Lichen Responses to Disturbance: Clues for Biomonitoring Land-use Effects on Riparian Andean Ecosystems

Leiddy Chuquimarca [1], Fernando P. Gaona [2,3], Carlos Iñiguez-Armijos [1,2] and Ángel Benítez [1,*]

[1] Sección de Ecología y Sistemática, Departamento de Ciencias Biológicas, Universidad Técnica Particular de Loja, San Cayetano s/n, 1101608 Loja, Ecuador; lady-eli04@hotmail.com (L.C.); cainiguez@utpl.edu.ec (C.I.-A.)

[2] Laboratorio de Ecología Tropical y Servicios Ecosistémicos (EcoSs-Lab), Universidad Técnica Particular de Loja, San Cayetano s/n, 1101608 Loja, Ecuador; fpgaona1@gmail.com

[3] Maestría en Biología de la Conservación y Ecología Tropical, Universidad Técnica Particular de Loja, San Cayetano s/n, 1101608 Loja, Ecuador

* Correspondence: arbenitez@utpl.edu.ec; Tel.: +593-072-370-1444 (ext. 3034)

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Abstract: The transformation of natural ecosystems due to anthropogenic land use is considered one of the main causes of biodiversity loss. Lichens, due to their poikilohydric nature, are very sensitive to natural and anthropogenic disturbances. Therefore, lichen communities have been widely used as bioindicators of climatic and environmental changes. In this study, we evaluated how the species richness and community composition of epiphytic lichens respond to land-use intensity in riparian ecosystems of the Andes in southern Ecuador. Additionally, we evaluate how the richness of six functional traits (photobiont type, growth form, and reproductive strategy) changed across the different land-use intensity. We selected 10 trees in twelve sites for a total de 120 trees, equally divided into four riparian land-use intensities (forest, forest-pasture, pasture and urban). We recorded a total of 140 lichen species. Species richness was highest in the forest sites and decreased towards more anthropogenic land uses. Lichen community composition responded to land-use intensity, and was explained by microclimate variables (e.g., precipitation, percentage forested area) and distance to the forest. Richness of functional traits of lichens also differed significantly among the four land-use intensity and decreased from forests to urban land-use. Taxonomic diversity and functional traits can be effectively applied as bioindicators to assess and monitor the effects of land-use changes in the riparian ecosystems of tropical montane regions.

Keywords: epiphyte communities; functional traits; bioindicators; riparian land-use; tropical Andes

1. Introduction

Ecosystem transformation due to anthropogenic disturbances such as land-use change is considered one of the main drivers of biodiversity loss [1–4]. Several studies state that current land-use practices will generate major impacts on the structure and functioning of ecosystems at different geographic scales [5–7], modifying biotic and abiotic conditions, increasing replacement rates and affecting local extinction [4–8]. Most of the tropical primary forests (e.g., montane Andean forests) were transformed to secondary forests, pastures, cropland, and urbanized areas to satisfy human needs [2,6,9]. In consequence, the diversity of plants, lichens, birds, arthropods, fish, reptiles and mammals has been diminished because of land use [4,10–12].

Epiphytic lichens are an essential component of tropical humid forests because of their important role in water and nutrient cycles [13]. Therefore, they are key organisms facilitating crucial ecosystem processes [10,14,15]. Epiphytic lichens are poikilohydric, thus they lack an active regulation of the loss and absorption of water [16], which in turn increases their sensitivity to environmental disturbances [17,18]. For these reasons, several biological traits of lichens as such as photobiont type, growth, reproduction, and development can be affected by environmental changes [19–22]. In this manner, these functional traits can be used as a complementary approach to better understand ecosystems because they allow us to assess the biodiversity and their relationship with ecosystem functioning [23,24].

As a general pattern, microclimatic variables (e.g., light, humidity, and temperature) that change in response to ecosystem transformation have been considered as constraining factors over the taxonomic and functional diversity of epiphytic lichens [21,25]. Therefore, several studies have used both taxonomic and functional diversity (e.g., richness of each functional trait) as indicators of land-use change [20,22,26,27], forest disturbance [14,21,28], global warming [29] and air quality [19,30–32].

In temperate ecosystems, most of the research has been focused on assessing the effects of different land uses on taxonomic and functional diversity of lichens [5,20,26,27]. Whereas in the tropics, studies have been restricted to determine the effects of disturbance and atmospheric pollution on lichen diversity [21,25,33,34]. This research is the first in Ecuador to quantify the response of taxonomic diversity and functional traits of epiphytic lichens to different land-use intensities along the riparian ecosystems of southern Andean streams. This area is affected by rapid forest transformation [9,35] and its riparian zones present a high degree of alteration [12,36,37]. Furthermore, we demonstrate, as in other regions (e.g., [20]), the complementary application of lichen's taxonomic and functional traits to detect and monitor changes in the structure and functioning of tropical Andean ecosystems. We predicted that intensive land-use can decrease the taxonomical diversity of species (richness and composition) and functional traits, and that these changes are related to alterations in the microclimate. Specifically, we addressed the following questions: 1) how does the species richness and community composition respond to land-use intensity? And 2) how does the richness of each functional trait respond to land-use intensity?

