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The effect of fragment size and habitat heterogeneity on plant diversity: a multiscale study in the subhumid low-boreal forest.

By

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Key words: upland low-boreal, vascular plants, bryophytes, lichens, diversity, fragmentation, microhabitats, microclimate, heterogeneity.

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Overview and research objectives

Woodlots are an integral part of sustainable forestry management, currently accounting for 20% of the timber annual sales, and an important component for any strategy to manage the post clearing landscape's biodiversity within the White Zone (Agricultural Area). As some woodlots are extensively managed, they are subjected to a significant environmental pressure. The fate of the biota in a short and long-term frame is of concern to private owners and forest managers. In a general context, the biota of woodlots represents an equilibrium situation of forest fragments, after sufficient time has passed for the full range of post fragmentation changes to occur.

Forest fragmentation over the landscape affects both habitat quality and quantity. By reducing the total area of continuous forest cover, forest fragmentation decreases the quantity of available habitat, and by changing the physical environment of the remaining forest fragments; it affects the quality of the remaining habitat. Since reduction of the total area of forest is often seen as inevitable, it is imperative that forest managers have an understanding of the qualitative changes in habitat in remaining forest fragments so that they can be minimised. Changes in the physical environment of forest fragments include increased wind exposure and higher levels of solar radiation (Camargo & Capos 1995, Sillet et al. 1995, Malcolm 1998). As a result, conditions for plant growth often become warmer and drier and shade-tolerant species are replaced by shade intolerant species (Smith 1996). These physical and biological changes are often termed 'edge effects' as they are most pronounced at the edge of forest fragments and decrease until the physical environment of the forest is similar to that of non-fragmented forest. This forest can be termed 'interior forest'. The amount of interior forest remaining in a forest fragment depends on the size and shape of the fragment. Very small fragments and fragments with a large amount of edge because of their shape may not contain any truly interior forest. Thus species requiring interior forest will be absent from these fragments and species diversity may decline.

The objective of this study is to determine how increased forest fragmentation and edge effects affect the microclimate, the number of available microhabitats (habitat heterogeneity), and plant and lichen species diversity in mature aspen dominated fragments of varying sizes and shapes in three areas of the subhumid low-boreal forest of Alberta.

Progress report

All the research objectives outlined in the original proposal were achieved. Also, we met several times with the Biodiversity (leader S. Boutin) and Land Use Cover Change (leader A. Sanchez) groups in order to coordinate our efforts with their research objectives. As a result of those meetings, we amended our focus to include: selecting a suite of indicators of plant and lichen diversity, establishing performance benchmarks for their utilisation, and offering practical instructions as to their use in the field. We have also successfully attained those added research objectives.

As stated previously, we have attended several meetings with both the Biodiversity and Land Use Cover Change groups and thus satisfied our objectives of linking with other SFM Network Projects. We believe that we are fully integrated into both those groups. We also attended a meeting at the national level with other network groups. We attended several meetings where we either presented our data or the data was presented for us to research partners. Therefore, we are satisfied that we have achieved our objective of linking with other SFM Network Projects and disseminating our results to Network Partners.

Our third major objective was to train a post-doctoral fellow, Dr. C. Mourelle. Unfortunately, we could not obtain sufficient funding from other sources to attain this objective. Alternatively, we tried to recruit a graduate student mid-way through the project to reach this objective. Again, we were not successful. However, we trained several research assistants some of whom have move on to: 1) PhD studies (S. Mills); 2) consulting company (N. Tashe); 3) starting her own business (translating environmental documents among others, N. Young); or 4) to different fields (biomedical technician degree, P. Robinson).

Key findings

Edge effects

Several fragments were studied in three different regions of Alberta: 18 fragments between 54° and 55 °N latitude and between 112° and 114 °W longitude (Athabasca area); 16 between 55° and 56° N latitude and 116° and 117°W longitude (Peace River area); and 11 between 56° and 57°N latitude and 117° and 118°W longitude (Manning area). The aspen dominated upland forest fragments that were selected for study in each region covered the range of sizes and shapes found in the area. Only fragments that were not extensively grazed by livestock and older fragments (> approx 70 years) were selected.

