 30 cm were recorded within all studied forests (Table 2). The data were not collected from 5 sampling units of 30 × 30 cm (four within Pustnicul Forest (two on an oak and the other two on another oak) and one in Brânzeasca Forest on an ash tree) because short branches were present in these sampling units. Within each 30 × 30 cm sampling unit, all lichen species were identified to determine their abundance.

On each tree and within each 30 × 30 cm sampling unit, the crevice depth was also measured with a ruler (cm). Measurements were made within each of the four quarters of the frame *i.e.,* there were 4 quadrats, each of which was 15 × 15 cm in size. Thus, four measurements were recorded on each cardinal face of the trunk *i.e.,* there were 16 measurements per tree trunk. The univariate statistics of tree circumferences and bark crevice depth variables are given in Table 4.

At the tree level, the lichen abundance was determined on a four-point scale (per tree) based on their frequency of occurrence within the 30 × 30 cm sampling units. The maximum abundance of each lichen species per tree was 4 (if a lichen species was found within all four sampling units per tree). The abundance was calculated as a percentage.

At the forest level, **lichen abundance** was determined based on the frequency of occurrence of each lichen species within each of the four investigated forests (the maximum value was 4, which indicated that a lichen species was found in all four forests). At the forest level, lichen abundance was calculated as a percentage. The lichen richness was calculated as the total number of lichen species per tree.

Forest-level variables (canopy variation and shrub cover) and tree-level variables (mosses and algae cover) were derived according to Mistry and Berardi (2005) using a scale that ranges between 1 and 3. The ordinal scale for canopy variation, shrubs, mosses and algae cover corresponds to thresholds that were arbitrarily adopted (Table 5).

The moss and algae coverages were estimated within the 30 × 30 cm sampling units. The lichen species collected were identified using keys (Ciurchea, 2004; Purvis et al., 1994), a stereo-microscope and an optical microscope. The nomenclature of the lichens follows the MycoBank Database (MycoBank, 2017) and that of cormophytes follows (IPNI, 2017).

The growth forms of the lichen species and the light index according to Nimis (2016) are given below. The light index is based on a scale that ranges between 1 and 5 as follows:

1 on very shaded substrata;

2 on shaded substrata, including the northern part of trunks in forests with closed canopies;

3 on substrata directly but weakly sunlit, for instance, in forests with open canopies;

4 on sunlit substrata, but no extreme sunlight; and

5 on very sunlit substrata, for instance, the southern part of trees in open areas.

A light index was attributed to each identified lichen species depending on their light conditions in the studied forests (Table 6). Thus, for lichen species found on shaded substrata, the light index was 2, for lichen species found on weakly illuminated substrata, the light index was 3, and for lichen species found on well-illuminated substrata, the light index was 4.

2.3. Statistical analysis

Any lichen species that were found in two or fewer sampling units were not considered in the correlation analysis.

Table 3. The genera of host trees sampled within each studied forest

Host tree genera	*PF*	*GF*	*BF*	*SF*	*Total number of host trees in the studied area*
Quercus	13	14	25	14	66
Pyrus	1	-	-	-	1
Fraxinus	5	-	1	-	6
Tilia	3	-	-	-	3
Populus	1	-	-	-	1
Total number of host trees in each forest	23	14	26	14	**77**

Legend: PF–Pustnicul Forest, GF-Golășei Forest, BF-Brânzeasca Forest, SF-Snagov Forest, - data not available

Table 4. The univariate statistics of the tree level variables

Forests	*Mean and Standard deviation (minimum-maximum values)*	
	Tree circumference (m)	*Bark crevice depth (cm)*
Pustnicul	1.98±0.67 (1.26-3.50)	1.45±0.91 (0.32-3.30)
Golășei	2.58±1.12 (1.60-5.33)	1.41±0.88 (0.61-3.49)
Brânzeasca	1.89±1.09 (1.15-5.40)	0.87±0.79 (0.18-3.53)
Snagov	2.00±1.45 (1.68-5.77)	1.07±0.99 (0.20-3.03)

