UNIVERSITÉ DU QUÉBEC À MONTRÉAL

STRUCTURE ET EFFETS DE LISIÈRES DES HABITATS LINÉAIRES RÉSIDUELS EN PESSIÈRE À MOUSSES AMÉNAGÉE DU NORD DU QUÉBEC

MÉMOIRE

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AVANT-PROPOS

Ce mémoire a été rédigé sous la forme de trois articles en anglais, et comporte un résumé, une introduction et une conclusion générale rédigés en français. Comme candidate à la maîtrise en biologie et conformément aux exigences de ce programme, j'ai effectué la récolte et la supervision des données, l'analyse des données et des résultats et la rédaction des articles à titre de premier auteur.

Les trois manuscrits qui comprennent ce mémoire seront soumis à des revues scientifiques arbitrées. Mes directeurs Pierre Drapeau et Karen Harper en seront les coauteurs pour tous les manuscrits.

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RÉSUMÉ

Dans les paysages aménagées de la forêt boréale du Québec, les habitats linéaires, comme les séparateurs de coupe et les bandes riveraines, sont laissés afin de réduire les effets visuels des coupes ainsi que pour protéger la qualité de l'eau des milieux aquatiques. Ces fragments forestiers sont aussi des éléments importants pour la conservation des attributs caractéristiques des forêts matures et surmatures. Dans ces habitats linéaires, la présence des bordures est un facteur important qui peut modifier la structure forestière originale qui existait avant la création d'une bordure.

Le premier chapitre de ce mémoire porte sur la structure forestière générale des habitats forestiers résiduels, dont les habitats linéaires tels que les séparateurs de coupe et les bandes riveraines. Les résultats indiquent qu'il existe peu de différences dans la structure forestière entre les fragments forestiers qui présentent une seule bordure en comparaison avec les habitats linéaires, qui ont deux bordures rapprochées. Ce sont les bandes riveraines qui présentent la plus grande similitude avec les conditions des forêts continues; tandis que les séparateurs de coupe sont les plus éloignés.

Le deuxième chapitre aborde les effets de bordures sur la structure végétale des fragments forestiers, afin de déterminer la distance d'influence de la bordure. Dans les habitats qui présentent seulement une bordure, il existe une influence de bordure jusqu'à 30 m de la bordure. Alors que dans les habitats linéaires, les effets de bordures sont omniprésents sur toute la surface de ces corridors.

Au troisième chapitre, l'interaction des effets des deux bordures rapprochées sur la structure forestière a été évaluée en utilisant des modèles d'influence des bordures. En utilisant ces modèles, il a été possible de prévoir une influence plus grande des bordures rapprochées, résultant de leur interaction. Un effet d'interaction des bordures a été possible pour toutes les variables évaluées, sauf pour l'abondance des arbres vivants. Une comparaison des modèles aux données empiriques, indique toutefois que les effets combinées de bordures sont principalement associées à la couverture de la canopée des habitats linéaires.

Cette étude montre que la structure de la végétation des habitats linéaires est affectée par les effets des bordures et que ces effets sont amplifiés par une interaction des bordures doubles. La largeur de ces habitats linéaires ne semble donc pas être appropriée pour soustraire ces habitats des effets de lisières ainsi que pour assurer l'intégrité des conditions structurales d'habitat des forêts de stades successionnels avancés des écosystèmes boréaux. Néanmoins les habitats linéaires conservent des attributs qui atténuent leurs différences de structure forestière avec l'intérieur des forêts continues. Ainsi, sans être optimales, ces conditions structurales se rapprochent davantage de celles qui prévalent à l'intérieur des forêts continues. Ce travaille indique que ces habitats linéaires peuvent jouer un rôle fonctionnel dans le maintien de la diversité biologique pour la faune et la flore forestière associées aux forêts âgées, mais que ce rôle serait consolidé si les habitats de rétention dans les aires de récoltes étaient plus larges et de forme moins linéaire.

