Edge Effects on Vegetation in Rights-of-Way

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As a result of an increasing use of ecological methods for the control of vegetation in rights-of-way, it has become necessary to understand the natural processes that are likely to facilitate or hinder management objectives. Several factors may influence species composition within corridors, but edge effects of the vegetation immediately adjacent to the right-of-way is one of the most important. To better measure and understand edge effects, we studied the spatial distribution of vegetation types on test right-of-way sites located in southern Quebec. Sampling was done along 133 transects located perpendicular to the right-of-way, with a distance of 50 m between transects. Each transect consisted of seven quadrats covering the vegetation within the corridor and two quadrats outside of the corridor. The results show that there is a strong edge effect on plant composition in the right-of-way corridor, especially when it is bordered by a forest. The edge effects result in a greater dominance of tree species and to a lesser extent a greater number of shrubs. Besides species richness, the species composition is also different at the edge of the right-of-way, with several species more likely to be found at the edge, while others occur more often in the central zone. There was little significant difference between north-facing and south-facing edges. Seed dispersal is assumed to be the main factor responsible for edge effects on plant composition. These results have implications on vegetation management in right-of-way corridors.

Keywords: Edge effects, corridor, right-of-way, spatial analysis, vegetation management

INTRODUCTION

One of the main objectives of vegetation management under powerline rights-of-way is to prevent or reduce the invasion or growth of trees. Environmental concerns brought an increasing use of ecological approaches to right-of-way management. It has become necessary to understand the natural processes that are likely to facilitate or hinder management objectives (Berkowitz, Canham, and Kelly 1995). Site conditions such as water regime or surficial material may be important factors in predicting tree invasion. For example, a humid depression supporting marsh plants such as cattail (*Typha latifolia*) will be less suitable to tree establishment, and thus will not require the same management as would a well-drained site of till deposit invaded by trembling aspen (*Populus tremuloides*). Yet, in a study of the vegetation of a powerline right-of-way in southern Quebec, we found that environmental variables such as drainage and soil conditions explained only 29% of the variance in vegetation based on a canonical correspondence analysis (Meilleur, Brisson, and Bouchard 1994). On right-of-way segments which are similar in abiotic conditions, some were strongly invaded by trees while others were dominated by shrub or herbaceous communities which are less suitable for tree invasion (Meilleur, Bouchard, and Bergeron 1994). From these observations, we hypothesized that the vegetation at the edge of rights-of-way may have a significant influence on its composition.

Edge effects can be defined as the changes in structure and composition of a community due to contact with another community type. Because of the linear nature of rights-of way, adjacent neighboring communities are always in close proximity, making edge effects potentially important. In the case of the edge effects of a forest on an open community type such as a right-of-way, the most direct influence of the forest is through the seed dispersal, which initiates tree invasion. However, the proximity of the forest may also influence the composition of the right-of-way by other

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means (Forman and Godron 1986). For example, the forest may act as a refuge for herbivores which come to feed in the neighboring right-of-way. Thus, pressure from herbivores may be greater in a right-of-way bordered by forests rather than by agricultural fields. In addition, the forest may act directly on the environmental conditions of the right-of-way, by reducing or funneling winds or by reducing solar radiation and temperature through shading. All of these effects may in turn influence the plant composition of rights-of-way. We must point out that despite the recent increase in scientific literature on edge effects, most of the articles focused on the effect of a non-forested site on a nearby forest edge, while few studied the opposite effects (Fraver 1994; Fritz and Merriam 1994; Matlack 1994).

The goal of our study is to measure the edge effects in a powerline right-of-way using methods of spatial analysis. We assume that the effects of bordering communities would be stronger at the edge of the right-of-way and decrease as we neared its center. We compare composition along transects perpendicular to the right-of-way in order to detect consistent differences in composition.