2. Materials and Methods

2.1. Study Area

This study was conducted around the city of Loja (180,000 inhabitants) in the southern Ecuadorian Andes, at altitudes between 2200 and 2400 masl (Figure 1). The climate is humid tropical with a mean annual temperature between 7–20 °C, and annual rainfall between 800–2500 mm [38].
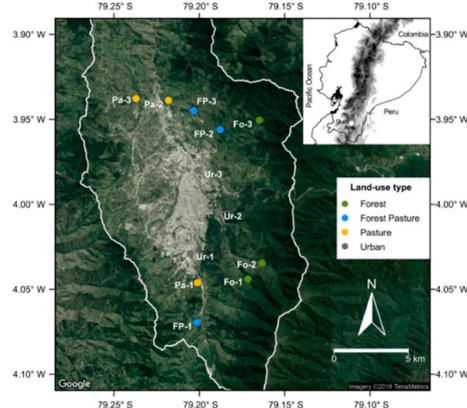
Figure 1. Location of the study area and 12 sampling sites equally distributed in four riparian land uses of Andean streams in southern Ecuador. Codes indicate the land-use intensity (Fo = forest, FP = forest-pasture, Pa = pasture, Ur = urban).

Since the 1960s, these native forests have been transformed into agricultural and urbanized land [31,36,37]. In this study, we distinguished four different land uses, i.e., forest, a combination of forest and pasture, pasture, and urban land use, where we established 12 sampling sites located in riparian margins influenced by those land uses mentioned before. Forest sites (Fo) are characterized by a dense canopy layer of evergreen montane tropical vegetation (ca. 72%–78% coverage). The upper canopy is composed of native trees of the genera *Croton*, *Hedyosmum*, *Clusia*, *Morella*, and *Juglans*. Forest-Pasture sites (FP) are characterized by a semidense canopy layer (ca. 52%–60% coverage). The disturbed forests are mixed with pastures dominated by planted trees of *Alnus acuminata* and *Eucalyptus globulus*. Pasture sites (Pa) are affected by deforestation. The canopy layer is ca. 31%–34% in coverage, mainly composed of planted trees of the genera *Inga* and *Eucalyptus*. Urban sites (Ur) are characterized by a very uniform structure and dominate sections of grassland with planted trees of *Salix* spp. The open canopy layer is ca. 31%–34% in coverage.

2.2. Data Collection

In each site (*n* = 12), we selected 10 mature trees with similar bark structure and diameter at breast height (DBH) over 20 cm within each site (120 trees total). They were selected about five meters from the river bank. We determined the occurrence of epiphytic lichens on 120 trees in total (10 trees per site). We used 20 × 50 cm quadrat on the bark of each selected tree, at the cardinal point with the most lichen abundance to 1.5 m above the ground. The sampling quadrat (20 × 50 cm) was divided into ten grids of a 10 cm × 10 cm, and the cover of each species in each grid was estimated as the proportion of the ten grids occupied by it. Lichen species cover was used as a surrogate of species abundance. For species identification, we used taxonomic and floristic papers [39–42]. In addition, we tested for specific secondary compounds using spot tests based on thallus fluorescence under ultraviolet light, with K (10% water solution of potassium hydroxide), Cl (bleach) and para-phenylenediamine (Pd). For the nomenclature of the species we followed mainly MycoBank. Finally, the specimens are stored in the Herbarium of Universidad Técnica Particular de Loja (HUTPL).

We evaluated six traits to perform the analysis of functional traits: (1) photobiont type; (2) growth form; (3) size; (4) reproduction type; (5) type of reproductive structure; and (6) thallus color (Table 1). The functional traits were selected based on previous studies, due to their relation to ecosystem functioning and land uses [5,19,21,22,25]. For instance, photobiont type and growth form (thallus morphology) are related with light, temperature and water requirements for the processes of photosynthesis and respiration [23,43–45], and with water uptake and loss [21,44]. Finally, reproductive strategy and reproductive structure are related to dispersion ability and establishment [22,25].

Table 1. List of the six functional traits and their categories of the epiphytic lichen community in four riparian land uses of Andean streams in southern Ecuador.

Functional Trait	Categories
Photobiont type	C = Chlorococcoid; CY = Cyanobacteria: T = Trentepohlia
Growth form	CR = Crustose; F = Filamentose; FB = Foliose with broad lobes; FN = Foliose with narrow lobes; FR = Fruticose; G = Gelatinose
Thallus size	MA = Macrolichens; MI = Microlichens
Thallus colour	L = Light; D = Dark
Reproduction type	A = Asexual; S = Sexual; AS = Asexual and sexual
Reproductive structure	AP = Apothecia; I = Isidia; L = Lirellae; P = Perithecia; SO = Soredia

2.3. Environmental Variables

We quantified aerial forests cover (%) for each site from a 2016 land uses map obtained in other study from high-resolution (0.30–2 m) imagery (pers. comm.). Land use was classified into forest, pasture, crops, urban, bare surface. In a GIS, we extracted the land use information for all sites, and the area (m^2 and %) covered by forest was calculated. Also, we calculated the distance to forests

for each site. Forest cover and distance to forests were obtained using the open source GIS software Quantum GIS 1.7.4 (QGIS). Light conditions were recorded by measuring canopy openness (%) using four digital hemispherical photographs per site. Digital photographs were always taken on overcast days and at breast height (1.3 meter), with a horizontally leveled digital camera and using a fish-eye lens. Photographs were analyzed using the software Gap Light Analyzer ver. 2.0 [46]. In addition, the following variables were measured: mean precipitation (mm) from the interpolated data of the meteorological stations located around the study area and tree diameter (DBH).