INTRODUCTION GÉNÉRALE

1.1 Fragmentation de paysage dans la forêt boréale

La forêt boréale est soumise à différents types de perturbations, soit naturelles ou anthropiques, de différentes fréquences, tailles et intensités (McCarthy 2001; Bergeron et al. 2001). Les incendies de forêt (Payette 1993; Bergeron et al. 2001), les épidémies d'insectes (MacLean 1980; Morin and Laprise 1990), le chablis (Morin 1990; Ruel 1995) et, plus récemment , l'exploitation forestière (Drapeau et al. 2000), sont considérés comme des facteurs importants de perturbation influençant la dynamique de la forêt boréale (Bergeron et al. 2001; McCarthy 2001). En raison des différentes perturbations, la forêt boréale a subi la fragmentation du couvert forestier et la perte d'habitats, notamment les forêts matures et surannées (Frelich and Reich 1998; Bergeron et al. 2001).

Les conséquences de la fragmentation du couvert forestier peuvent déterminer la dynamique, l'hétérogénéité et la persistance de la biodiversité régionale d'un écosystème (Graham and Jain 1998; Engelmark et al. 2000). Dans les territoires aménagés, les effets de lisière constituent l'un des facteurs les plus importants agissant sur la dynamique et la structure forestière des forêts résiduelles (Murcia 1995).

En la forêt boréale aménagée du Nord ouest du Québec, le paysage résultant de la fragmentation forestier peut être considéré comme un mosaïque où les aire de coupe et les forêts résiduelles sont observés. Depuis 1986, le Ministère de Ressources Naturelles du Québec a établi le règlement sur les normes d'intervention dans les forêts, a fin de respecter certaines ressources de l'environnement. Selon ce règlement, en pessière noire la forêt publique doit être exploitée par coupes d'un maximum de 150 ha séparées par forêts résiduelles laissées sous la forme d'habitats linéaires. Deux types d'habitats linéaires doivent être laissées après la coupe: (a) séparateurs de coupe, soit 60 m, quand les aires de coupe ont moins de 100 ha ; ou 100 m, quand les aires de coupe ont entre 100 et 150 ha; (b) bandes riveraines, au mois 20 m a chaque coté des rivières, ruisseaux ou lacs. Ainsi, le paysage forestière résultant de l'aménagement est constitué par aires de coupe séparées par forêts résiduelles, principalement habitats linéaires, qui constituent le seul type de forêts laissés après la coupe.

1.2 Effets de bordure sur la structure forestière

L'effet de bordure ou de lisière est défini comme le changement des conditions environnementales de deux écosystèmes adjacents qui agissent l'un sur l'autre. Résultat de la présence d'une zone brusque de transition (frontière), cette influence modifie les processus et les attributs écologiques de ces deux écosystèmes près de la bordure (Malcolm 1994; Murcia 1995; Esseen and Renhorn 1998; Harper and Macdonald 2001; Burton 2002; Honnay et al. 2002). Les zones de bordure générées pas la fragmentation des habitats, peuvent présenter une structure et une composition différentes des habitats originaux adjacents et ils se distinguent également des habitats non forestiers ouverts (Chen et al. 1992; Murcia 1995; Cadenasso et al. 1997).

Dans les paysages forestiers, les bordures dérivées à partir de l'aménagement forestier deviennent des composantes qui peuvent jouer un rôle important sur la structure et la dynamique forestières (Murcia 1995; Forman 1997). Considérant que la forêt boréale a été historiquement soumise à un processus naturel de fragmentation, par exemple par les feux, une tolérance à l'augmentation de la quantité de bordures résultant de l'aménagement forestier devrait être considérée pour cet écosystème.

Plusieurs études ont évalué les effets de lisière dans les fragments forestiers (Laurance and Yensen 1991; Chen et al. 1992; Euskirchen et al. 2001; Burton 2002). Même s'ils existent plusieurs et divers études sur les effets de bordure, la quantification de ces effets pose un défi, entre autres en raison du nombre élevé de variables à considérer, des facteurs impliqués dans ce processus et aussi parce que les méthodes pour déterminer, mesurer et quantifier l'influence de la bordure, changent également selon les auteurs considérés (Murcia 1995; Esseen and Renhorn 1998; Harper and Macdonald 2001).