METHODS

Study site

The 60 m-wide right-of-way under study is for electrical powerlines. It is located in the south-western part of the province of Québec (Canada), between the Saint-Lawrence River to the north and the state of New York (U.S.A.) to the south (Fig. 1). The region has a humid continental climate. The annual average temperature is

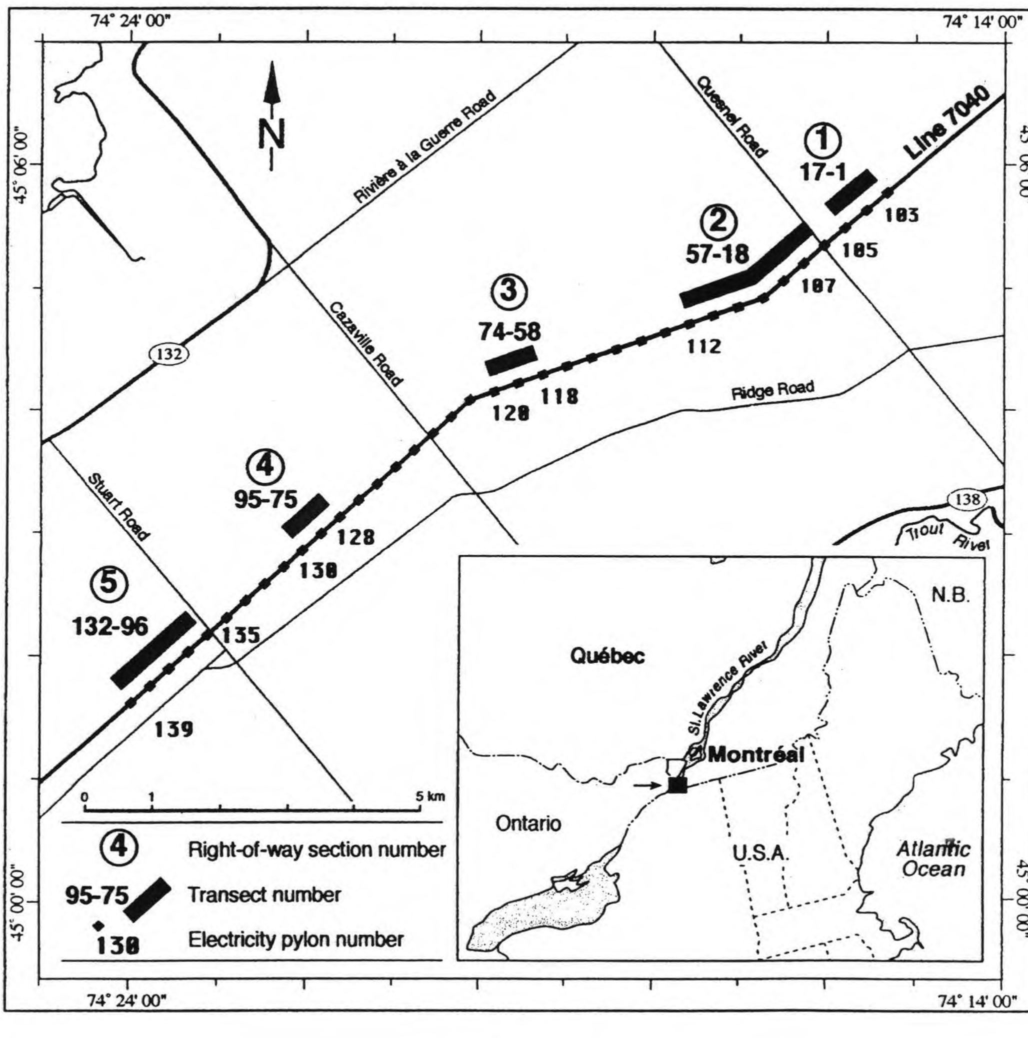


Fig. 1. Study area.

6.1°C in Huntingdon (elevation 75 m) with mean temperatures of –10°C in January and 20.8°C in July (Anonymous 1982). The average frost-free period is 140 days. The annual number of degree-days for plant growth is 2093 (Wilson 1971). The regional bedrock are dolomite and limestone (Globensky 1981).

The area under study is part of the northern hardwood zone that belongs to the Great Lakes–Saint-Lawrence Forest region (Rowe 1972). Mesic forests are generally dominated by *Acer saccharum*, with *Fagus grandifolia, Tsuga canadensis, Ostrya virginiana*, and *Tilia americana* (Meilleur, Bouchard, and Bergeron 1994). Forests growing on poorly drained soils or open sites are mostly dominated by *Fraxinus pennsylvanica* and *Acer rubrum. Acer saccharinum* can grow on more fertile and poorly drained sites, while on xeric sites *Pinus strobus, Acer rubrum, Populus tremuloides* and *Betula populifolia* are the dominant species (Meilleur, Bouchard, and Bergeron 1994).