2.4. Data Analysis

Species richness of epiphytic lichens was defined as the total number of species found in each tree. We calculated sampling completeness with the rarefaction curves (95 % confidence intervals) and the Chao 2 species richness estimator. For the calculation of the rarefaction curves and species richness estimators, we used the R package 'vegan'. Similarly, the species richness of each functional trait category was calculated as the total number of species with each trait category found in each tree. Thus, the effects of land use, % forests, distance to forest, precipitation, DBH and tree high on the species richness and the richness of each functional trait at the tree level were modeled by generalized linear mixed models (GLMMs) using Poisson distribution [47]. This modeling approach was chosen because our data present a hierarchical structure with sites nested within land use and trees nested within sites. Predictors were included as explanatory variables (fixed factors), and sites were included as random sources of variation. We used a logistic transformation for canopy openness and % forests variables [48]. Following this, we performed a stepwise best-model selection using a stepwise regression backwards, with predictors variables scaled and centered (mean = 0, SD = 1). Canopy openness was omitted in the model selection due to collinearity with % forests and precipitation. For GLMMs, the minimal adequate model was selected based on Akaike's Information Criterion (AIC) provided for the model selection procedure. We used the package 'nlme' with *lme* function [49] for the mixed-effect model analyses in R environment [50].

Shifts in lichen species composition were evaluated through a canonical correspondence analysis (CCA) based on chi-square distances. CCA analysis was applied to an abundance matrix square-root transformed. Land-use intensity was established as the covariate and remaining variables were used as explicative variables. Prior to the analysis, we applied a logistic transformation to explanatory variables % forest and distance to the forest; and a square-root transformation to precipitation.

Variation in lichen species composition at the tree level in relation with measured environmental variables was explored by constrained ordinations [51]. As the first step, our data set (120 trees × 140 species) was subjected to a detrended correspondence analysis (DCA) to determine the most appropriate constrained ordination. Due to the length of the first DCA axis was 7.84 standard deviation units, we used a canonical correspondence analysis (CCA) to test the null hypothesis that species composition is independent of environmental variables [52]. CCA analyses were conducted between environmental variables and the epiphytic lichens abundances (square-root transformed). Land-use intensity was established as a covariate and remaining variables were used as explicative variables. Prior to the analysis, we applied a logistic transformation to explanatory variables % forest and distance to a forest; and a square-root transformation to precipitation. The model selection for the ordination was determined with a stepwise procedure based on a permutation test (using the *ordistep* function and 999 permutations). Then, the significance of explanatory variables on ordination was evaluated with ANOVA-like permutation test for Canonical Correspondence Analysis (using *anova.cca* function and 999 permutations). Additionally, the Pearson correlation coefficient of the explanatory continuous variables with the first two axes of the ordination (CCA1 and CCA2) was calculated. Also, in order to identify characteristic species in each ordination axis and relate them to predictor variables, we extracted the scores of the lichen species that were found at the end of the axes. For ordination analysis we used the 'vegan3d' package [53].

The IndVal function in the labdsv package [54] were used for indicator species analysis (ISA) [55] to determine individual species that are mainly associated with one land-use intensity. The indicator value ranges from 0 (one species was absent from one land-use intensity) to 1 (one species occurred in all trees of one land-use intensity and was absent from other trees). The significance was tested using a Monte Carlo permutation test with 1000 replicates.

3. Results

3.1. Species Richness and Community Composition

We recorded a total of 140 species of epiphytic lichens on 120 trees, distributed in 36 genera and 22 families. A total of 94 species were found in forest sites, 66 species in forest-pasture, 57 species in pasture, and 61 in urban sites. The Chao-2 richness estimator, confirming a high number of species estimated in forest, followed by forest-pasture, urban and pasture (Figure 2). Species richness of epiphytic lichen decreased along the land-use intensity, i.e., from forest to urban (Table 2; Figure 3a).
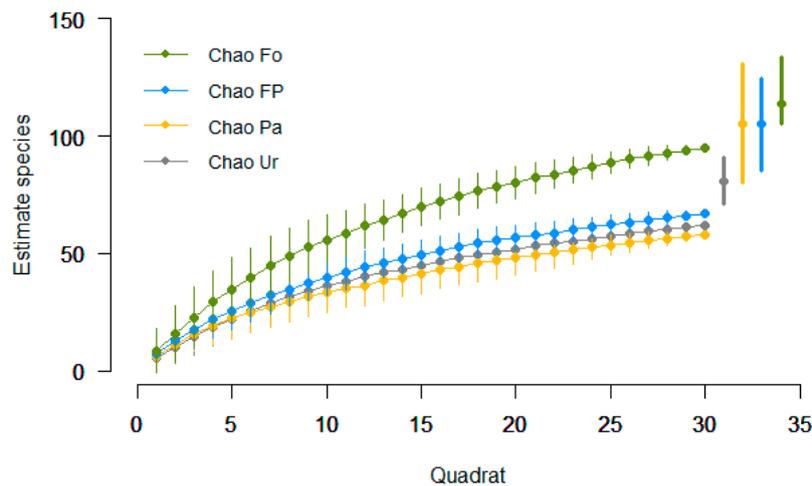
Figure 2. Rarefaction curves with 95 % confidence intervals and Chao 2 estimator (points in the right of figure) of four study land-use intensity. Forest (Fo); Forest-pasture (FP); Pasture (Pa); and Urban (Ur).
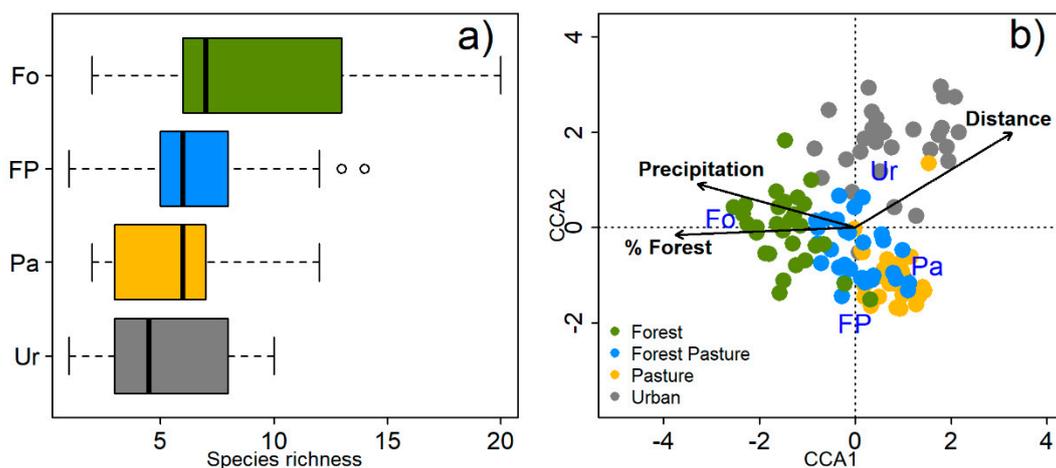
Figure 3. (**a**) Variation in species richness of epiphytic lichens in four riparian land uses of Andean streams in southern Ecuador. (**b**) CCA ordination plot of the lichen community using abundance data per tree and land-use intensity (covariate) precipitation, distance to forest and percentage of forest (predictors). Fo = Forest, FP = Forest Pasture, Pa = Pasture, Ur = Urban.