Cependant, on a besoin d'étudier et d'analyser les interactions des variables et des facteurs qui ont un rôle important dans les effets de bordures sur les habitats résiduels qui sont laissés après coupe. Ceci en raison, entre autres, des préoccupations récentes de maintenir dans les territoires aménagés des legs structuraux (structural legacies *sensu* Franklin et al. 2002) de manière comparable à ceux qui sont laissés par les perturbations naturelles (Chen et al. 1992; Murcia 1995; Franklin et al. 1997, 2002).

Les conséquences des effets de bordures sur les forêts résiduelles sont très diverses (Murcia 1995). Par exemple, la quantité de lumière près de bordures augmente d'au moins 100% (Chen et al. 1995; Brosofske et al. 1997; Dignan and Bren 2003). Aussi, il a été montré que les sites proches des bordures, sont davantage exposés aux vents de forte vélocité (Ruel et al. 2001), ainsi qu'a une plus grande variation des niveaux d'humidité et de température, que ceux observés à l'intérieur des forêts (Chen et al. 1992; Chen et al. 1995; Jose et al. 1996). Les effets de bordures sur la structure et la composition forestières, incluent divers changements. La diminution du couvert forestier vers la bordure est le résultat de la diminution de la densité des arbres vivants liée à une mortalité accrue des arbres (Brosofske et al. 1997; Oosterhoorn and Kappelle 2000; Harper and Macdonald 2001; Harper and Macdonald 2002a; Harper and Macdonald 2002b; Macdonald et al. 2003). Une augmentation de la quantité des arbres morts sur pied (chicots) a aussi été documenté (Chen et al. 1992; Young and Mitchell 1994), ainsi que le dommage accru aux arbres vivants près des bordures (Ferreira and Laurance 1997). Une plus grande quantité des arbres tombés au sol peut également traduire cet effet de bordure (Chen et al. 1992; Burton 2002; Harper and Macdonald 2002b; Harper et al. 2004). Aussi, il a été documenté que tous ces changements dans la structure et la composition forestières, peuvent également affecter la distribution, la dispersion et les mouvements de la faune et de la flore (Esseen and Renhorn 1998; Euskirchen et al. 2001; Harper and Macdonald 2001; Honnay et al. 2002; Rheault et al. 2003).

1.3 Les habitats linéaires de protection dans la forêt boréale aménagée

Après la coupe, les habitats linéaires sont souvent laissés le long des routes, des rivières, des ruisseaux et des lacs, afin de réduire ou d'éliminer les impacts visuels de l'utilisation des forêts ou pour protéger la forêt et les ressources aquatiques adjacentes aux coupes forestières (Castelle et al. 1994; O'Laughlin and Belt 1995; Brosofske et al. 1997; Acker et al. 2003). Ces habitats linéaires peuvent jouer un rôle écologique important en fournissant des conditions d'habitat aux espèces végétales et animales associées à des forêts continues ainsi qu'agir comme corridors de déplacements ou dispersion (Naiman et al. 1993; Machtans et al. 1996; Hylander et al. 2002; Acker et al. 2003).

Au Québec en forêt boréale, deux types d'habitats linéaires sont laissés après l'aménagement forestier, soit les séparateurs de coupe et les bandes riveraines. Dans ces habitats linéaires, l'influence des bordures devient évidente en raison de la forme allongée de ces habitats. Les séparateurs de coupes et les bandes riveraines sont longs et minces, et ont proportionnellement plus de bordures que des forêts résiduelles de forme ronde ou carrée. Par conséquent, ces habitats linéaires sont avantage exposés aux effets de bordures (Saunders et al. 1991). En raison de la présence d'une plus grande superficie exposée à l'influence des bordures, il en découle des changements de la structure et de la dynamique de la végétation, ainsi qu'un plus grand risque de chablis près des bordures et donc une augmentation potentielle du recrutement et de la régénération en bordure de ces habitats (Saunders et al. 1991; Coates 2002).