The right-of-way, created in 1977, was previously occupied by 13% cultivated fields, 30% abandoned fields or shrubs, 35% aspen forests and 22% forests dominated by species such as *Acer saccharum, Thuya occidentalis* and *Pinus strobus*. Since the opening of the corridor, the vegetation mosaic has been modified by three herbicide treatments (foliar application of 2,4-D + picloram) in 1978, 1981 and 1984, as well as by manual cuts in 1987 and 1990.

Sampling

During summer 1994, we sampled in five sections of a 32-km (20-mile) segment of the right-of-way (Fig. 1). These sections were selected in order to cover a wide range of community types bordering the right-of-way. Sections 1 and 2 are characterized by loamy soils and they are bordered by young disturbed forests and occasional agricultural fields. Section 3 is on well-drained moraine deposits and is mainly bordered by shrub communities and young forests. Section 4 is on sandy soil with imperfect drainage and is bordered by forests with different degrees of disturbance. Finally, Section 5 is characterized by organic surface deposits with poor drainage, and it is bordered by forests and occasional agricultural fields. A total of 133 transects were located perpendicular to the right-of-way, with a distance of 50 m between each transect within a right-of-way section. Each transect consisted of 7 quadrats of 5 × 5 m, equally spaced between both edges of the right-of-way corridor, with one quadrat right in the center (Fig. 2). Two additional circular quadrat of 15 m of radius were located in the adjacent communities on either side of the right-of-way. Their center was 20 m away from the nearest edge of the right-of-way (Fig. 2).

In each quadrat, we recorded microtopography and drainage. Percent plant cover was estimated for shrubs, trees and the most abundant herbaceous species. For less abundant herbaceous species or for more complex taxonomic groups, percent cover was estimated in categories: sedges, graminoids, rushes, other herbaceous species less that 30 cm high (low herbaceous), and other herbaceous species taller than 30 cm (high herbaceous). This method allowed us to efficiently increase sampling speed, and consequently sample size. In the forested quadrats, percent cover data for tree species were estimated for each of the following size-classes: (1) less than 5 cm in diameter at breast height (DBH), (2) DBH greater than 5 cm but less than 15 cm, and (3) DBH greater than 15 cm.

Analysis

Determination of discontinuities in right-of-way vegetation
The goal of this analysis is to determine whether there are differences in vegetation from the edges of the right-of-way to its center by looking at discontinuities in composition. Two different algorithms were used to detect these discontinuities. Each analysis was performed on the entire data set as well as on data sets divided by growth form (herbaceous, shrubs, trees) and by right-of-way sections. While the lattice-wombling method finds discontinuities based on percent covers, the rate of change method is based entirely on presence–absence. The discontinuities found in each method may reflect different responses to underlying environmental processes (Fortin, Drapeau, and Jacquez 1996).

The lattice-wombling method computes the first partial derivative in the x and y spatial direction given the value of a variable (here species percent cover)

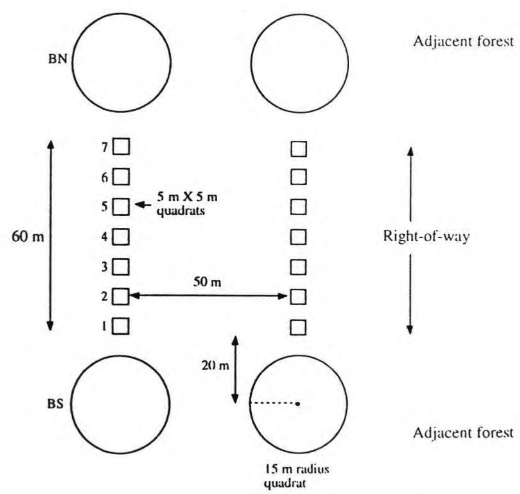


Fig. 2. Sampling design. BS = Quadrat in the plant community at the southern border of the right-of-way; BN = Quadrat in the plant community at the northern border of the right-of-way.

between sets of four sampled locations that form a square (for mathematical details and assumptions, see Fortin 1994, and Fortin and Drapeau 1995). The magnitude of rate of change in composition is calculated for the centroid location of each set of four samples. When the composition of the four corners is similar, the magnitude of the rate of change assigned to the centroid is close to zero, while it increases as the value at the four corners changes abruptly. Note that in our case, the set of four samples is defined as two neighboring quadrats of a transect, and their adjacent quadrats of the next parallel transect. The lattice-wombling method requires that rate of change be calculated on four points that are equidistant, which is not the case in our study. However, our results are valid since we consider rates of change in one direction only, perpendicular to the right-of-way. For multivariate data sets, the overall rate of change in composition is defined as the average rate of change of all the species' percent cover at a given centroid.