Table 2. Summary of the GLMM applied on species richness in four riparian land uses of Andean streams in southern Ecuador. Significant differences at *p*-value < 0.05. DBH: diameter at breast height.

Source of Variation	Coefficient	Standard Error	Z-value	*p*-value
Forest	2.651	0.297	8.908	<0.001
Forest-Pasture	−0.663	0.286	−2.313	0.020
Pasture	−0.976	0.336	−2.899	0.003
Urban	−1.661	0.537	−3.093	0.001
Distance to forest	0.445	0.160	2.767	0.005
DBH	−0.004	0.056	0.078	0.937

Results GLMMs showed that lichen richness was lower in land uses with more intensity, i.e., forest-pasture, pasture and urban sites had a negative correlation with lichen richness. Conversely, distance to forests and forest land use showed a positive correlation (Table 2). The mean tree diameter (DBH) was not significant in any case (Table 2).

CCA indicated that precipitation, distance to forest and % forest were important factors to distinguish the taxonomic composition of the epiphytic lichen community among land uses (Figure 3b; Table 3). Together, these variables explained a total variation of 10%. The % forest and precipitation were negatively correlated to axis 1, while distance to forest was positively correlated (Figure 3b, Table S1). Only distance to forest and precipitation were positively correlated to CCA axis 2. Across CCA axis 1, the lichen species *Heterodermia leucomela*, *Dirinaria picta*, *Parmotrema arnoldi* and *Physcia aipolia* showed more preference for disturbed sites (pasture and urban site) with less canopy cover, low humidity and more light availability. Conversely, lichen species such as *Leptogium millegranum*, *Leptogium diffractum*, *Puntelia rudecta*, *Sticta fuliginosa* and *Sticta tomentosa* preferred the conditions of more humidity and closed canopy provided by the forest sites. Similarly, across CCA axis 2 the lichen species *Cococarpia palmicola.*, *Leptogium coralloideum*, *Leptogium laceroides*, *Lobaria subexornata* and *Sticta fuliginosa* were related to sites with closed canopy and high humidity; whereas, *Heterodermia diademata*, *Heterodermia leucomela*, *Physcia aipolia*, *Physcia crispa*, *Telochistes exilis* and *Ramalina celastri* were related to open canopy sites and less humidity (Figure 3b).

Table 3. Shift in lichen species composition in relation to predictor variables, measured with ANOVAlike permutation test in four riparian land uses of Andean streams in southern Ecuador. Significant differences at *p*-value (<0.05) are shown in bold. DBH: diameter at breast height.

Source of Variation	Degrees of Freedom	Chi Square	F-statistic	*p*-value
Land use	3	1.196	2.316	**0.001**
Precipitation	1	0.242	1.410	**0.003**
Distance to forest	1	0.283	1.6477	**0.001**
% Forest	1	0. 245	1.423	**0.014**

Eighteen species were the best indicators of forests land-use intensity, followed by forest-pasture with seven species and six and four species for urban and pasture respectively (Appendix A).

