The Effects of Edge and Pollution on Lichen Richness, Abundance, and Distribution in Cañitas, Costa Rica

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ABSTRACT

Lichens are commonly known to be biological indicators of pollution and edge effects. Their use as indicators in temperate regions is well documented, however, less is known about their function as a bioindicator in the tropics. There is also debate over the consequences of edge effects, such as increased temperature, less moisture and wind, on lichen richness and abundance. In this study lichen communities on tree trunks in three habitat sites (primary forest, pasture, and roadside) were examined. In total 88 trees were censused in order to determine lichen richness, abundance, and similarity. Overall 68 species of lichen were observed. The pasture site demonstrated the highest total number of species (42), average number of species (5.97), and average abundance (28% coverage). In contrast, the road showed the lowest total number of species (16), average number of species (2.39), and average abundance (.37%). It was speculated that these trends were due to the strong effects of edge and air pollution, however, these factors were not directly measured. The moist primary forest site appeared to have moss competing with lichen for area on the tree trunk, possibly limiting the number of species and abundance of lichen in that site. The highest similarity between sites was observed between the pasture and roadside, most likely due to the similarity of these two environments. Both were subject to edge effects, however the road had the additional pressures of air pollution and dust.

RESUMEN

Los líquenes son indicadores biológicos de contaminación y efectos de orilla. Su uso en regiones templadas está bien establecido, sin embargo, sabemos menos de su función como indicador biológico en el trópico. Además, hay desacuerdos acerca de las consecuencias del efecto de borde, como lo son el aumento de temperatura, la disminución de la humedad, y el viento sobre la riqueza y la abundancia de líquenes. En este estudio se examinaron tres hábitats (Bosque primario, potreros y borde del camino), 88 árboles fueron considerados y 68 especies de liquen fueron considerados. Yo analicé comunidades de líquenes sobre los troncos de árboles en términos de la riqueza de especies, abundancia y similitud. El potrero mostró el número de especies (42), número promedio de especies (5.97) y abundancia promedio más altos (28%). Por otro lado, el camino mostró el número de especies (16), el numero promedio de especies (2.39), y abundancia promedio más bajos (.37%). Yo especulé que esto se debe a los efectos fuertes del borde y a la contaminación. El bosque primario húmedo pareció tener musgo compitiendo con líquen por el área en el tronco; por lo tanto posiblemente limita el número de especies y abundancia de líquenes en ese hábitat. La similitud más alta entre sitios se observó entre el potrero y el camino, probablemente debido a la similitud de los dos terrenos. Los dos están sujetos a fuertes efectos del borde; sin embargo, el camino también exhibe las presiones adicionales de contaminaction del aire y polvo.

INTRODUCTION

Lichens, although commonly thought of as a single entity, are in fact a symbiosis between a fungus and a photosynthesizing organism. Lichen fungi, many (over 40%) belonging to the Division Ascomycota, associate with green algae or cyanobacteria (Purvis 2000). The fungal partner, or mycobiont, provides the physical structure for the photosynthesizing component, or photobiont, and absorbs minerals and moisture from the environment (Brodo et al. 2001). The photobiont photosynthesizes and provides carbon and nitrogen to the mycobiont. Lichens occur in diverse habitats worldwide, from the tropics to polar-regions, and to the most arid and harsh environments. About 8% of Earth's land surface is covered by vegetation that hosts lichen (Purvis 2000). Close to 14,000 species of lichens are known, exhibiting diverse color, form and size (Brodo et al. 2001).

For over 140 years, lichens have been recognized as being extremely sensitive to air pollution (Brodo et al. 2001). Having no roots, they efficiently absorb water and nutrients from air and rainwater across their surface. This adaptation makes them vulnerable and sensitive to chemicals in their environment. The symbiosis between the mycobiont and photobiont further contributes to this sensitivity; if one component becomes damaged by the pollutant then the partnership will not function and the lichen will die (Brodo et al. 2001). For these reasons lichens are commonly used as biological indicators of pollution. Air quality, specifically concentrations of sulfur dioxide, fluoride, and ammonia, has been monitored using lichens. Although lichens are well-studied bioindicators in temperate regions, less is known about their usefulness as pollution indicators in the tropics partly due to their higher species diversity (Wolseley and Aguirre-Hudson 1997).