Table 5. The description of forest- and tree-level ordinal variables based on an ordinal scale published by Mistry and Berardi (2005)

Scale level	*Thresholds*	*Tree level variables*		*Forest level variables*	
		Moss cover	*Algae cover*	*Canopy variation*	*Shrub cover*
1	0-33%	Lower	Lower	Open canopy	Lower
2	33-66%	Moderate	Moderate	Semi-open canopy	Moderate
3	66-99%	Higher	Higher	Closed canopy	Higher

Table 6. Information about the growth forms and light index for each lichen species (according to Nimis, 2016)

Species	*Growth form*	*Range of the light index according to Nimis (2016)*	*Light index assigned according to field observations*
Acrocordia gemmata (Ach.) A. Massal.	crustose	2; 3	2
Buellia schaereri De Not.	crustose	4; 5	4
Candelaria concolor (Dicks.) Arnold	squamulose	4; 5	4
Candelariella efflorescens R.C. Harris & W.R. Buck	crustose	4; 5	4
Flavoparmelia caperata (L.) Hale	foliose	3; 4	4
Lecanora carpinea (L.) Vain	crustose	3; 4; 5	4
Lecanora sambuci (Pers.) Nyl.	crustose	3; 4; 5	3
Melanohalea exasperatula (Nyl.) Blanco et al.	foliose	3; 4; 5	3
Melanelia fuliginosa subsp. *glabratula* (Lamy) Coppins	foliose	3; 4	3
Parmelia sulcata Taylor	foliose	3; 4; 5	4
Parmelina quercina (Willd.) Hale	foliose	4; 5	4
Parmelina tiliacea (Hoffm.) Hale	foliose	3; 4	4
Pertusaria albescens (Huds.) M. Choisy & Werner	crustose	3; 4	3
Phaeophyscia nigricans (Flörke) Moberg	foliose	4; 5	4
Phaeophyscia orbicularis (Neck.) Moberg.	foliose	3; 4; 5	3
Physcia adscendens (Fr.) H. Olivier	foliose	4; 5	4
Physcia tenella (Scop.) DC.	foliose	4; 5	4
Physcia stellaris (L.) Nyl.	foliose	4; 5	4
Physconia detersa (Nyl.) Poelt.	foliose	4	4
Physconia enteroxantha (Nyl.) Poelt.	foliose	4; 5	4
Physconia grisea (Lam.) Poelt.	foliose	3; 4; 5	3
Pleurosticta acetabulum (Neck.) Elix & Lumbsch	foliose	4; 5	4
Pseudevernia furfuracea (L.) Zopf.	fruticose	3; 4; 5	4
Ramalina pollinaria (Westr.) Ach.	fruticose	3; 4; 5	3
Xanthoria parietina (L.) Beltr.	foliose	3; 4; 5	4

Aspect was treated as a dummy variable and coded as follows: 1.0 for the dummy variable of a given sample and 0.0 for the other dummy variables of the same sample (Lepš and Šmilauer, 2003). Additionally, pastoral activities were coded as nominal variables: 1.0 for grazing and 0.0 for no grazing. Timber harvesting was estimated using a scale that ranges between 0 and 3 (Lepš and Šmilauer, 2003), where 0 corresponds to a lack of timber harvesting (a forest with no tree cutting; 0% timber harvesting), the first level corresponds to a low intensity of cutting (some trees were cut, especially by local countrymen; 1-33% timber harvesting), the second and third levels correspond to moderate (33-66%) and high (66-99%) intensities of timber harvesting (a large amount of wood was extracted from the studied forests).