The second method looks at changes in composition based on species replacement along each transect analysed individually, using presence–absence data. In this method, a rate of change between two neighboring quadrat is simply calculated as the sum for all the species of the difference–mismatch between two adjacent sample locations along a transect (Oden, Sokal, Fortin, and Goebl 1993).

Both lattice-wombling and rate of change were calculated on observed data. To assess their statistical significance against the null hypothesis of absence of spatial pattern, 100 random permutations were generated (Fortin 1994).

Relation between right-of-way vegetation and adjacent plant communities

Several characteristics of the vegetation in the adjacent plant communities were determined from the species data: total number of species, number of species and relative frequency of herbaceous, shrubs and trees (total, <15 cm in DBH, >15 cm DBH). These characteristics were correlated with species diversity (total, herbaceous, shrubs, trees) of each quadrat of the same transect in the right-of-way, and rates of change of each quadrat pair as determined by the replacement method. Diversity was calculated as the average number of species per quadrat position (average richness). Correlations were performed separately for the northern and southern adjacent plant communities.

RESULTS

In total, 102 species were sampled in the right-of-way and in the bordering communities, 71.6% of which were common to both territories. Of this total, 32 species were trees, 33 were shrubs and 37 were herbaceous. However, our number of herbaceous is an underestimation given the broad categories that we established in order to speed up sampling. The average number of species of trees and shrubs was maximum at the edge of the right-of-way and decreased toward the center (Fig. 3). The opposite pattern was observed for herbaceous species. The greatest change in average species richness occurred between the outer quadrat pairs (1–2 and 6–7).

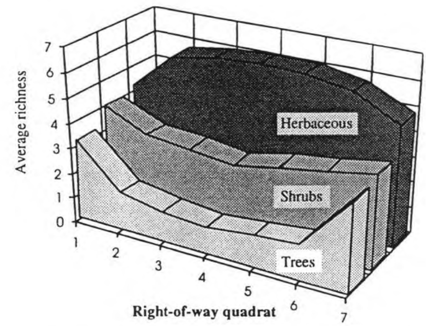


Fig. 3. Average richness of species of herbaceous, shrubs and trees according to position of right-of-way quadrats.

Sharp discontinuities, as determined by the rate of change in species composition, also occurred mainly between outer quadrat pairs, especially for tree species (Table 1). There were no strong differences between northern and southern edges, except in the case of herbaceous species where there was a greater total number of discontinuities at the northern edge. However, this difference was not consistent across the entire right-of-way: it was entirely due to the contribution of Section 1, where there were seven significant discontinuities at the northern and none at the southern edge.

The pattern was slightly different when the Womble algorithm was used to determine sharp discontinuities in right-of-way vegetation. There were more significant discontinuities in the outer quadrat pairs than in central quadrats when tree species were considered, and to a lesser extent for shrub species, but the pattern was not as strong (Table 2). There was no clear pattern in the total number of discontinuities for herbaceous species. There were differences in patterns between right-of-way sections, with Section 5 showing 51 discontinuities as opposed to only seven significant discontinuities in Section 4. This difference may be only partly explained by the larger number of transects in Section 5 (37 transects compared to 21 for Section 4).