Studies to determine the pollution tolerance of lichen in the tropics are becoming more common. A popular technique is to transplant lichens from a habitat without pollution to an area with pollution, and vise versa to monitor what is absorbed and the rate of absorption. One such study in Venezuelan cloud forests transplanted lichens from an urban and presumed polluted habitat to an area without pollution, and from the pristine habitat to the urban area (Gordon et al. 1995). Fog frequencies in both habitats were very high (up to 326 days a year) and previous studies showed that the fog from the urban area was characterized by high concentrations of Pb, Zn, and Mn. These metals were thought to come from human sources; including heavily leaded gasoline and Zn from tire dust. Elevated concentrations of these metals were found in the transplanted lichen at the urban site after only a few months. Conversely, the lichen transplanted from the polluted site to the forest lost significant amounts of Pb after six to ten months.

The findings of a tropical lichen study in San Jose, Costa Rica suggested that the Pb and other chemicals in gasoline had an adverse effect on lichen communities (Monge-Najera et al. 2002). Lichen cover change was recorded from 1976-1997 within a 10 x 10 cm template positioned 1.5 m above ground on the south, east, north, and west sides of ten trees per station in 11 study stations. Mean lichen cover was 23% in 1976, 12% in 1986, 9% in 1990, and 22% in 1997. Most stations reflected a reduction in mean coverage after 1976, but increased after 1990, possibly due to improved traffic regulations and elimination of lead from gasoline, which was banned in Costa Rica in 1995 (Muñoz, 11/23/04, www.tierramerica.net/2002/1006/iacento3.shtml).

Lichens are sensitive not only to pollution, but to edge effects as well, although there is debate as to how these affect lichen abundance and species richness. Forest fragmented by a road, pasture or other natural or human caused disturbances, have decreased moisture, higher temperature, and more wind along forest edges. A 1998 study collecting data on the fruticose lichen, *Alectoria sarementosa*, showed that a significantly lower mass of lichen grew along the forest edge than deeper within the forest (Esseen and Renhorn 1998). Other studies found that edge effects may increase lichen species richness and abundance. In one study of two managed forests, the percent of a plot occupied by gaps was strongly correlated with lichen species richness (Neitlich and McCune 1997). Larger gaps supported higher species richness, suggesting that edge effect, which increase with the size of a gap, may contribute to higher species richness and diversity. Another study conducted by Wolseley et al. (1991) suggested that high lichen species richness may be found along forest edges or roads because less sensitive species succeed in disturbed areas. Some species of lichen are more sensitive than others to specific types of pollution and disturbance, and therefore many types of lichen may still thrive in mildly polluted areas (Brodo et al. 2001).

An edge effect specific to unpaved roads is increased dust and airborne particulates. Monteverde, Costa Rica has two distinct seasons: wet and dry/misty. The wet season ranges from April to November and the dry/misty season for the remainder of the year. The dry/misty season is defined by more wind and increased intervals without measurable precipitation. Lacking moisture at this time of year, the roads become dustier and vegetation alongside them is covered in a film of sand and dust. Physical effects of dust and sand on plants include cell destruction and blocked stomata (Spellerberg 1998). A 1993 study of the effects of dust on plants and plant communities found that epiphytic lichens, sphagnum, and some mosses were the most sensitive of the taxa studied (Farmer 1993). Therefore, in Monteverde dust must be included as an edge effect of roadside disturbances.

Monteverde offers many environments to study the consequences of pollution/dust and edge effects on lichen. Unpaved roads provide areas to study the effects of pollution and dust as well as strong edge effects such as lower moisture, increased temperature, and wind. Pasture areas are relatively unpolluted and free of dust, but still are subject to common edge effects. And primary inner-forest environment shows very little edge and pollution/dust effects.

In this study I expect to find that both pollution/dust and edge effects have a negative effect on lichen species richness and abundance. Therefore, the forest interior lichen should demonstrate the highest species richness and abundance. Without the effects of pollution and dust, pasture lichen should show the second highest richness and diversity. Due to pollution/dust and edge effects, roadside lichen will have the lowest species richness and abundance. I expect the roadside and pasture sites to have the most similar species compositions because they are both subject to edge effects. My pasture site borders the forest, so perhaps the forest and pasture sites will have the next highest species composition, leaving the forest and roadside sites to have the lowest similarity.