3.2. Functional Traits

Species richness of lichens with cyanobacteria and trentepohlia decreased from forest sites to urban sites (Figure 4a). A similar pattern was observed in the growth form, thus, crustose, foliose with broad lobes and gelatinose lichen species decreased along the land-use intensity (Figure 4b). Macrolichens with dark thallus decreased in pasture or urban sites (Figure 4b–d). Conversely, lichen with fruticulose growth form were more abundant in disturbed sites (Figure 4b). Lichens with sexual and asexual reproduction; and with apothecia, isidia and soredia as reproductive structure decreased in land use gradient (Figure 4e–f).
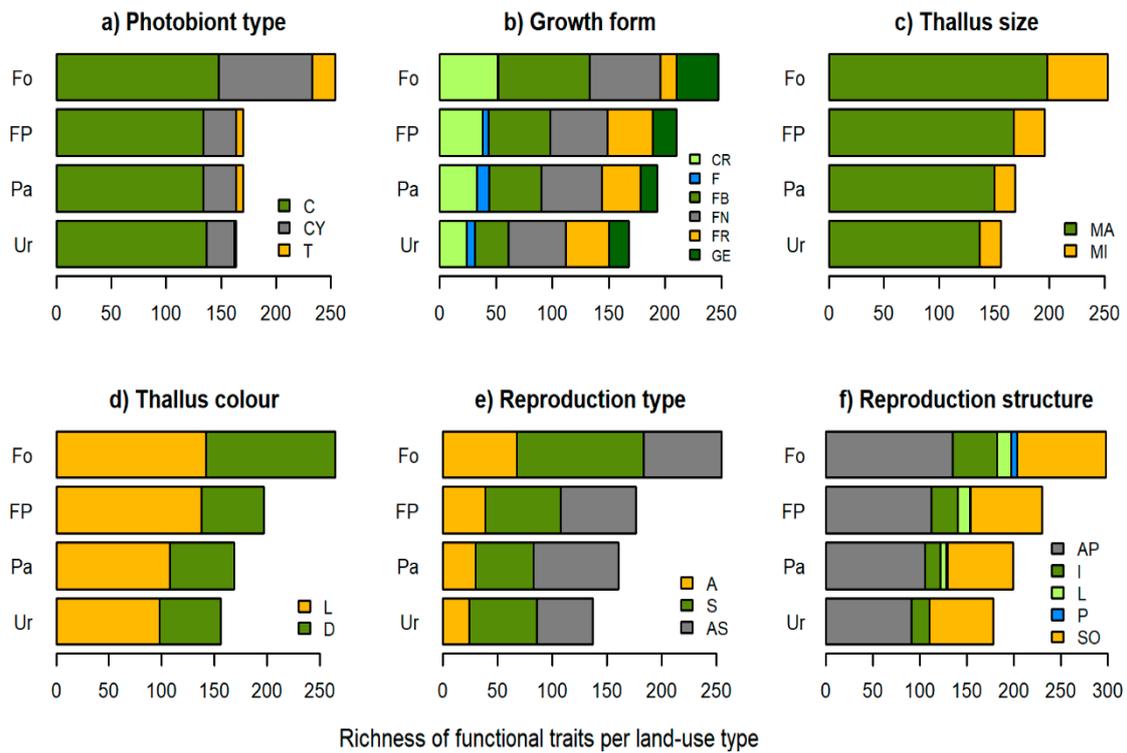
Figure 4. Variation in the richness of functional traits of the epiphytic lichen community in four riparian land uses of Andean streams in southern Ecuador. Functional trait and categories evaluated are indicated as follows. Photobiont type (**a**): C = Chlorococcoid; CY = Cyanobacteria: T = *Trentepholia*. Growth form (**b**): CR = Crustose; F = Filamentose; FB = Foliose with broad lobes; FN = Foliose with narrow lobes; FR = Fruticose; G = Gelatinose. Thallus size (**c**): MA = Macrolichens; MI = Microlichens. Thallus color (**d**): L = Light; D = Dark. Reproduction type (**e**): A = Asexual; S = Sexual; AS = Asexual and sexual. Reproductive structure (**f**): AP = Apothecia; I = Isidia; L = Lirellae; P = Perithecia; SO = Soredia. Fo = Forest; FP = Forest Pasture; Pa = Pasture; y Ur = Urban.

The GLMMs models showed that the most relevant predictor for richness of functional traits of lichens was land-use intensity (Table 4). The land-use intensity forest, % forests, and distance to forest (correlated with canopy cover and precipitation) showed a positive correlation on lichen species with cyanobateria as photobiont, and gelatinose and foliose with broad lobes growth forms and macrolichens (Table 4). Conversely, forest-pasture, pasture and urban land use showed positive correlation with lichens species with frutiulose thallus. Lichens with dark colour, apothecia, soredia and isidia reproductive structure were correlated positively with forest (Table 4). The tree diameter (DBH) showed a positive effect on isidia as reproductive structure (Table 4).

Table 4. Summary of the GLMM applied on the functional traits of the epiphytic lichen community in four riparian land uses of Andean streams in southern Ecuador. Coefficient of variation with differences at *p*-value (<0.05) are indicated in brackets. DBH: diameter at breast height. Fo = Forest; FP = Forest-Pasture; Pa = Pasture; y Ur = Urban. DBH = diameter at breast height, Dist-F = distance to forest; %Fo = percentage of forest.

Functional Traits	Land-use Intensity				DBH	Dist-F	%Fo
	Fo	FP	Pa	Ur			
Photobiont type							
Chlorococcoid	1.883 (0.004)						
Cyanobacteria	0.927 (0.001)	−0.871 (0.01)	−0.953 (0.01)	−1.195 (0.002)			
Trentepohlia				−1.969 (0.03)			
Growth form							
Crustose	1.033 (0.005)	−0.704 (0.04)	−0.977 (0.02)	−1.847 (0.01)			
Filamentose				−6.699 (0.04)		2.347 (0.02)	
Foliose with broad lobes	1.277 (0.002)			−2.064 (0.01)		0.789 (0.04)	
Foliose with narrow lobes	0.911 (0.003)						
Fruticose	−0.844 (0.02)	1.007 (0.03)		1.013 (0.04)			
Gelatinose		−1.028 (0.02)	−2.211 (0.01)	−2.13 (0.02)			
Thallus size							
Macrolichens	2.112 (0.009)						
Microlichens						1.553 (0.01)	1.368 (0.006)
Thallus colour							
Light	1.519 (0.001)						
Dark	1.818 (0.001)	−1.091 (0.02)	−1.17 (0.03)				
Reproduction type							
Asexual	1.539 (0.001)	−1.263 (0.004)	−1.929 (0.002)	−2.226 (0.001)			
Sexual	1.298 (0.001)		−0.818 (0.01)	−0.622 (0.04)			
Asexual and sexual	0.775 (0.001)						
Reproductive structure							
Apothecia	1.769 (0.001)						
Isidia	0.502 (0.006)	−0.492 (0.03)	−0.98 (0.005)	−1.281 (0.008)	0.271 (0.02)		
Lirellae							
Perithecia							
Soredia	1.099 (0.03)						

4. Discussion

4.1. Species Richness, Functional Traits and Community Composition

Our findings reveal a negative effect of land-use intensity on several metrics of taxonomic diversity and functional traits of the epiphytic lichen communities across riparian buffers in the