Graphic representations of the relationship between such microclimatic variables as air temperature (Fig. 1), relative humidity (Fig. 2), and light intensity (Fig. 3) that were measured as differences between values inside and outside each fragment show wide variations at each distance from the edge. However, those graphs indicate a trend of diminishing temperature and light intensity and increasing humidity with increasing distance from the margin. Those trends also indicate that air temperature at ground level stabilises at approximately 30 m from the margin while relative humidity and light intensity tend to stabilise at approximately 15 m. Air temperatures at ground level (Fig. 1) indicate differences of up to 15 °C between temperatures inside and outside the fragment. Differences between inside and outside air temperatures at 1 m and 2 m above the soil (not shown) also show trends of decreasing with distance from the edge, but those differences are smaller than those encountered at ground level: up to 7°C at 1 m and up to 6°C at 2 m. Temperatures at 1 m and 2 m above the soil also equilibrated at approximately 15 m from the edge.

Figure 1. Relationship between air temperature at ground level measured as differences between temperatures inside and outside the fragment and the distance from the edge of the fragment.

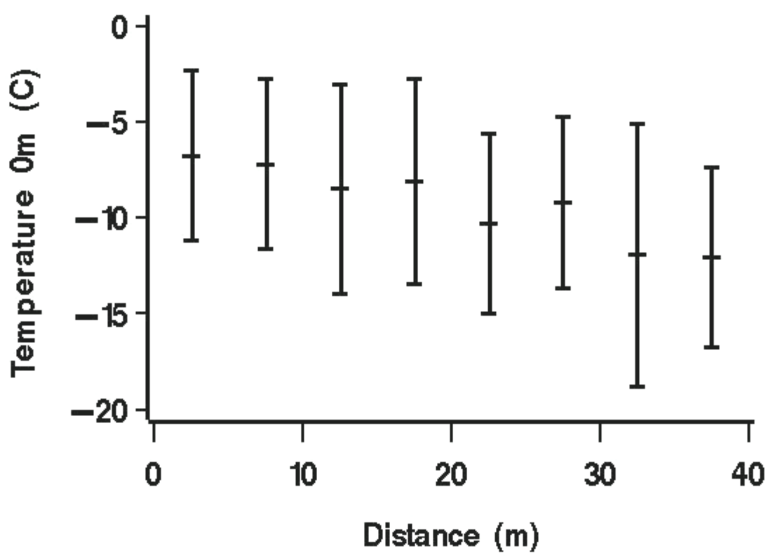


Figure 2. Relationship between relative humidity measured as differences between the humidity inside and outside the fragment and the distance from the edge of the fragment.

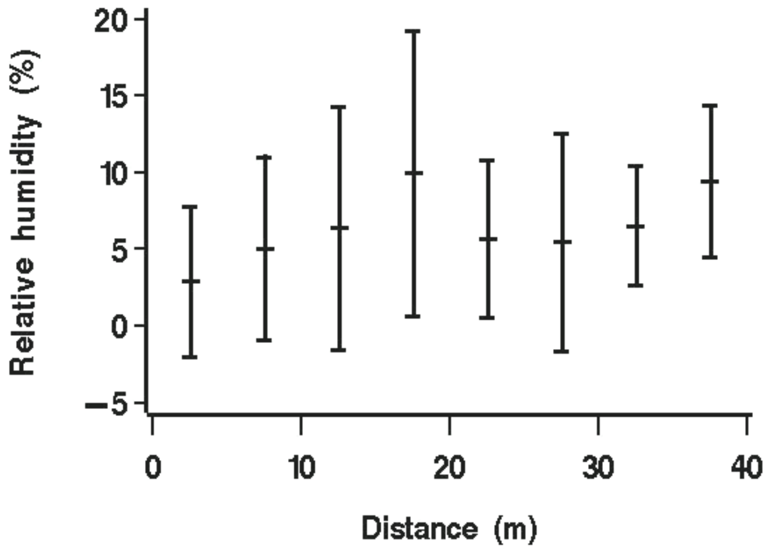
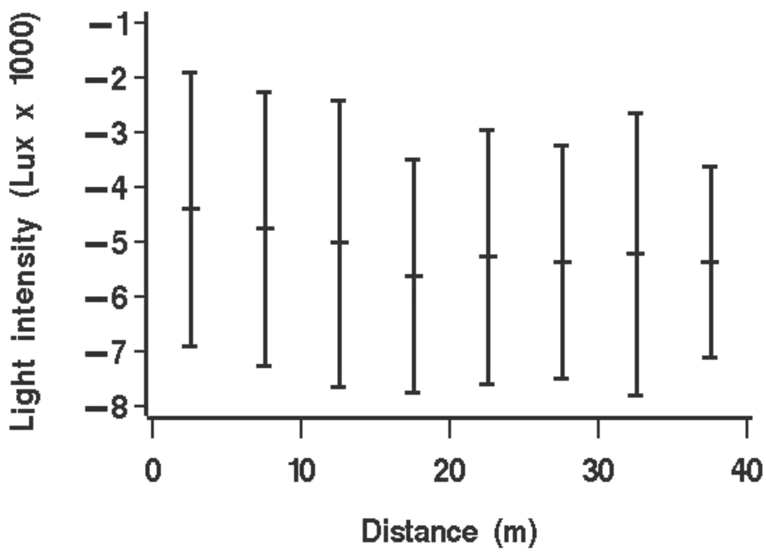