The normality of the quantitative data was verified using the Shapiro-Wilk *W* test (Mărușteri, 2006). This normality test showed a non-normal distribution ($p < 0.05$) despite data log transformation. The categorical and semi-quantitative variables were not log-transformed to avoid losing some of the data. Thus, the effect of the environmental factors on the abundance and richness of lichen species was analysed using the Kendall rank-order correlation coefficient (Dytham, 2011). In the case of the variables classified according to an ordinal scale (i.e., canopy variation, shrub cover, timber harvesting, mosses and algae cover), a correlation analysis was performed separately for each level of the ordinal scale as follows: level 1 of the scale was coded as 1.0, and the other levels of the scale were coded as 0.0. The same rule was applied for all other levels of the ordinal scale. This coding method is useful for determining the effect of different levels of the categorical and semi-quantitative variables on the response variables. The Kendall rank-order correlation coefficient was used to determine the effect of the environmental factors (canopy variation and shrub cover) on the lichen species based on their growth forms. The growth forms were separated into the following four categories: crustose, foliose, squamulose and fruticose. There was only one lichen species with a squamulose growth form; therefore, for this species, the analysis was not performed. In the correlation analyses, each category of the growth forms was repeatedly analysed with each scale of the canopy variation and shrub cover. Each category of the growth forms was separately analysed with each level of the light index, which were established based on field observations (Table 6).

The differences in lichen composition between the investigated forests based on human activities (the intensity of grazing and timber harvesting) and the consequence of timber harvesting intensity (the development of a shrub layer) were obtained using the Multi-Response Permutation Procedure (MRPP). Environmental factors such as host tree species, tree circumferences and canopy variation were also used to identify the differences in the lichen composition between the studied forests. The differences were calculated as the chance-corrected within-group agreement (*A* value). An *A* value less than 0.10 indicates within-group heterogeneity. The significance of the *A* value was determined by an associated *p* value (McCune et al., 2002). The Chord distance coefficient was used as a measure of dissimilarities based on 999 permutations. The MRPP analysis was performed using the mrpp function within the vegan package (vers. 2.5-2, Oksanen et al., 2018).

The SIMPER method was used to identify the main lichen species responsible for the differences among the studied forests, *i.e.*, to determine which species separate the forests by differences in their abundances. An overall SIMPER analysis was performed by pooling all forests and all species. The Chord distance coefficient was used as a distance measure in the SIMPER analysis (Ludwig and Reynolds, 1988). Both tree cutting and grazing might affect lichen abundance by changing the shrub cover. Thus, as a result of the large-scale cutting of trees, the shrub layer becomes dense around trees, shading them and creating shaded microhabitats. Additionally, grazing prevents large-scale shrub development and the loss of lichen species that are intolerant to shaded microhabitats. Based on field observations, it was expected that human activities would influence shrub cover. This expectation was assumed to be a primary mechanism by which human activities influence lichen abundance. Therefore, the anthropogenic pressures on studied forests, such as pastoral activities and timber harvesting, were treated as environmental variables, and shrub cover (one component of the forest structure) was treated as a co-variable in the statistical analysis. Because it is an important aspect of lichen abundance, the relationships between the intensity of timber harvesting and canopy variation were assessed. The intensity of timber harvesting is expected to determine the changes in the canopy variation. This analysis was performed to show the impact of human activities on the forest variables that influence lichen abundances. The univariate (log-transformation and normality test), bivariate (Kendall rank-order correlation coefficient) and multivariate (SIMPER) statistics were performed using the software PAST (Hammer et al., 2001). The Multi-Response Permutation Procedures were performed in the R software (vers. 3.5.1, R Core Team, 2018).

3. Results and discussion

At the regional scale, the species recorded in the present study belong to the *Xanthorion* alliance, as the studied forest fragments are found predominantly in an intensive agro-industrial landscape situated at the limit of a sylvosteppe area. It is well known that *Xanthorion* communities inhabit nitrogen-enriched substrata, which are created by agricultural practices (Loppi et al., 1999; Ruoss, 1999), industrial activities (Loppi, 2019) and vehicular traffic (Sims et al., 2017). A total of 26 lichen taxa were identified on 77 trees. The majority were found on oaks, followed by ash, linden, poplar and pear (see Table 3 and Table 7). The forests from the studied area are mixed, with oak as the dominant element, which is supplemented by other scarce elements such as ash, linden, hornbeam, and pear (Bălteanu et al., 2006; Doniță et al., 1992).

Of all the macro-variables, only high shrub cover had a significant effect on the abundance of *Parmelia sulcata*. Additionally, the micro-variables, such as aspect and algae cover, had a significant influence on lichen abundances (Table 8).