MATERIALS AND METHODS

This study was conducted at three sites on or near the property of Jim Wolfe and Martha Salazar in Cañitas, Costa Rica, from October 25 to November 15, 2004. The sites included primary forest (1405 m), pasture (1400 m), and roadside (1305 m), all near or in forest classified as Holdridge Lower Montane Wet Forest. The primary forest was a fragment between two dairy farm pastures. Thirty trees from this habitat were censused from the interior no closer than 8 m from the forest edge. Pasture data were collected from 30 trees in one of these dairy farm pastures. Data for the roadside were gathered from 28 trees directly bordering the main road, Calle Principal, to the West below the property of Jim and Martha.

Trees with a diameter at breast height (DBH) of more than 28 cm were randomly chosen for study in all three habitats. For each tree, an area of 56 x 225 cm was censused for lichen area covered and for the presence of morphospecies. A clear laminate grid was placed 1 m from the ground over the bark of the tree to delineate the study area. The lichen was censused by counting the total number of squares filled by lichen in the 56 x 225 cm area. Morphospecies found within this area were recorded as well as tree DBH. Photos of each species were taken with a Sony Cyber-shot DSC-S85 digital camera and later used to accurately identify them throughout the study.

A Simple Linear Regression Test was used to determine whether the number of species or percent coverage was related to the average tree DBH. A one-way ANOVA was used to test whether the mean number of species and percent coverage differed between sites. Finally, a Sorenson's Quantitative Index was used to determine similarities in morphospecies composition between the three sites.

RESULTS

A total of 68 species were found at the three different sites: 28 in the primary forest, 42 in the pasture, and 16 along the road (Figure 1). The pasture had the highest total species richness, followed by the primary forest and roadside sites.

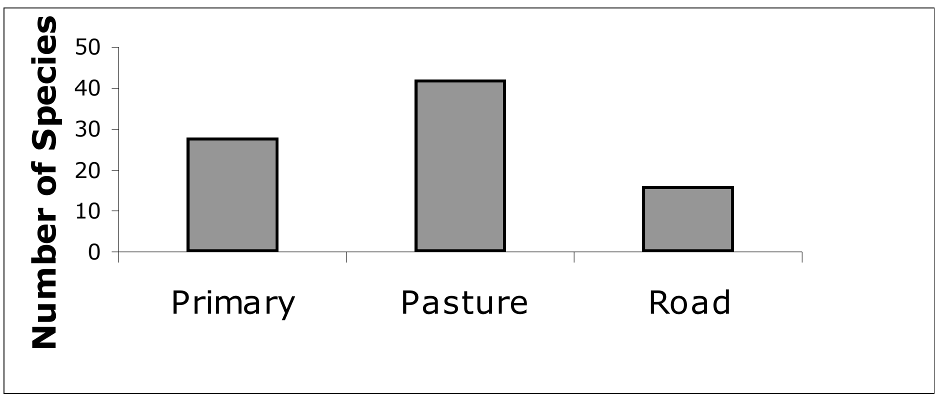
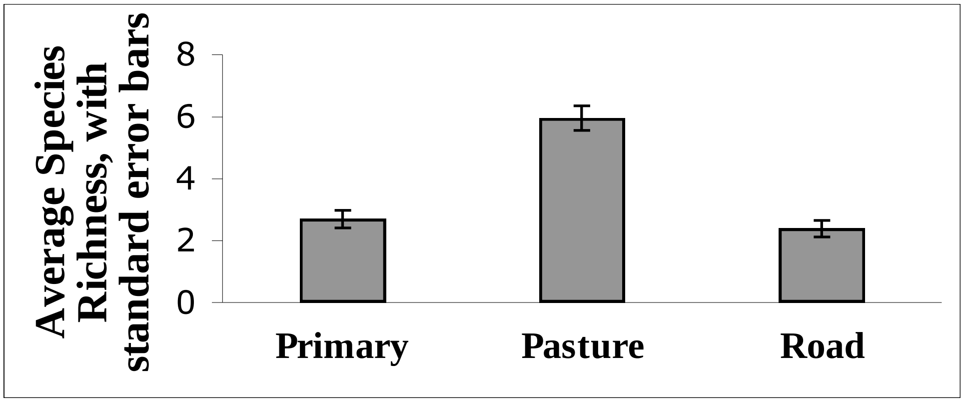


Figure 1 Total lichen morphospecies observed at three sites in Cañitas, Costa Rica.