Andes of southern Ecuador. There was a decrease in species richness and changes in community composition from forest to urban sites, as in other studies [5,20,56–59]. Similarly, the richness of functional traits such as photobiont type and growth form of epiphytic lichens diminished along the land-use intensity. Other studies have also demonstrated that land-use change has affected the functional traits of lichens [5,15,19,21,22,25,27,60]. Following this pattern for richness of functional traits Pinho et al. [20], Benitez et al. [21] and Koch et al. [22], showed that forest disturbance and urbanization have a strong correlation on the richness of functional traits of the epiphytic lichen communities. This phenomenon associated with species richness and functional traits can be explained by the ecological and physiological requirements related to water availability. Thus, a greater richness of sensitive species (e.g., *Leptogium*), species with cyanobacteria and gelatinose growth were present in forest sites with a closed canopy [5,14,18,19,61–64] than in pasture and urban sites. This is because they are intolerant to light and strongly depend on atmospheric humidity, in some cases they even need liquid water to do photosynthesis [65].

On the other hand, the highest occurrence of heliophytic lichen species with green algae and cortical pigments, microlichens, lichens with narrow lobes, light and fruticose thallus were related to sites with a more anthropogenic land use (e.g., forest-pasture, pasture and urban zones). These species show a higher tolerance to lower humidity and more light intensity promoted positively by an open canopy [5,14,18–20,23,63,64]. In our case, heliophytic lichen species (e.g., *Parmotrema*, *Teloschistes*, and *Usnea*), species with narrow lobes such as *Physcia*, *Heterodermia* and *Hypotrachyna*, and fruticose species (e.g., *Usnea* and *Teloschistes*) were present in more anthropogenic areas because these sites present high levels of solar radiation and water stress [22,63]. These lichen species can hydrate very fast, as well as rapidly lose water, because they occupy more surface and a have broad fixation structure to substrate [25,56]. In addition, most of the recorded species present secondary metabolites (i.e., atranorine or usnic acid) that provide protection against solar radiation typical in altered zones [21,22]. In the disturbed sites we also observed an increase of lichen species with chlorococcoid green algae. An explanation to this finding is that green algae species are better adapted to open forests because they avoid the photoinhibition by using a minimum amount of water in their thallus during photosynthesis [5,20–22,56,63].

Epiphytic lichen community composition was also influenced by the differences in land-use intensity. A forest cover reduction leads to less humidity and more intensity of light, thus lichen species restricted to undisturbed forests (shade epiphytes) are more affected [10,19,63]. In our study, the forest sites were dominated by species of the genera *Leptogium*, *Sticta* and *Lobaria*, which are species with cyanobacteria as a photobiont with high needs of water and forest cover [26,62,66]. These species are strictly associated with forest and can be considered good indicators of land-use intensity. On the other hand, another group of species were favored by the disturbance gradient, because they are capable of tolerating more light intensity and low humidity [10,14]. Thus, forest-pasture, pasture, and urban sites were dominated by xerophytic species (sun epiphytes) of the genera *Heterodermia*, *Parmotrema*, *Physcia*, *Teloschistes* and *Usnea* [15,22,59]. The adaptive advantage of sun epiphytes against shade epiphytes is their secondary metabolites that make them tolerant to high levels of radiation [21]. Both indicators and some non-indicator species have important ecological implications in the riparian ecosystems of the southern Ecuadorian Andes. For instance, most species of the genus *Leptogium* (e.g., *L. burgesii*, *L. cochleatum*, *L. coralloideum*, *L. corticola*, *L. laceroides* and *L. marginellum*), *Lobaria* (*L. subexornata*) and *Sticta* (*S. ferax*, *S. fuliginosa* and *S. tomentosa*); are associated with forest land use intensity and can be considered as good indicators of riparian forests with closed canopy and higher humidity [10]. *Heterodermia hypoleuca*, *H. leucomela*, *Physcia aipolia* and *Ramalina celastri* are the best indicators for urbanization, whereas that *Dirinaria picta* and *Flavopunctelia flaventior* for pasture. In accordance with other studies, the presence of these species indicates exposed conditions and can be considered a good indicator of the effects of land-use changes [10,20–22,28].

4.2. Application in Biomonitoring

Along our disturbance gradient, our measures of epiphytic lichen species richness, community composition, and functional traits richness, performed well when detecting the negative effect of land use intensity. However, functional traits have an advantage over community structure and species richness, of providing evidence of potential alterations in the biodiversity-ecosystem functioning relationships [21,22,24]. In this context, photobiont type and growth form of epiphytic lichens are easily measured and could be suitable indicators for detecting land-use intensity along riparian margins in Andean ecosystems. Likewise, growth form is a more sensitive indicator to changes in canopy cover facilitating a quantification of the effects of riparian forest disturbance, and potentially to assess the success of forest management in riparian buffers that promote and enhance the ecosystem health of Andean streams [36]. This first study in Ecuador, which assesses the suitability of a set of taxonomic and functional metrics of the epiphytic lichen community could be used as a complementary approach to understand the structure and functioning of riparian ecosystems in the tropical Andes. Therefore, these metrics could be effective indicators of land-use transformation in tropical Andes. Furthermore, the information provided here can contribute to better management practices in riparian margins of montane ecosystems in general.

Supplementary Materials: The following are available online at http://www.mdpi.com/1424-2818/11/5/73/s1, Table S1: Lichen species contribution to CCA axes using abundance data per tree and land-use intensity (covariate) precipitation, distance to forest and percentage of forest (predictors).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Indicator species analysis found in forest, forest-pasture, pasture and urban.