At the tree level, an ecological pattern with different behaviours of lichen abundances was only demonstrated for some species. According to field observations, although the shrub layer was well developed in the studied forests, the results did not indicate a significant effect of shrub cover on lichen abundance. Thus, only *P. sulcata* increased in abundance because of relatively higher shrub cover. In the studied area, the shrub density was a severe consequence of the conversion of old-growth forest to young-growth stands based on the inappropriate non-selective cutting of trees (Dolocan, 2012; Giurgiu, 2010). The preference of epiphytic lichens for particular aspects depends on differences in canopy cover, which alter the light and humidity at the understory level (Moe and Botnen, 1997).

At the tree level, only algae cover significantly influenced the lichen richness ($\tau = -0.23$; $p = 0.01$). At the forest level, semi-open canopies had a significant effect on lichen richness ($\tau = 0.23$; $p = 0.003$).

At the forest level, the canopy variation and shrub cover had a significant effect on the lichen abundance. Thus, the level of canopy openness influenced the lichen abundance (Table 9).

The openness of the canopy was an important driver for epiphytic lichens due to the increase in incident sunlight (Li et al., 2013). In similar studies, lichen richness was positively related to open canopies due to better sunlit microhabitats (Benítez et al., 2015; Horak et al., 2014; Marmor et al., 2011; Marmor et al., 2012). The native structure of the forests had a positive influence on the lichen community due to the heterogeneity of the understory microhabitats, which harbour both shade- and light-adapted lichens (Käffer et al., 2009). It was determined that (a) the grazing of shrubs around the trees prevented them from creating shade and gave the lichens enough sunlight to grow; and (b) where there was large-scale cutting of trees, the shrub layer became very dense, shading the lower part of the trunks. The influence of pastoral activities (sheep and cattle grazing) on lichen abundance was significant ($\tau = 0.39$; $p = 0.005$).

Table 7. The list of lichen species and their host trees within the 4 studied forests

Species	***Host tree in each investigated forest***			
	PF	***GF***	***BF***	***SF***
Acrocordia gemmata (Ach.) A. Massal.	*Quercus, Fraxinus*	-	-	-
Buellia schaereri De Not.	*Quercus*	-	-	-
Candelaria concolor (Dicks.) Arnold	-	-	*Quercus*	-

Candelariella efflorescens R.C. Harris & W.R. Buck	*Quercus*, *Fraxinus*	*Quercus*	*Quercus*	-
Flavoparmelia caperata (L.) Hale	-	*Quercus*	-	*Quercus*
Lecanora carpinea (L.) Vain	-	-	*Quercus*	-
Lecanora sambuci (Pers.) Nyl.	-	-	-	*Quercus*
Lepraria spp.	*Quercus*, *Tilia*, *Populus*	*Quercus*	*Quercus*	*Quercus*
Melanohalea exasperatula (Nyl.) Blanco et al.	-	*Quercus*	-	-
Melanelia fuliginosa subsp. *glabratula* (Lamy) Coppins	*Quercus*	*Quercus*	-	-
Parmelia sulcata Taylor	*Quercus*	*Quercus*	*Quercus*	*Quercus*
Parmelina quercina (Willd.) Hale	-	*Quercus*	-	-
Parmelina tiliacea (Hoffm.) Hale	-	*Quercus*	*Quercus*	-
Pertusaria albescens (Huds.) M. Choisy & Werner	*Quercus*	-	-	-
Phaeophyscia nigricans (Flörke) Moberg	*Quercus*, *Fraxinus*	*Quercus*	*Fraxinus*, *Quercus*	*Quercus*
Phaeophyscia orbicularis (Neck.) Moberg.	-	-	*Fraxinus*, *Quercus*	*Quercus*
Physcia adscendens (Fr.) H. Olivier	*Quercus*, *Fraxinus*, *Populus*	*Quercus*	*Quercus*	*Quercus*
Physcia tenella (Scop.) DC.	-	*Quercus*	*Quercus*	-
Physcia stellaris (L.) Nyl.	-	-	*Quercus*	*Quercus*
Physconia detersa (Nyl.) Poelt.	*Fraxinus*	-	-	-
Physconia enteroxantha (Nyl.) Poelt.	*Fraxinus*	*Quercus*	*Quercus*	*Quercus*
Physconia grisea (Lam.) Poelt.	-	*Quercus*	*Quercus*	-
Pleurosticta acetabulum (Neck.) Elix & Lumbsch	-	-	-	*Quercus*
Pseudevernia furfuracea (L.) Zopf.	-	*Quercus*	*Quercus*	*Quercus*
Ramalina pollinaria (Westr.) Ach.	*Quercus*	-	-	-
Xanthoria parietina (L.) Beltr.	*Pyrus*, *Populus*	-	*Fraxinus*, *Quercus*	*Quercus*
Total number of lichen species	**13**	**14**	**15**	**12**