Figure 3. Relationship between light intensity as measured by differences between light inside and outside the fragment that were taken simultaneously and the distance from the edge of the fragment.



A multiple regression analysis of species richness at the quadrat level and distance from the edge, microclimatic variables as well as the number of different microhabitats (Table 1) revealed that distance from the edge is consistently the most important variable for vascular plants and mosses and liverworts in each area. The second most important variable for vascular plant species richness changes from area to area and includes the number of microhabitats and microclimatic variables. However, the second most important variable for the richness of bryophytes is always the number of microhabitats. The number of microhabitats is consistently the most important variable for lichen species richness. Distance from the edge is the second most important variable for lichens only in the Peace River area.

To conclude, edge effects on the microclimate extend to approximately 15 m from the margin and significantly affect the number of vascular plant and bryophyte species in fragments from all three areas. Species richness for those two taxa increased with increasing distance from the edge. Lichen species richness was not affected as much by the distance from the edge. An examination of the data indicated that epiphytic lichens were found on trees at the margins of the fragments and this may have negated edge effects on this taxon. However, some groups such as *Cladonia* sp and *Peltigera* sp that grow on the forest floor were only found in moderately large to large fragments indicating that they were also affected by the proximity to the edge.

Table 1. Multiple linear regression analyses between the number of plant and lichen species and distance from the edge, the number of different microhabitats, air temperatures at ground level (temp 0m) and at 1 m (temp 1m) and 2 m (temp 2m) above the soil surface, relative humidity, and light intensity for fragments in three different areas of Northern Alberta. *** = p <0.005. ns = not significant.

All species		Vascular Plants		Mosses and Liverworts		Lichens	
Variable	R^2	Variable	R^2	Variable	R^2	Variable	R^2
Athabasca area							
distance	0.29 ***	distance	0.19***	distance	0.29***	microhabitat	0.11***
microhabitat	0.37	temp 1m	0.24	microhabitat	0.34	light	0.12
light	0.38	temp 2m	0.24	temp 2m	0.34	temp 0m	0.14
temp 2m	0.38	micohabitats	0.24	temp 0m	0.35	distance	0.14
Peace River area							
distance	0.22 ***	distance	0.22***	distance	0.18***	microhabitat	0.32***
microhabitat	0.31	microhabitat	0.27	microhabitat	0.26	distance	0.45
temp 1m	0.33	temp 0m	0.28	temp 1m	0.29	humidity	0.51
humidity	0.33	humidity	0.28	humidity	0.30	temp 0m	0.53
Manning area							
distance	0.28 ***	distance	0.13***	distance	0.30***	microhabitat	0.07ns
microhabitat	0.34	temp 1m	0.18	microhabitat	0.41	humidity	0.12
temp 1m	0.39	temp 2m	0.20	temp 2m	0.41	distance	0.15
temp 2m	0.41	humidity	0.20	temp 0m	0.42	temp 1m	0.23

Effects of fragment size and shape on plant and lichen diversity

The data for all vascular plants for each fragment was entered into a two-way table. The data matrix was organised as fragments forming columns and the presence or absence of each plant species forming the rows. The fragments were ranked according to the number of species that were present, whereas the species were ranked by the number of occurrences on all sites from the most common to the least common. A nested analysis was performed on this table in order to determine if rarer species are found in richer sites (Patterson 1990). Two tests were performed on the results. Each test counted the number of times a species occurs on a less rich site. The first test was a comparison with completely randomized data while the second test kept the species total fixed and assigned presences weighted by site totals. The table was randomised a thousand times.

The statistic that is calculated is the same for both forms of test. The difference is that in one there is a complete randomization (CR) and in the other the randomization is restricted (RR), with the species totals constant and the probabilistic assignment weighted by the site totals. The results (Table 2) show that all groups in all regions are significantly nested compared to complete randomness and restricted randomness. Thus, rarer vascular plant, moss and liverwort, and lichen species are found in richer fragments.