Most of the previous results suggest that the bordering community has the strongest effect at the edge of the right-of-way, and that the effect is especially strong on tree species. The characteristic of bordering plant communities that shows the strongest relationship to the right-of-way vegetation is the number of species represented in the tree layer (DBH > 15 cm), which is a composite indication of the successional stage of the

Table 1. Number of significant discontinuities in species composition between neighboring quadrats located in the right-of-way, as calculated by the rate of change algorithm

ROW section	Growth form	Right-of-way quadrats boundary					
		1–2	2–3	3–4	4–5	5–6	6–7
1	Herbaceous	–	–	–	1	1	7
	Shrubs	1	–	–	–	3	1
	Trees	–	–	–	–	–	3
2	Herbaceous	1	–	1	–	–	1
	Shrubs	3	1	1	–	–	5
	Trees	8	–	–	–	–	2
3	Herbaceous	1	–	–	–	–	2
	Shrubs	1	–	–	–	–	1
	Trees	–	–	–	–	–	1
4	Herbaceous	–	–	–	–	–	–
	Shrubs	3	–	–	–	–	–
	Trees	1	–	–	–	–	–
5	Herbaceous	3	1	1	1	3	2
	Shrubs	4	–	–	1	3	–
	Trees	7	1	–	–	–	11
Total	Herbaceous	5	1	2	1	3	12
	Shrubs	12	1	1	1	3	7
	Trees	16	1	–	–	–	17

Table 2. Number of significant discontinuities in species composition between neighboring quadrats located in the right-of-way, as calculated by Womble algorithm

ROW section	Growth form	Right-of-way quadrats boundary					
		1–2	2–3	3–4	4–5	5–6	6–7
1	Herbaceous	3	–	–	1	–	1
	Shrubs	1	–	–	–	–	4
	Trees	–	–	1	1	1	–
2	Herbaceous	3	6	1	2	4	–
	Shrubs	–	–	–	–	1	1
	Trees	8	–	–	–	–	1
3	Herbaceous	–	–	1	–	–	–
	Shrubs	–	–	–	–	–	2
	Trees	8	6	5	5	11	13
4	Herbaceous	–	–	–	–	–	–
	Shrubs	–	–	–	–	–	3
	Trees	–	–	–	–	1	3
5	Herbaceous	1	2	1	–	1	–
	Shrubs	5	4	3	3	2	1
	Trees	4	–	–	–	–	7
Total	Herbaceous	7	8	3	3	5	1
	Shrubs	6	4	3	3	3	11
	Trees	20	6	6	6	13	24

Table 3. Correlation between tree diversity (DHP > 15 cm) in the communities adjacent to the right-of-way (BS and BN) and the rate of change (herbaceous = H, Shrubs = S, and Trees = T) between the two nearest quadrats at the edge of the right-of-way. (+) = Positive correlation, (–) = Negative correlation, (*) Significance at $p = 0.05$, (**) Significance at $p = 0.01$, (***) Significance at $p = 0.01$.

ROW section	Correlation between tree diversity in bordering forest south (BS) and rate of change between the two nearest right-of-way quadrats (1–2)				Correlation between tree diversity in bordering forest north (BN) and rate of change between the two nearest right-of-way quadrats (6–7)			
	H	S	T	HST	H	S	T	HST
1	–	+*	+*	+*	+	–	+*	+
2	–*	–	+	–	–	–	+	–
3	–	–	+	–	+	–	+	+
4	+	+	+*	+	–	–*	–	–
5	–	+	+	+	–	+	+	+
Total	–	+	+***	+	–	–	+	–

vegetation (abandoned fields and young communities have a value of 0) and of the diversity of the forest.The most significant correlation was between this measure and tree species diversity in the nearest right-of-way quadrat, both for the south and the north edges (Table 3). This relationship may extend to the third nearest quadrat although the positive correlation was not significant. There was a negative correlation between tree diversity in the northern bordering forest and shrub diversity in all right-of-way quadrats, while the relationship with the southern forest was positive for the nearest quadrat and varied thereafter. There was also an apparent difference in the relation between herbaceous species diversity in the right-of-way and the aspect, with an overall positive correlation for the southern forest edge and a negative one for the northern forest edge. However, few of these correlations were significant.

Table 4. Correlation between tree diversity (DHP > 15 cm) in the communities adjacent to the right-of-way (BS and BN) and species diversity (herbaceous, shrubs and trees) in the right-of-way according to quadrat position. Note that the order of the quadrats reflects a decreasing distance from the edge: for BS from quadrat 1 to 7, for BN from quadrat 7 to 1.