Legend: PF-Pustnicul Forest, GF-Golășei Forest, BF-Brânzeasca Forest, SF-Snagov Forest

Table 8. Kendall rank-order correlations between the environmental factors and lichen abundances (only the species with significant *p*-values are reported)

Response variable	***Environmental variables***	***Kendall rank order coefficient***
Candelariella efflorescens	Western part of trunk	0.67*
Parmelia sulcata	High shrub cover	0.67**
	Northern part of trunk	0.43*
Phaeophyscia nigricans	Northern part of trunk	0.55***
	Southern part of trunk	0.51***
	Algae cover	-0.46**
Phaeophyscia orbicularis	Eastern part of trunk	0.64*
Physconia enteroxantha	Western part of trunk	0.66***

*Legend: *** p < 0.001, ** p < 0.01, * p < 0.05*

Table 9. Kendall rank-order correlations indicated the effect of canopy variation and shrub cover on lichen abundance at the forest level

Response variable	***Environmental variables***					
	Canopy variation			***Shrub cover***		
	1	2	3	1	2	3
Lichen abundance	0.66****	0.51**	0.34*	0.44**	0.37**	0.29^{ns}

*Legend: 1-open canopies, 2-semi-open canopies, 3-closed canopies, **** p < 0.0001, ** p < 0.01, * p < 0.05, ns-not significant*

This finding is potentially supported by the fact that a great part of the identified lichens were nitrophiles. Grazing was an important contribution to maintaining adequate microhabitat conditions for the epiphytic lichens (Paltto et al., 2008). Additionally, significant results were obtained with regard to the effect of low timber extraction intensity on lichen abundance (τ = 0.35; p = 0.01). Based on field observations, the extraction of small amounts of wood by countrymen did not affect lichen abundance. A low intensity of cutting positively influenced lichen abundance due to an increase in canopy openness (Paltto et al., 2008). Alternatively, the lichen abundance was negatively influenced by moderate wood extraction (τ = -0.15; p =0.01). Moderate shrub cover was significantly related to moderate and high intensity timber harvesting (τ = 0.38; p = 0.006 and τ = 0.45; p = 0.001, respectively). Forests subjected to intensive cutting have a dense shrub layer that colonises the forest gaps (Lawes et al., 2007). The forest patches that had no timber extraction showed a significant increase in canopy openness (τ = 0.25; p = 0.00005). In contrast, a low intensity of timber harvesting resulted in a decrease in canopy openness (τ = -0.28; p = 0.000005). Thus, timber extraction, even in relatively low quantities, leads to the loss of canopy continuity. Timber harvesting negatively affected lichen communities, due to changes in the understory and canopy structure of forests, with unfavourable consequences on lichen microhabitats (Bunnell et al., 2008).

The semi-open canopies had a significant effect on crustose lichen (τ = -0.35; p = 0.01).

The relationships between the light index (levels 2 and 4 on the scale established according to field illumination conditions) and the crustose lichens indicated an increase on the shaded substrata represented by level 2 (τ = 0.36; p = 0.01) and a decrease in these lichens on sun-lit substrata represented by level 4 (τ = -0.34; p = 0.01). Another study confirmed that crustose lichens decrease in sunlit microhabitats due to their intolerance of relatively high light intensity and low humidity levels (Chongbang et al., 2018). In contrast, foliose lichens were positively related to the light index represented by level 4 on the scale (τ = 0.37; p = 0.009). On sunlit substrata, certain foliose lichens may be more abundant (Coxon and Stevenson, 2007).