Table 2. Results form nestedness analyses on the diversity of plants and lichens found in fragments of the sub-humid low-boreal forest in three areas in Northern Alberta. ↑ indicates that the data were significantly nested while ↓ indicates significantly not nested when compared to 2 different null hypotheses.

Location	Vascular plants		Mosses & liverworts		Lichens	
	RR	CR	RR	CR	RR	CR
Athabasca	↑	↑	↑	↑	↑	↑
Peace River	↑	↑	↑	↑	↑	↑
Manning	↑	↑	↑	↑	↑	↑

Disturbance in this study was measured as the area and perimeter of the fragment where smaller areas and perimeters indicates greater disturbance. Disturbance was also measured as a shape index that accounts for both perimeter and area (Aznar et al. 2003, Forman & Godron 1986). Greater perimeter to area ratios that are the result of disturbance produced smaller shape indices. All three disturbance metrics were highly correlated with each other and with species richness for all three taxa in the three areas (Spearman rank correlation, $p<0.001$). Since the shape index incorporates both area and perimeter, it was used as the measure of disturbance.

There was a significant ($p \leq 0.05$) linear relationship between the number of different habitats present in each fragment and the shape of the fragments (Fig. 4). There are significant linear or second order polynomial relationships ($p \leq 0.05$) between species richness for all taxa and the shape of the fragments for each of the three areas (Fig. 5). R^2 values ranged between 0.58 for lichens in the Peace River area and 0.97 for mosses and liverworts in the Manning area. The only relationship that was significantly improved by the addition of a second order polynomial was for vascular plants in the Athabasca area.

Figure 4. Relationship between the number of different microhabitats and the shape of fragments located in three areas of the subhumid low-boreal Forest of Northern Alberta.

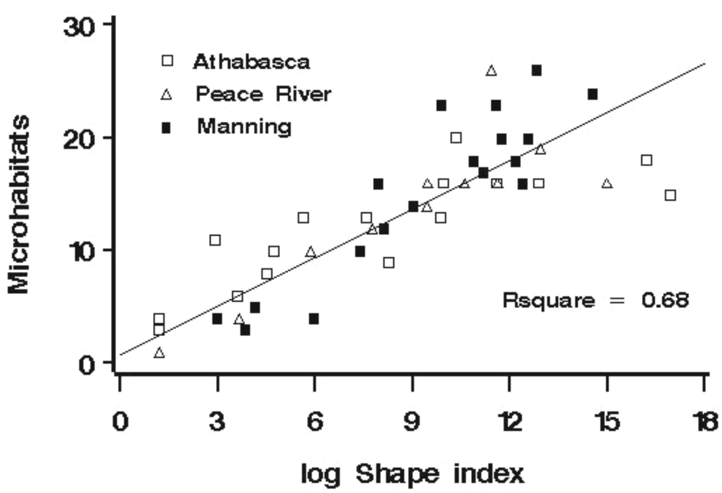
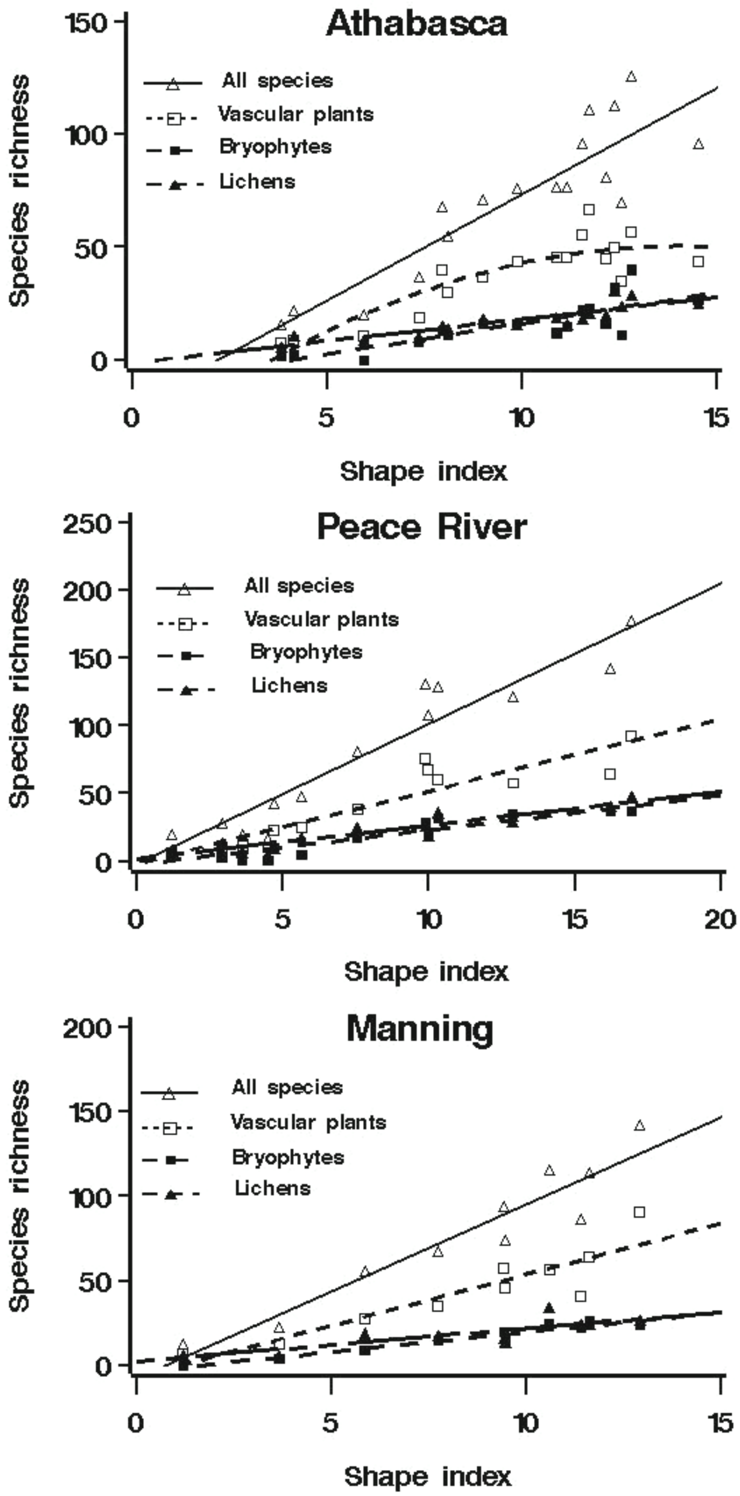