	Right-of-way quadrats relative to their position from the bordering forest						
	1st	2nd	3rd	4th	5th	6th	7th
Herbaceous – BS	+	+	+*	+	+	–	+
Herbaceous – BN	–	–	–	–	–	–	–
Shrubs – BS	+*	+	–*	–	–*	–	+
Shrubs – BN	–*	–**	–*	–*	–*	–**	–*
Trees – BS	+***	+	+	+	–	–	+
Trees – BN	+***	+	+	–	+	+	+

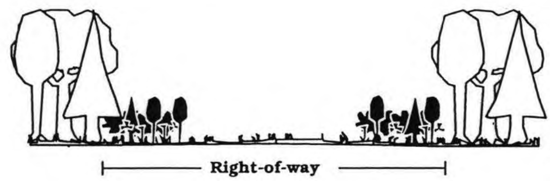
1st = nearest; 7th = furthest.

Tree diversity in the bordering communities also best explained the high discontinuities in tree species diversity between neighboring quadrats at the edge of the right-of-way. In all the sections, there were positive correlations (three of which were statistically significant) between bordering forest diversity and the rate of change of the two nearest quadrats, with the exception of the northern border of Section 4 (Table 4). The overall relationship was highly significant for the southern border. There were no clear patterns for discontinuities in terms of shrub or herbaceous diversity.

Of the 25 tree species that occurred in all right-of-way sections, 19 were more likely to be found at the edge (Table 5). This included all four tree species that are considered shade tolerant, i.e. *Acer saccharum*, *Fagus grandifolia*, *Ostrya virginiana*, and *Tilia americana*. There was also a large number of shrub species that were more abundant at the edge, some of which are characteristic of the forest understory such as *Acer spicatum*, *Cornus alternifolia* and *Taxus canadensis*. There was only one herbaceous species, *Apocynum androsaemifolium*, that was significantly more likely to occur at the edge of the right-of-way. Of the 38 species showing preference to right-of-way edges, only two were significantly more likely to be found at one edge in particular: both *Quercus macrocarpa* and *Vitis riparia* preferred the northern edge (Table 5).

The picture was very different in the central zone of the right-of-way, where no trees and only two species of shrubs were more likely to be found (Table 6). In contrast, there were 11 species or categories of herbaceous more likely to be found in the central zone. If we exclude the "high herbaceous species" and "low herbaceous species" categories, about which no conclusion can be drawn, all of the others were species or genera characteristic of open communities.

Table 5. Species significantly more likely to be found at the edge of the right-of-way (χ^2 test with $p < 0.05$). (N) = More likely to be found at the northern edge



Species	Growth form*			Shade tolerance*		
	H	S	T	I	M	T
Acer rubrum			x		x	
Acer saccharinum			x		x	
Acer saccharum			x			x
Acer spicatum		x				x
Alnus rugosa		x			x	
Amelanchier sp.		x		x		
Apocynum androsaemifolium	x			x		
Betula alleghaniensis			x		x	
Betula populifolia			x	x		
Carpinus caroliniana		x		x		
Carya cordiformis			x		x	
Celastrus scandens		x			x	
Cornus alternifolia		x		x		
Cornus stolonifera		x		x		
Fagus grandifolia			x			x
Fraxinus pensylvanica			x		x	
Ilex verticillata		x		x		
Malus pumila		x		x		
Ostrya virginiana			x			x
Parthenocissus quinquefolia		x			x	
Pinus strobus			x		x	
Populus balsamifera			x	x		
Populus grandidentata			x	x		
Populus tremuloides			x	x		
Prunus pensylvanica			x	x		
Prunus serotina			x		x	
Prunus virginiana		x		x		
Quercus macrocarpa (N)			x		x	
Rhamnus catharticus		x		x		
Ribes sp.		x			x	
Rubus odoratus		x		x		
Taxus canadensis		x				x
Thuya occidentalis			x		x	
Tilia americana			x			x
Ulmus americana			x		x	
Viburnum lentago		x		x		
Vitis riparia (N)		x			x	
Zanthoxylum americanum		x		x		
Total	1	18	19	16	16	6

*Growth form: H = herbaceous, S = shrubs, T = trees.
Shade tolerance: I = intolerant, M = intermediate, T = tolerant.

Table 6. Species significantly less likely to be found at the edge of the right-of-way (χ^2 test with $p < 0.05$).