The average species richness and average coverage were both highest at the pasture site (Figure 2). Primary and roadside sites had very similar average species values (2.7 and 2.4 respectively) but dissimilar average proportion coverage values (23.9% and 3.7% respectively). One-way ANOVA analysis showed that average species richness for both the primary forest/pasture and pasture/road sites was significant. The primary/road sites were not significantly different. The difference in average lichen abundance was significant for the primary forest/road and pasture/road sites. However, the lichen abundance for the primary forest/pasture sites was found to be not significant.

A



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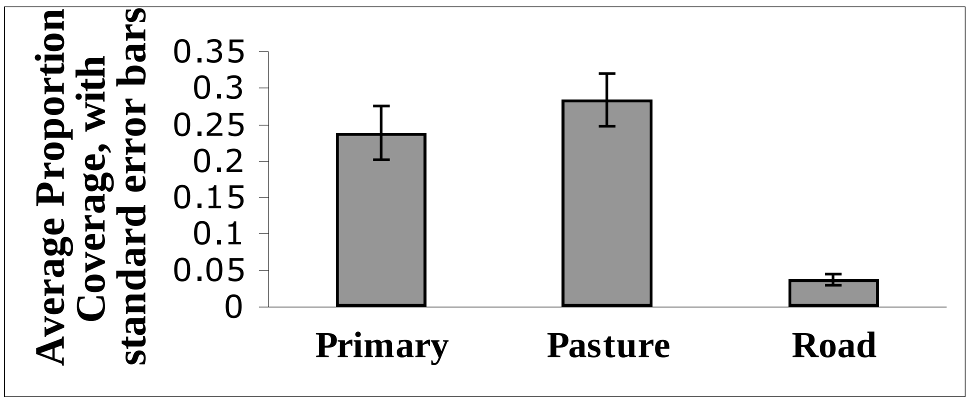

Figure 2. Showing variation in average number of lichen species (A) and average lichen coverage (B) at three sites in Cañitas, Costa Rica. **A**. $F = 36.791$, $p<.0001$; $n = 30, 30, 28$ for primary forest, pasture, and roadside respectively. **B**. $F = 17.873$, $p <.0001$; $n = 30, 30, 28$ for primary forest, pasture, and roadside, respectively.

Table 1. Post-Hoc Analysis of average lichen species richness (A) and average proportion lichen coverage (B) in the primary forest, pasture, and along the roadside.

A

	Mean Diff	Crit. Diff.	P-Value
Primary/Pasture	-0.048	0.086	0.275
Primary/Roadside	0.202	0.087	<.0001
Pasture/Roadside	0.249	0.088	<.0001

B

	Mean Diff.	Crit. Diff	P-Value
Primary/Pasture	-3.267	0.911	<.0001
Primary/Roadside	0.307	0.928	0.512
Pasture/Roadside	3.574	0.928	<.0001

Lichen species similarity calculated with Sorenson's Quantitative Index (Figure 3) showed that there was highest similarity between the pasture/road sites, followed by the road/primary forest sites, and lastly, the primary forest/pasture sites (Quantitative values = 0.464, 0.148, and 0.1 respectively).