Figure 5. Relationship between vascular plant, bryophyte and lichen species richness and the log of the shape index of fragments located in three areas of the subhumid low-boreal forest in Northern Alberta.



In conclusion, the size and shape of fragments play a significant role in determining habitat heterogeneity and species richness for all taxa. Smaller fragments have fewer habitats and fewer species. Size and shape are also related to the abundance of rarer species since larger fragments are richer in species and those richer fragments contain more rare species.

Indicator species analyses

An Indicator Species Analysis (ISA) and TWINSPAN functions in PC-ORD (McCune & Mefford 1997) were used to identify species indicative of species diversity and by extension fragment size and shape. ISA calculates the indicator value (i.v.) (% of perfect indication) for each species in each pre-defined group by multiplying the species' proportional abundance by its' proportional frequency for that group (Dufrêne & Legendre 1997) while TWINSPAN is a hierarchical divisive clustering method that classifies sites and species (Hill 1979).

The first TWINSPAN division using the frequency all species in each fragment separated the smallest woodlots from all others in all three areas. In all cases, *Brachythecium campestre* was the indicator of the larger fragments. The division of the group of large fragments, separated largest fragments from those of intermediate size based on the presence of *Hylocomnium splendens*. These were the only meaningful TWINSPAN divisions. This analysis found both *Brachythecium campestre* and *Hylocomnium splendens* to be indicators of fragment groupings that correspond to different levels of fragment size and shape.

The three TWINSPAN groups that were distinguished in each area were then subjected to Indicator Species Analysis (ISA) in order to select other indicators for each group. Only species that had indicator values over 65 (with a maximum of 100) and that were consistently found in all three areas were selected. Indicators of larger fragments in order of decreasing indicator value were: *Hylocomium splendens*, *Pleurozium schreberi*, *Ptilium crista-castrensis*, and *Mitella nuda*. Indicators of the smaller fragments were: *Brachythecium campestre*, *Linnaea borealis*, *Cladonia* species, and *Rubus pubescens*. Although TWINSPAN did not select an indicator species for the intermediate group, the ISA analysis selected several indicators that were found in all three areas: *Peltigera* species, *Lonicera dioica*, and *Ribes triste*.