Species or categories	Growth form		
	H	S	T
Asclepias syriaca	x		
Daucus carota	x		
Eupatorium perfoliatum	x		
Graminaceous	x		
Low herbaceous species	x		
High herbaceous species	x		
Hypericum perforatum	x		
Lytrum salicaria	x		
Pastinaca sativa	x		
Phragmites communis	x		
Rubus occidentalis		x	
Salix petiolaris		x	
Scirpus sp.	x		
Total	10	2	0

DISCUSSION

Edge effects

There is a strong edge effect on plant composition in the right-of-way corridor. This effect manifests itself especially at the very border of the right-of-way. When the community that borders the right-of-way is a forest with high tree diversity, the edge effect results in a greater dominance of tree species and, to a lesser extent, a greater number of shrubs. Besides species richness, the species composition is also different at the edge of the right-of-way, with several species more likely to be found at the edge, while others are more likely to occur in the central zone. The edge effect does not seem to extend very far from the edge, since beyond a certain distance from it, the vegetation becomes more uniform.

It seems obvious that the proximity of seed bearing trees probably explains the pattern observed for tree species to a large degree, since seed dispersal is often cited as an important limiting factor in right-of-way corridors (Hill, Canham, and Wood 1995). Changes in the environment at the edge of the right-of-way may also be favorable to some species. For example, the southern edge experiences prolonged periods of shade when it is bordered by a forest, a factor that should provide an advantage to species of intermediate to high shade tolerance. However, the low difference in species composition between the northern and southern edges of the right-of-way suggests that this factor does not play a major role in our case.

In the recent literature, the significance of the edge effects has been primarily studied in reference to the effects of abutting pastures or clearcuts on forest edges. It was found that these forest edges typically had increased solar radiation (Kapos 1989; Brothers and Spingharn 1992), lower humidity and higher air temperature (Kapos 1989; Williams-Linera 1990), higher soil temperature (Brothers and Spingharn 1992) and increased wind speed (Raynor 1971). These changes, in turn, alter plant species composition and structure. Forest edges generally have higher stem density than the forest interior (Wales 1972; Whitney and Runkle 1981; Ranney et al. 1981), a greater proportion of shade intolerant species and exotic plant species (Whitney and Runkle 1981; Ranney, Bruner, and Levenson 1981), and a greater species richness (Brothers and Spingharn 1992). There were also differences between the north-facing edges as opposed to south-facing edges, with the edge effect generally strongest on south-facing edges, presumably due to increased solar radiation (Wales 1972; Palik and Murphy 1990). While several studies showed results that were not always consistent with these generalizations (Matlack 1994; Murcia 1995), edge effects on forest ecosystems were often found to be an important factor in affecting plant composition and structure.

The edge effect of abutting forest on open plant communities such as abandoned fields or rights-of-way is also an important structuring factor, but one that has attracted much less interest in the scientific literature. While the edge effect on forests is assumed to be mainly due to changes in the physical environment, the edge effect on open communities may be largely a result of a difference in propagule availability. Changes in solar radiation, humidity and temperature may also play an important role, and one that should be different between north-facing and south-facing edges, although our results do not reveal any such significant differences.

In the right-of-way corridor we studied, the establishment of shade tolerant, forest interior species was almost entirely due to edge effects. Most other tree species were also more frequently present at the edge. The lesser abundance and diversity of herbaceous species at the edge is probably the result of competitive exclusion by shading from woody species. As a result, edges are more rapidly dominated by woody species, which eventually reach a development that is incompatible with power-line operation and safety.

Management recommendations

The objective of vegetation management on powerline rights-of-way is to reduce woody plant populations that may interfere with powerline operation. The proximity of a forest enhances the invasion and dominance of tree species at the right-of-way edge, thus increasing the frequency of required interventions and the cost of vegetation management. Therefore, it is recommended that when new corridors are planned in a patchy landscape, forest patches should be avoided when possible (Luken 1991). For existing rights-of-way, since the edge effect is particularly strong at the very edge of the corridor, the possibility of enlarging the corridor when it is bordered by a forest should be examined and weighed against other costs. The zone of significant tree invasion would then be located outside the original zone acceptable for powerline operation and safety, thus reducing intervention frequency. Finally, alternative ecological methods for reducing tree invasion, such as the establishment of dense shrub or herbaceous communities that inhibit tree establishment (Meilleur, Véronneau, and Bouchard 1997) should be implemented preferentially at the edge of right-of-way corridors bordered by forests, in order to maximize their benefits.

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