Un autre facteur possible affectant la dynamique et la structure des habitats linéaires renvoie à l'interaction des deux bordures, qui peut entraîner une plus grande influence de bordure en comparaison à l'effet généré par une seule bordure (Malcolm 1994; Harper et al. non publié). Les changements de structure et de composition des forêts dans de tels habitats linéaires dépendront des effets combinés des deux bordures et on peut s'attendre à ce que l'augmentation de la quantité de lumière et du vent verront leurs effets s'accroître sur les paramètres structuraux de ces habitats (Dignan and Bren 2003).

L'interaction entre les bordures dans des fragments forestiers a été documentée par peu d'études (Malcolm 1994; Fernández et al. 2002; Harper et al. non publié). L'influence de plus d'une bordure a été conceptualisée par différents auteurs comme étant que: (1) l'influence totale tout le long d'un fragment forestier qui incorpore la nature additive des effets de bordure par rapport à la distance à partir de la bordure (Malcolm 1994; Fernández et al. 2002) ou (2) de possibles interactions des influences des bordures, comprenant un effet combiné de deux bordures ou plus, l'influence d'une seule bordure ou la résistance d'une bordure ancienne à l'influence d'une bordure plus jeune (Harper et al. non publié).

On a reconnu l'importance de laisser les habitats linéaires dans les secteurs forestiers aménagés a fin de protéger l'ensemble de la forêt (Potvin and Bertrand 2004). Par contre, la largeur de ces habitats, particulièrement pour les bandes riveraines, demeure controversée (Castelle et al. 1994; O'Laughlin and Belt 1995; Brosofske et al. 1997; Forman 1997; Hylander et al. 2002; Dignan and Bren 2003). Même si ces habitats linéaires n'ont pas été considérés dans les efforts de conservation des habitats forestiers de stades successsionels avancés (Brosofske et al. 1997; Dignan and Bren 2003), il est important d'évaluer si leurs attributs structuraux offrent les conditions appropriées d'habitat pour persister, soutenir, et maintenir la biodiversité forestière caractéristique des habitats d'intérieur.

1.4 Objectifs de l'étude

L'objectif de cette étude est d'évaluer la structure forestière des forêts résiduelles, comme les séparateurs de coupe et les bandes riveraines, en fonction des effets de bordures qui peuvent être amplifiés dans les habitats linéaires de divers secteurs forestiers aménagés du Nord-Ouest du Québec. Ce mémoire de recherche comporte trois chapitres.

Le premier chapitre propose une analyse détaillée de la structure forestière des habitats résiduels des territoires aménagés en forêt boréale québécoise. Spécifiquement l'objectif de cet chapitre est déterminer si la structure forestière des habitats résiduels, dont les habitats linéaires tels que les séparateurs de coupe et les bandes riveraines qui sont laissés dans les grandes agglomérations de coupes avec protection de la régénération et des sols (CPRS), est similaire de celle de forêts continues. Au chapitre 2 et 3, l'importance des effets de lisière sur la structure du couvert forestier des habitats résiduels est évaluée. Plus spécifiquement, au chapitre 2 les objectifs de l'étude sont: (1) déterminer l'étendue d'influence de la bordure sur la structure forestière des forêts résiduelles, et (2) comparer l'influence de la bordure sur la structure forestière entre les séparateurs de coupe et les bandes riveraines, pour déterminer si la présence d'un risseau peut diminuer les effets de bordure dans les habitats linéaires étroits. Ainsi, la distance de l'influence de la bordure (DIB) est comparée entre les fragments forestiers présentant seulement une bordure (interfaces forêt-parterres de coupe) et ceux présentant deux bordures (habitats linéaires), pour détecter la distance à partir de la bordure où il est possible de détecter des changements dans la structure forestière de ces habitats., Finalement, l'objectif du troisième chapitre est d'évaluer les différents modes possibles dans lesquels deux bordures rapprochées peuvent agir en raison de son influence sur la structure forestière des habitats linéaires. Alors, la proximité des bordures des habitats linéaires est évaluée en utilisant des modèles d'interaction des bordures comparés aux données empiriques, a fin de déterminer si la proximité des bordures accroît les effets de lisière