Performance benchmarks of species loss

In this study, the absence of *Brachythecium campestre*, a medium sized moss species that forms yellow green mats, *Cladonia*, are relatively small upright lichens found on the forest floor or on rotting logs, and two relatively small trailing perennial vascular plant species, *Linnaea borealis* and *Rubus pubescens*, are not only indicative of small fragments but also of fragments containing less than 45 species (performance benchmark) (Fig. 6). Fragments that do not contain any of those species are realistically too small to 1) protect a portion of the site from edge effects or 2) preserve most of the species found in the area.

As the extent of fragmentation decreases (shape index is bigger), and total species richness increases, a different suite of indicator species can be used to monitor fragments of intermediate size and shape. The presence of *Peltigera*, a large leafy lichen genus found on the forest floor or on rotten logs, and two shrubs, *Lonicera dioica* and *Ribes triste* is indicative of fragments that contain more than 65 species (Fig. 7).

The presence of three mosses normally found in shaded coniferous dominated communities in the boreal forest is indicative of larger fragments that contain more than 85 species (Fig. 8). The three mosses, *Pleurozium schreberi*, *Hylocomnium splendens* and *Ptilium crista-castrensis* are large feather mosses that are relatively easy to identify. Fragments that contain those three species also contain most of the species found in each area. *Mitella nuda*, a small perennial vascular plant, can also be used as an indicator of larger fragments.

Figure 6. The relationship between the frequency of occurrence of 3 indicator species and the genus *Cladonia* that have a performance benchmark of 45 species and total species richness for 45 fragments of the subhumid low-boreal forest in Northern Alberta.

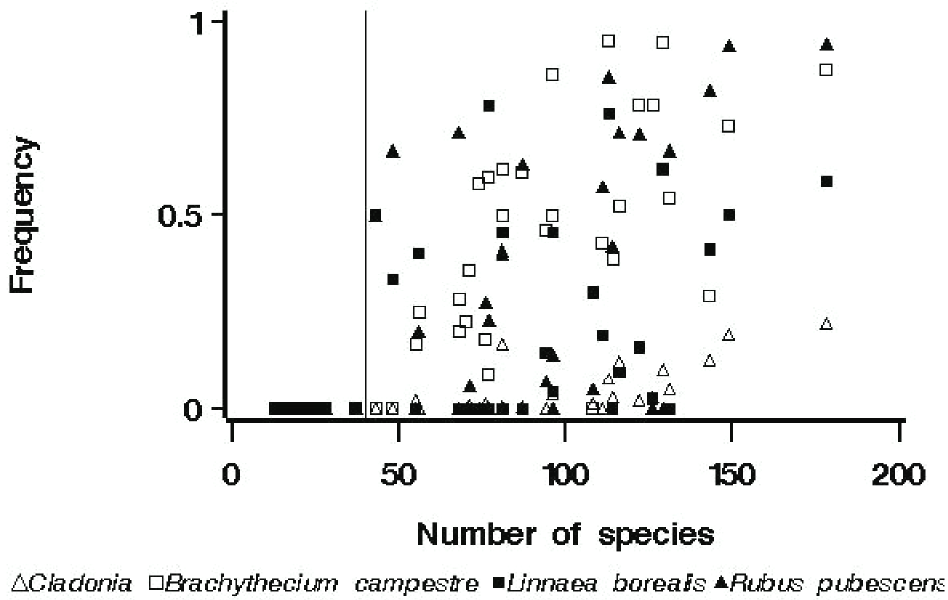
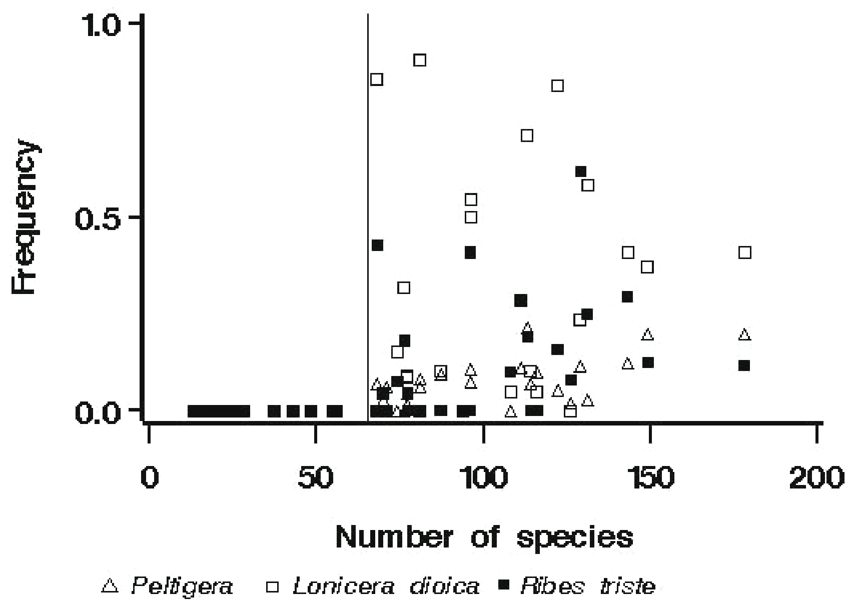
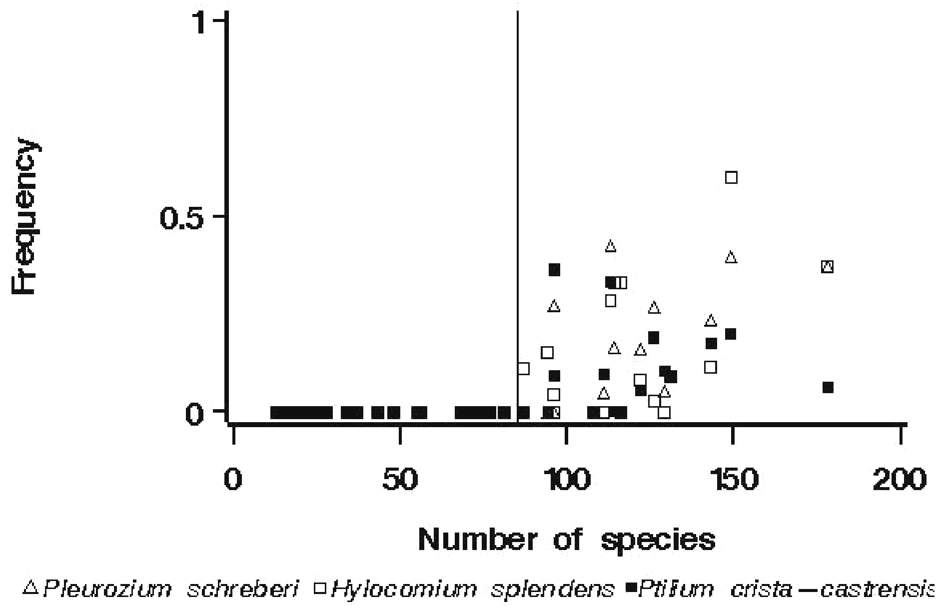