Taxa	Land-use Intensity	Indicator Value	*p*-value
Bacidia sp.	Forest	3.3	1.000
Bacidia sp. 1	Pasture	1.7	1.000
Bacidia sp. 2	Forest	3.3	1.000
Bacidia sp. 3	Forest-pasture	3.3	1.000
Byssoloma subdiscordans (Nyl.) P. James	Pasture	4.8	0,3211
Candelaria concolor (Dickson) Stein	Urban	6.7	0.2438
Candelaria sp.	Forest	3.6	0.6059
Canomaculina pilosa (Stizenb.) Elix & Hale	Pasture	6.2	0.2464
Chapsa aff. *dilatata* (Müll. Arg.) Kalb	Forest	1.9	1.00
Chapsa aff. *diploschistoides* (Zahlbr.) Frisch	Forest	3.3	1.000
Chapsa sp.	Forest-pasture	5.3	0.4695
Chrysothrix candelaris (L.) JR Laundon	Urban	10.7	0.0494
Cladonia coniocraea (Flörke) Sprengel	Forest	23.3	0.0008
Coccocarpia palmicola (Spreng.) Arv. & D.J. Galloway	Forest	3.3	1.000
Coccocarpia pellita (Ach.) Müll. Arg.	Forest	6.7	0.2368
Coenogonium linkii Ehrenb	Forest	20	0.0016
Coenogoium pineti (Ach.) Lücking & Lumbsch	Forest-pasture	3.3	1.000
Dirinaria picta (Sw.) Clem. & Schear	Pasture	10	0.0444
Flavopunctelia flaventior (Stirt.) Hale	Pasture	31.7	0.0012
Graphis sp.	Forest	6.7	0.2272
Graphis sp. 1	Forest	3.3	1.000
Graphis sp. 2	Forest	3.3	1.000
Graphis sp. 3	Forest	3.3	1.000
Heterodermia albicans (Pers.) Swinscow & Krog	Forest-pasture	3.3	0.7986
Heterodermia andina Moberg	Urban	5.7	0.2745
Heterodermia comosa (Eschw.) Follmann & Redón	Pasture	3.3	1.000
Heterodermia corallophora (Taylor) Skorepa	Pasture	15.1	0.0162
Heterodermia diademata (Taylor) D.D. Awasthi	Forest	3.3	1.000
Heterodermia galactophylla (Tuck.) W.L. Culb.	Pasture	5.4	0.4147
Heterodermia hypoleuca (Mühl.) Trevis.	Urban	18	0.0026
Heterodermia isidiophora (Nyl.) D.D. Awasthi	Forest	14.1	0.0468