Generally, the SIMPER method showed relatively low values of individual lichen contribution (with the majority under 0.50) among pairwise tests of the studied forests. A slightly higher contribution of lichen abundances was observed when comparing the Golășei *vs*. Snagov forests (Table 10).

The MRPP analysis indicated that significant differences in lichen composition among the four forests were due to moderate shrub cover (A = 0.01, p = 0.03), closed canopies (A = 0.02, p = 0.01), relatively low timber harvesting (A = 0.02, p = 0.01), moderate timber harvesting (A = 0.01, p = 0.02), and relatively high timber harvesting (A = 0.01, p = 0.03). The other variables, such as grazing, host tree species and their circumferences, did not induce significant differences in lichen composition between the studied forests (A = -0.004, p = 0.851; A = -0.012, p = 0.916; and A = -0.036, p = 0.614). Different patterns of the microhabitats of lichen species were not identified. Forest structure and anthropogenic pressure determine differences in lichen composition; these differences could be explained by the dependence of epiphytic lichens on changes in environmental conditions (Benítez et al., 2015; Horak et al., 2014). Lichen composition is sensitive to timber harvesting (Lõhmus et al., 2018); therefore, an adequate silviculture regime based on maintaining the multi-layered canopies should be applied (Benítez et al., 2015). Forest structure is influenced by different management regimes (Dulamă et al., 2017), which act synergistically on lichen communities (Edman et al., 2008; Nascimbene et al., 2019).

Table 10. The contribution of individual lichen species to the pairwise differences between studied forests assessed using the SIMPER method (only values higher than 0.10 were given)

Studied forests	***Species***	***Contribution***
Pustnicul vs Golășei	*Physconia enteroxantha* *Ramalina pollinaria*	0.19 0.15
Pustnicul vs Brânzeasca	*Phaeophyscia nigricans* *Ramalina pollinaria*	0.14 0.15
Pustnicul vs Snagov	*Phaeophyscia nigricans* *Phaeophyscia orbicularis* *Ramalina pollinaria*	0.20 0.18 0.15
Golășei vs Brânzeasca	*Phaeophyscia nigricans*	0.18
Golășei vs Snagov	*Phaeophyscia nigricans* *Phaeophyscia orbicularis* *Physconia enteroxantha*	0.25 0.18 0.53
Brânzeasca vs Snagov	*Physconia enteroxantha*	0.30

In managed forests, lichen species are affected by modern management practices (Lelli et al., 2019). In this regard, selective wood extraction should be performed to maintain old trees, which are considered reliable sources of propagules for young trees in managed forests (Morley and Gibson, 2010). A forest structure with the specified attributes could harbour the different ecological patterns needed by lichen species with different ecological preferences (Edman et al., 2008).

4. Conclusions

The general pattern of the lichen community was described relative to both human impact and forest structure. Human activities have modified the components of the forest structure; therefore, adequate management practices should be applied. Thus, a lower amount of timber harvesting and grazing around trees could represent adequate management measures, which are needed for the survival of epiphytic organisms.

Based on the significant findings of this study, management measures for the creation of a structural mosaic, represented by (i) small patches with the removal of the shrub layer from around the trees to ensure the survival of light-adapted lichens and (ii) small patches with no removal of the shrub layer from around the trees to favour the growth of shade-adapted lichens, are recommended.

A higher intensity of timber harvesting has negative consequences both on forest structure and lichen abundance; therefore, timber harvesting should be performed to maintain an adequate forest structure suitable for epiphytic cryptogams. This concept should be practically applied by reducing the large-scale cutting of the trees so that they do not affect the continuity of canopies and do not create gaps that are favourable to large-scale shrub development. An important finding revealed that where timber harvesting did not occur, the forest structure was not affected.

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