Figure 7. The relationship between the frequency of occurrence of 2 indicator species and the genus *Peltigera* that have a performance benchmark of 65 species and total species richness for 45 fragments of the subhumid low-boreal forest in Northern Alberta.



In conclusion, three suites of species that are indicative of fragment size and shape, habitat heterogeneity, and species richness can be used to monitor fragments without having to measure them or do a detailed analysis of the flora. Species that were selected are, for the most part, easily identifiable. Species in each suite are best used together since a fragment may have one or a combination of species but not all of them as shown in Figures 6, 7 and 8.

Figure 8. Relationship between the frequency of occurrence of 3 indicator species that have a performance benchmark of 85 species and total species richness for 45 fragments of the subhumid low-boreal forest in Northern Alberta.



Contributions to the advancement of knowledge

This project contributes to our knowledge of the role of fragmentation on plant and lichen diversity at different scales in aspen dominated communities in the subhumid low-boreal forest. This problem had not been explicitly studied previously. This is one of only a handful of studies that has examined effects of fragmentation on vascular plants, mosses and lichens together. Most studies of this nature focus on only one taxon. As a result, this project adds to our understanding of the relative of importance of several environmental variables on each taxon's diversity.

Also, this project sheds new light on the role of habitat heterogeneity on moss and lichen diversity in general as well as in severally fragmented landscapes. Previous studies of this nature focused on the role of habitat heterogeneity alone and did not relate that variable to other such factors as microclimate and edge effects. Thus, results of this research may prove to be an important contribution to protecting bryophyte diversity in fragmented habitats. We feel that this is a significant contribution to the field of bryophyte and lichen ecology.