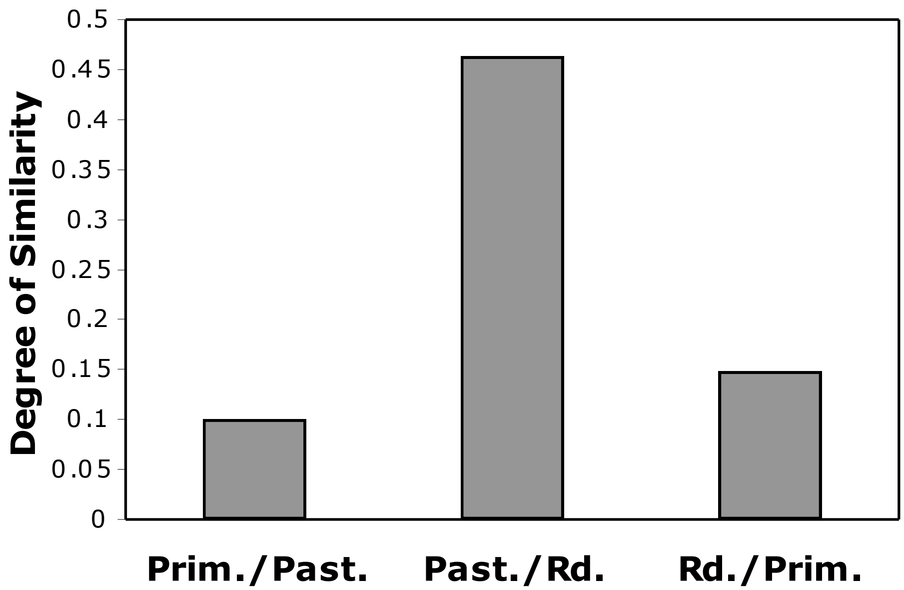

Figure 3. The degree of similarity found using the Sorenson's Quantitative index between the three sites in Cañitas, Costa Rica showing the highest similarity of lichen species between the pasture/road sites, followed by the road/primary forest and finally the primary forest/pasture.

There were no significant relationships found between the DBH of trees at the three sites and their species richness or abundance in single linear regressions (Figure 4). Species richness and abundance showed a slight negative trend with DBH in the primary forest. For the pasture site species richness showed no correlation with DBH and abundance demonstrated a very slight positive trend. Both species richness and abundance demonstrated a slight positive trend with DBH along the roadside.