Forest structure of forest remnants in managed black spruce forests of Quebec

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ABSTRACT

This study documents the forest structure of forest remnants, including cutblock separators and riparian buffer strips which are practically the only forest remnants preserved in the managed landscapes, of the eastern boreal black spruce forest in Quebec. We compared the forest structure of linear remnant habitats with large forest patches and continuous forest conditions. We observed lower densities of live trees in linear corridors in comparison with the continuous forest conditions; however, in all the forest treatments, there were similar proportions of trees within each diameter category. Most of the differences were observed in the densities of dead trees. Linear habitats showed the lowest density of standing dead trees and the greatest density of fallen dead trees. Using a discriminant function analysis, we found that the main variables that could discriminate treatments were those related to the density and basal areas of recent snags and broken snags. It was not possible to clearly differentiate in the ordination space all forest treatments, since they shared a high degree of similarity. However, riparian buffer strips were the linear habitat more related to the continuous forest conditions, while the cutblock separators had some plots that were not similar to other forest treatments. The similarity with some structural charactristics observed in continuous forest conditions makes linear corridors, in principle, good legacies of what were the unmanaged interior continuous boreal forests. This study provides a baseline on the forest structure of these forest remnants.

Key words: linear corridors; riparian buffers; cutblock separators; forest structure; boreal forest; forest management.

INTRODUCTION

In recent years, timber harvesting throughout the world has considerably modified the forest cover, particularly by reducing the amount of continuous forests over the landbase (Saunders et al. 1991; Simberloff 2001;Fahrig 2003). In the boreal ecosystem, extensive clearcutting is accompanied by the retention of remnant forest habitats that are often of linear shape to either protect water quality near streams and lakes (Hannon and Schmiegelow 2002) or reduce visual impacts of large cut-over areas (Potvin and Bertrand 2004). These linear corridors may mitigate forest fragmentation by facilitating dispersal for many forest species and thus allowing connectivity between reserves (Saunders et al. 1991; Lindenmayer and Nix 1993; Naiman et al. 1993; Beier and Noss 1998). There has been, however, some controversy on how linear corridors can promote the retention of species in landscapes altered by habitat fragmentation (Simberloff et al. 1992, see also Hannon and Schmiegelow 2002). While these remnant habitats were not planned to meet ecological objectives such as maintaining structural heterogeneity and protecting biological legacies (*sensu* Franklin et al. 2002), they contribute to ensure some degree of structural heterogeneity which is known to play an important role in forest ecosystem function and biological diversity (Bunnell et al. 1999).

In the harvested boreal forest of Quebec, which represents an important proportion of the eastern black spruce forest of Canada, linear corridors are the main type of retention legacy left in the extensive tracts of cutover areas. To determine their role in protecting biological legacies and hence, biodiversity, it is important to have more precise knowledge on the forest structure of such habitats. The purpose of this paper is to determine if linear corridors offer similar forest structure conditions to those of continuous forests. Our rationale is that silvicultural systems should aim towards leaving some standing structure from the original forest given that natural disturbances nearly always leave some biological legacies that play an important role in ecosystem function and biodiversity patterns.

STUDY AREA

The study area is located in the Claybelt region of Quebec and Ontario between 49°00’ and 49°45’ North and from 76°00’to 77°30’ West. It is part of the west bioclimatic zone of black spruce and feather moss, in the Abitibi region of Northwest Quebec (Saucier et al. 1998). The topography in the region is generally flat, of glaciolacustral, clay, and till deposits, where organic soils are present (Gauthier et al. 2000). The selected forest stands were 70-120 years old and were dominated by *Picea mariana* (Mill.) B.S.P. in codominance with *Pinus banksiana* Lamb. and *Abies balsamea* (L.) Mill.; *Betula papyrifera* Marsh., *Populus tremuloides* Michx. and *Larix laricina* (Du Roi) Koch. are sparsely distributed.