Although plant and lichen species have often been used as indicators of different kinds of environmental disturbances, this may be the first utilisation as indicators of plant and lichen diversity in severally fragmented forests. Those indicators can also be used to indirectly measure effects of fragment size and shape, edge effects and habitat heterogeneity. As a result, this research provides important guidelines for the management of private woodlots immersed in an agricultural matrix in order to minimize edge effects and maximize diversity.

Practical applications of the research

The indicator species and their benchmarks that were selected in this study can be used to monitor effects of fragmentation on plant and lichen diversity in mature upland aspen dominated communities of the subhumid low-boreal forest. These fragments can be the result of such different types of land use as logging, agriculture or urban development. Although the method was developed for fragments in an agricultural matrix, it can readily be applied to measure the effectiveness of such smaller upland fragments as residuals that are left on the landscape after logging or parkland in an urban matrix after clearing for housing developments.

The indicator species method is inexpensive and relatively easy to apply. Fragments should be sampled no less than three years after the surrounding forest has been cleared to ensure that species have equilibrated to the modified habitat. In order to document species occurrence and abundance, one can use the following method: 1) walk along one or several straight lines from one edge of the fragment to the other; 2) determine indicator species presence at approximately 5 m intervals along each line within a radius of approximately 2.5 m (the number of lines walked should permit observations at a minimum of 20 plots); 3) calculate the frequency of occurrence of each indicator species by dividing the number of plots in which the species was found by the total number of plots; 4) if values for one or several species within each of the three suites of indicators are greater than 0.2, then the benchmark for that suite of species can be applied to the fragment. For example, if the frequency of occurrence of *Hylocomium splendens* is greater than 0.2 and *Ptilium crista-castrensis* and/or *Pleurozium schreberi* were also found, then it would be safe to assume that there are more than 85 species in the fragment and it is of sufficient size to protect at least a portion of the interior from edge effects. We recommend that at least one mature aspen dominated fragment containing *Pleurozium schreberi*, *Hylocomnium splendens* and *Ptilium crista-castrensis* remain on the landscape until other such communities reach maturity in order to protect as much plant and lichen diversity as possible in the area.

Related research to be undertaken

This study only analysed plant and lichen diversity in mature aspen dominated fragments of the subhumid low-boreal forest. Results cannot and should not be applied to other such communities as white spruce dominated fragments or wetland sites that are found in the same area. Each of those communities would require separate analyses of the same intensity as was applied to the aspen dominated sites. It is quite likely that each of those communities harbor different plant and lichen species and would also require different stand sizes to protect against edge effects.

We deliberately selected fragments that were not under any recognisable pressure from the surrounding land use in agricultural zones. It would certainly be necessary to examine effects of fertilizer and weed control applications in adjacent fields on plants and lichens in fragments. Also, a significant proportion of the fragments are heavily grazed by cattle. Grazing visibly impacts the fragments but, to our knowledge, there have not been any studies that have focused on impacts of those aspects of land use on moss and lichen diversity.

In order for us to understand the impacts of land use in the agricultural zone of the subhumid low-boreal forest on plant and lichen diversity, all the different community types and anthropogenic pressures on fragments need to be studied. It is only then that we can determine how much of the remaining forest actually retains enough of the original diversity to protect that diversity at the landscape level.

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References

Aznar, J.-C., A. Dervieux & P. Grillas. 2003. Association between aquatic vegetation and landscape indicators of human pressure. Wetlands 23: 149-160.

Camargo. J.L.C. & V. Kapos. 1995. Complex edge effects on soil moisture and microclimate in central Amazonian forest. J. Tropical Ecology 11: 205-221,

Dufrêne, M. & Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67(3): 345-366

Forman, R.T.T & M. Godron. 1986. Landscape Ecology. John Wiley & Sons, New York.

Hill, M.O. 1979. TWINSPAN - a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, New York, Cornell University

Malcom, J.R. 1998. A Model of Conductive Heat Flow in Forest Edges and Fragmented Landscapes. Climate Change 39: 487-502

McCune, B. & Mefford, M.J. 1997. PC-ORD. Multivariate analysis of ecological data, Version 3.2. MJM Software Design, Glenedon Beach, Oregon.

Patterson, B.D., 1990. On the temporal development of nested subset patterns of species composition. Oikos 59: 330-342.

Sillet, S.C., S.R. Gradstein & D. Griffin. 1995. Bryophyte diversity of Ficus tree crowns from cloud forest and pasture in Costa Rica. Bryologist 98: 218-227.

Smith, R.L., 1996. Ecology and Field Biology. 5th edition. Harper Collins College Publishers, New York.