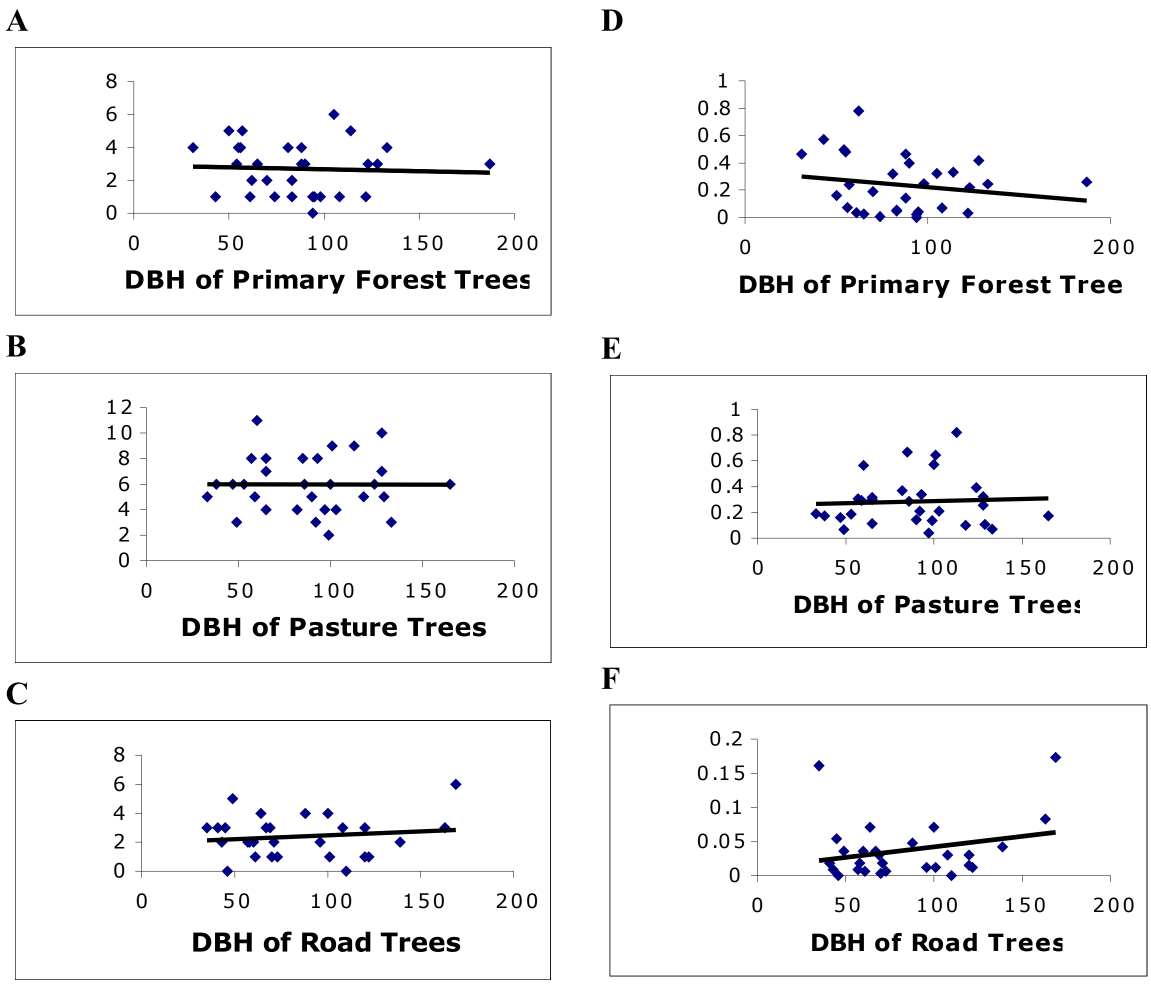

Figure 4. Relationships between tree DBH, lichen species and lichen coverage for each tree at each site in Cañitas Costa Rica. Simple linear regressions showed no significance for any of the relationships.

DISCUSSION

The greatest total species were observed at the pasture site, followed by the primary forest, and the road sites (Figure 1). Contrary to my hypothesis, that the primary forest would have the highest species richness, in fact the pasture was found to have the most species of lichen. One observation that may account for this is the interaction between lichen and moss. Moss survival is dependent upon constant moisture. Of the three sites, moss appeared to flourish most in the primary forest, seemingly competing with the lichen for area on tree trunks. Whereas moss was mainly absent in the pasture habitat, which is subject to edge effects such as lower moisture and higher temperature. This suggests that moss prefers habitats without edge effects, and lichen, perhaps a poor competitor with moss, can thrive in disturbed areas. Sulyma and Coxon (2001) found in British Columbia that lichen coverage was overtaken by feather moss mats in mid- to late-successional forests, with moss mats often burying lichen that previously had occupied microsites. Canopy leaf area was found to have a positive effect on the area of moss mats in forest microsites. This finding agrees with the data of this study because highest average proportion coverage was found in the pasture (Figure 2B) where there is least canopy leaf area.

The lowest richness of lichens was found along the road, and little moss was observed there as well, perhaps due to the limited moisture. The road is subject to the same edge effects as the pasture, but has the additional pressures of pollution and dust. Fewer total species along the road suggests that the added edge effects of pollution and dust along the road negatively impact many lichen species and those that remain are more tolerant.

In addition to total species observed at each site, the pasture had the highest average species richness per tree being greater than both the primary forest and roadside trees (Figure 2A). This further suggests that lichens thrive in areas of disturbance where there is lower moisture and higher temperatures. Both of these sites have lower average lichen species richness, perhaps because the primary forest lichens must compete with moss, and lichens along the road are limited by pollutants and dust. However, not all lichens may be classified together by their preferred environments; some lichen need moisture, other need dry habitats, and others such as *Xanthoria sp*. even thrive on nitrogen rich agricultural dust (Stone 2004).

The difference in average lichen coverage was found to be significant for the primary forest/road and pasture/road sites (Figure 2B, Table 1). Because the road had such an extremely low average percent coverage, both other sites were significantly different when compared with it. The pasture showed the highest average coverage of lichen and the road showed the lowest. Both sites were subject to edge effects, while the road also probably experienced pollution and dust. This is again suggestive that pollution and dust contribute to low roadside abundance. Both the primary forest/pasture sites had relatively high average abundances and were found to have no significant differences in abundance.

The high similarity between the pasture and the road sites (Figure 3) could be explained by the physical similarity between these two habitats. Both are subject to heavy edge effects, but differ in that the road is subject to pollution and dust as well. Therefore, the species that overlap between these two sites are probably those that can best tolerate pollution and dust, and would thus be poor bioindicators because they are least sensitive. Those species that do not overlap and are found only in the primary forest and or pasture might serve as good bioindicators. An example of such species is *Usnea*, a genus found only in the pasture site, is commonly used as a bioindicator in Europe to map pollution levels (Brodo et al. 2001). Lichen communities of the road and primary forest demonstrate the second highest similarity followed by the primary forest and the pasture with the lowest similarity (Figure 3). The primary forest is included in the two lowest similarity comparisons, perhaps because the lichen species that colonize a forest specialize within that habitat and need a moist, lower light environment.