Table A1. *Cont.*

Taxa	Land-use Intensity	Indicator Value	*p*-value
Heterodermia japonica (M. Satô) Swinscow & Krog	Pasture	12.2	0.0714
Heterodermia leucomela (L.) Poelt	Urban	15.5	0.0084
Heterodermia pseudospeciosa (Kurok.) Culb.	Forest	3	0.6067
Heterodermia sitchensis Goward & Noble	Pasture	14.8	0,2697
Heterodermia squamulosa (Degel.) Culb	Forest-pasture	13	0.0086
Heterodermia spathulifera Moberg & Purvis	Forest	21.8	0.0006
Heterodermia speciosa (Wulfen) Trevisan	Pasture	2	1.000
Heterodermia sp.	Forest	3.3	1.000
Hypotrachyna costaricensis (Nyl.) Hale	Forest-pasture	6.7	0.2446
Hypotrachyna revoluta (Flörke) Hale	Forest	4.6	0.2931
Hypotrachyna rockii (Zahlbr.) Hale	Forest	34	0.0002
Hypotrachyna reducens (Nyl.) Hale	Pasture	15.7	0.1236
Hypotrachyna sinuosa (Sm.) Hale	Forest	2.2	1.000
Lecanora chlarotera Nyl.	Urban	10	0.0566
Lecanora helva Stizenb.	Urban	3.3	1.000
Lecanora sp.	Urban	3.3	1.000
Lepraria sp.	Forest	3.8	0.7365
Leptogium austroamericanum (Malme) CW Dodge	Forest	6.3	0.1882
Leptogium azureum (Sw.) Mont.	Urban	7.4	0.2442
Leptogium burgesii (L.) Mont.	Forest	20	0,0004
Leptogium burnetii Dodge	Forest-pasture	3.3	1.000
Leptogium cochleatum (Dicks.) P.M. Jørg. & P. James	Forest	24.1	0.0002
Leptogium coralloideum (Meyen & Flot.) Vain.	Forest	11.1	0.0388
Leptogium corticola (Taylor) Tuck.	Forest	15.9	0.0036
Leptogium cyanescens (Rabh.) Körb.	Forest-pasture	5.7	0.3835
Leptogium diaphanum (Sw.) Nyl.	Forest-pasture	20.3	0,019
Leptogium laceroides B. de Lesd.	Forest	10	0.0466
Leptogium marginellum (Sw.) Gray	Forest	10	0.0468
Leptogium millegranum Sierk	Urban	9.8	0.0558
Leptogium olivaceum (Hook.) Zahlbr.	Forest	6.7	0,2388
Leptogium phyllocarpum (Pers.) Mont.	Urban	6.7	0.2442
Leptogium sp.	Forest	13.3	0.025
Lobaria erosa (Eschw.) Nyl.	Forest	2,8	1.000
Lobaria subexornata (Yoshim.) Yoshim.	Forest	16.7	0.0024
Megalospora melanodermia (Müll. Arg.) Zahlbr.	Forest	13.3	0.0134
Normandina pulchella (Borrer) Nyl.	Forest	13.3	0.0134
Parmotrema arnoldii (Du Rietz) Hale	Forest-pasture	4.6	0.8822
Parmotrema austrosinense (Zahlbr.) Hale	Pasture	13.8	0.067
Parmotrema chinense (Osbeck) Hale y Ahti	Urban	5.6	0.3569
Parmotrema conferendum Hale	Forest-pasture	7	0.2651
Parmotrema cristiferum (Taylor) Hale	Forest	8.1	0.1466
Parmotrema exquisitum (Kurok.) DePriest & B.W. Hale	Forest-pasture	4.7	0.5609
Parmotrema peralbidum (Hale) Hale	Forest-pasture	3.1	1.000
Parmotrema subtinctorium (Zahlbr.) Hale	Forest	2.5	0.6121
Parmotrema sp.	Forest-pasture	12.4	0.0242
Pannaria conoplea (Ach.) Bory	Forest-pasture	21.3	0.0042
Pertusaria sp.	Forest	3.3	1.000
Pertusaria sp. 1	Forest	6.7	0.242
Pertusaria sp. 2	Urban	6.8	0.1912
Pertusaria sp. 3	Forest	6.7	0.2442
Pertusaria sp. 4	Forest	6.7	0.232
Pertusaria sp. 5	Forest-pasture	3.3	1.000
Pertusaria sp. 6	Forest-pasture	1,7	1.000
Phaeographis brasiliensis (A. Massal.) Kalb & Matthes-Leicht	Forest	8.8	0.0598
Phaeographis decipiens Müll. Arg.	Pasture	3.3	1.000
Phaeographis dendritica (Ach.) Müll.Arg.	Forest-pasture	2.3	1.000
Phaeographis intricans (Nyl.) Vain.	Forest	6.7	0,2476
Phaeographis inusta (Ach.) Müll. Arg.	Pasture	3.3	1.000
Phaeographis quadrifera (Nyl.) Staiger	Forest-pasture	15,4	0,0052
Phaeographis punctiformis (Eschw.) Müll. Arg.	Forest	3.3	1.000
Phaeographis subtigrina (Vain.) Zahlbr.	Forest-pasture	2.3	0.9884
Phaeophyscia aff. *limbata* (Poelt) Kashiw.	Pasture	9.2	0.1222
Phaeophyscia sp.	Forest	11.1	0.2202
Phyllopsora isidiotyla (Vain.) Riddle	Pasture	30.9	0.0002
Physcia aipolia (Ehrh. Ex Humb.) Fürnr.	Urban	12	0.0372
Physcia atrostriata Moberg	Pasture	3.3	1.000
Physcia crispa Nyl.	Urban	10.9	0.0638
Physcia endochrysea (Nyl.) Hampe	Urban	14.9	0.0088
Physcia poncinsii Hue	Urban	6.7	0.2446
Physcia sorediosa (Vain.)	Urban	6.7	0.248
Physcia sp.	Urban	3.3	0.6163
Physcia sp. 1	Urban	3.3	1.000
Physcia sp. 2	Pasture	5.2	0.2494
Pseudocyphellaria aurata (Ach.) Vain.	Forest-pasture	11.9	0.0144
Pseudocyphellaria crocata (L.) Vain.	Pasture	10.3	0.0998
Punctelia aff. *crispa* Marcelli, Jungbluth & Elix	Forest-pasture	3.3	1.000

Table A1. *Cont.*

Taxa	Land-use Intensity	Indicator Value	*p*-value
Punctelia reddenda (Stirt.) Krog	Forest-pasture	10	0.0616
Punctelia rudecta (Ach.) Krog	Forest	4.2	0.6065
Punctelia subrudecta (Nyl.) Krog	Forest	14.9	0.0088
Punctelia sp.	Forest	2.0	1.000
Punctelia sp. 1	Forest	3.3	1.000
Punctelia sp. 2	Forest-pasture	2.1	0.912
Pyrenula sp	Forest-pasture	10.0	0.053
Pyrenula sp1.	Forest-pasture	11.9	0.0932
Pyxine cocoës (Sw.) Nyl.	Forest	10.0	0.0616
Ramalina celastri (Spreng.) Krog & Swinscow	Urban	12.8	0,0132
Ramalina cochlearis Zahlbr.	Urban	2.2	1.000
Ramalina peruviana Ach.	Forest-pasture	4.0	0.6189
Rimelia reticulata (Taylor) Hale	Forest-pasture	2.1	1.000
Rimelia subisidiosa (Müll. Arg.) Hale	Pasture	3.7	0,7261
Rinodina sp.	Forest	11.4	0,033
Sticta andensis (Nyl.) Trevis.	Forest	3.3	1.000
Sticta ferax Müll. Arg.	Forest	16.7	0.0028
Sticta fuliginosa (Dicks.) Ach.	Forest	39.8	0.0002
Sticta humboldtii Hook. f.	Forest	6.7	0.2488
Sticta tomentosa (Sw.) Ach.	Forest	20	0.0008
Sticta sp.	Pasture	13.3	0.015
Teloschistes flavicans (Sw.) Norman	Urban	6.9	0.1842
Teloschistes chrysophthalmus (L.) Beltr.	Pasture	2.5	0.8224
Teloschistes exilis (Michaux) Vain.	Forest-pasture	9.6	0.5153
Teloschistes hypoglaucus (Nyl.) Zahlbr.	Urban	1.7	1.000
Usnea sp.	Forest-pasture	14.9	0.0336
Usnea sp. 1	Urban	2.4	1.000
Usnea sp. 2	Pasture	8.2	0.3405
Usnea sp. 3	Urban	16.4	0.0188
Usnea sp. 4	Urban	9.0	0.1246
Usnea sp. 5	Urban	5.3	0.4397
Usnea sp. 6	Forest-pasture	3.9	0.6755
Usnea sp. 7	Urban	6.0	0.2809

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