Temperate epiphytic lichen diversity tends to increase with the age of the substrate, therefore, indicators are often associated with trees +200 years (Rose, 1976). However, in a study conducted in tropical forests in Thailand there was little evidence for an increase in diversity with host tree size (Wolseley and Aguirre-Hudson 1997). My study supports the results of Wolseley and Aguirre-Hudson (1997). There were no significant relationships found between the DBH of trees at the three sites and their species richness or abundance (Figure 4). Furthermore, in the primary forest, where the oldest and largest trees are expected to be found, both species richness and abundance revealed a slight negative correlation with DBH.

Increasing habitat fragmentation with the building of roads and other human activities in the tropics intensifies the need to understand how these activities affect tropical richness and biodiversity. As more habitat edge is created, lichen community structure will be altered, as evidenced in this study. Both of the disturbed areas in my study, pasture and roadside, showed significantly different lichen communities than the relatively undisturbed primary forest. If the findings of the Sulyma and Coxon (2001) experiment are also applicable in the tropics, that higher leaf area index values correlate with higher amounts of moss, then manipulation of stand structure in managed forests may delay successional changes and promote continued lichen growth where moss might otherwise have dominated. But it is not only lichen and moss communities that are affected by disturbances. The status of lichens as bioindicators is similar to the idea of the "canary in the mineshaft" species. It would be interesting for future studies to assess how changes in lichen communities correlate with changes in other floral and faunal communities.

For future studies of lichen in the Monteverde area, it would be interesting to explore lichens' dispersal range ability in the context of E.O. Wilson and Robert Macarthur's Island Biogeograpy Theory. It seems that the pastures and surrounding fragmented forests serve as both "islands" and "oceans" for the other. For example, if a fragment of forest is surrounded by pasture, how likely are the forest lichen species to distribute their genes outside of the pasture area, and vise versa. In addition, a closer analysis of the competition between moss and lichen and how it affects the abundance of each in forest environments would be helpful in understanding the dynamics of lichen communities.

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LITERATURE CITED

Brodo, I. M., S.D. Sharnoff, S. Sharnoff. 2001. *Lichens of North America*. New Haven: Yale University Press.

Esseen, P.A., and K.A. Renhorn. 1998. Edge effects on an epiphytic lichen in fragmented forests. *Conservation Biology*. 12(6):1307-1316.

Farmer, A.M. 1993. The effects of dust on vegetation—a review. *Environmental Pollution*. 79:63-75.

Gordon C.A., R.T. Herrera, C. Hurchinson. 1995. The use of a common epiphytic lichen as a bioindicator of atmospheric inputs to two Venezuelan cloud forests. *Journal of Tropical Ecology*. 11:1-26.

Monge-Najera J, M.I. Gonzalez, M.R. Rossi, V.H. Mendez-Estrada. 2002. Twenty years of lichen cover change in a tropical habitat (Costa Rica) and its relation with air pollution. *Revista de Biologia Tropical*. 50(1):309-319

Muñoz, N., Costa Rica's Unleaded Air. 2002. [cited 2004 Nov. 23]; http://www.tierramerica.net/2002/1006/iacento3.shtml

Neitlich, P.N. and B. McCune. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. *Conservation Biology*. 11(1):172-182.

Purvis, W. 2000. *Lichens*. Washington DC: Smithsonian Institution Press.

Rose, F. 1976. Lichenological indicators of age and environmental continuity in woodlands. *Lichenology Progress and Problems*. 279-307.

Spellerberg, I.F. 1998. Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography Letters*. 7(5):317-333.

Stone, Daphne. 2004. PhD University of Oregon, Eugene Oregon. Personal Communication.

Sulyma, R. and D. Coxon. 2001. Microsite displacement of terrestrial lichens by feather moss mats in late seral pine-lichen woodlands of north-central Britich Columbia. *Bryologist*. 104(4):505-516.

Wolseley, P.A., B. Aguirre-Hudson. 1997. The ecology and distribution of lichens in tropical deciduous and evergreen forests of northern Thailand. *The Journal of Biogeography*. 24:327-343.

Wolseley, P.A., C. Moncrieff, B. Aguirre-Hudson. 1991. Lichens as indicators of environmental stability and the change in the tropical forests of Thailand. *Global Ecology and Biogeography Letters*. 1:170-175.