The dynamics of the boreal forest is associated with natural disturbances, such as wildfires, windthrow and insect outbreaks; as well as with human disturbances like timber harvesting. The harvested landscapes include clearcuts areas divided by linear forested corridors and surrounded by large forest remnants. Linear corridors are left as cutblock separators of 60 m width when the adjacent clearcuts are less than 100 ha; or as cutblock separators of 100 m width when clearcut areas are between 100 and 150 ha; and as riparian buffers of 20 m width minimum on each side of streams, rivers or lakes.

METHODS

The sampled forest remnants included (1) cutblock separators, approx. 60 m wide; (2) riparian buffer strips, 45-75 m wide; and (3) large forest patches, adjacent to a single clearcut boundary, extending from the clearcut edge to at least 150 m into the forest. Continuous forest conditions were characterized near each large forest patch at least 100 m away from any boundary or clearcut area.

Forest structure was sampled in ten independent sites for each treatment. Transects were established across cutblock separators and riparian buffers; in the large forest patches, transects extended 60 m perpendicular from the clearcut edge. Continuous forest conditions were sampled with transects 100 m long.

Vegetation data were collected in rectangular plots parallel to the forest edge (5 x 20 m long). Plots were located contiguously every 5 m along the established transects in the forest remnants. Continuous forest conditions were sampled with three plots located 50 m apart from each other on each transect.

Data were collected in summer, 2003. Within each plot, the abundance of all live and dead mature trees; dbh (diameter at breast height, 1.3 m), canopy position (dominant, co-dominant and suppressed), and species of all mature trees > 5 cm dbh were recorded. We also recorded decay classes 3-6 for snags (Thomas et al. 1979) and we noted the presence of a broken top, and recorded decay classes 1-2 for logs (Maser et al. 1979). Deadwood in more advanced decay classes was not sampled because forest remnants were near edges that were created by forest harvesting between 1993 and 1998, and the general objective of this study was to detect the structural changes after harvesting.

DATA ANALYSIS

A discriminant function analysis was performed to classify forest remnants according to their structural components. For this analysis, we categorized live trees, snags and logs into 18 mutually exclusive structural groups based on diameter classes for trees, and diameter and decay classes for dead trees; including 4 groups of live trees, 12 of snags and 8 of logs (Table 1). Different analysis were performed based on the density of live and dead trees as well as on basal areas. We only considered plots in the first 25 m from the edge for the forest remnants, to compare the same number of plots in all forest remnants. The discriminant function analysis was performed considering the four forest treatments as the grouping variable and the 18 categories of the forest structure characteristics as the independent variables. The stepwise method of Wilks' lambda with a criterion of one standard deviation was used for the analysis. The discriminant analysis was performed in SPSS version 10.0 (SPSS Inc., 1999). To facilitate comparisons among treatments, 95 % concentration ellipses were overlaid on the dispersion diagram. The 95 % criteria was chosen to include all sampling stations for which coordinates on the first two axes were within one unit of standard deviation from the centroid of each treatment, thus providing a view of the mean size of each cluster of sampling stations. Concentration ellipses were obtained using Systat ver. 10.

RESULTS

Forest structure

In all forest treatments, living tree density was dominated by *Picea mariana* (> 88 % of sampled living trees); while *Abies balsamea* was the second most abundant species in all forest treatments except in riparian buffer strips (Table 2). *Pinus banksiana* was mostly sampled in large forest patches; while *Betula papyrifera, Populus tremuloides and Larix laricina* also occurred on all forest sites, with low densities (Table 2).

Continuous forest conditions were characterized with a high density of live and dead trees (Table 2)and high mean basal areas of living trees; while linear corridors showed the lowest mean values for these structural characteristics. Continuous forest conditions showed a great amount of medium live trees; while densities of large and very large trees (dbh > 20 cm) were similar across treatments (Fig. 1).

Mean basal areas of dead trees were similar between continuous forest conditions and the riparian buffer strips but were lower than the observed in large forest patches and cutblock separators (Table 2). We observed the greatest density of standing dead trees in continuous forest conditions, while the lowest density was found in riparian buffers. Recently and intermediate decayed snags had similar densities among treatments, except in riparian buffer strips (especially of small an medium dbh classes; Fig. 2). Broken snags showed the highest densities in continuous forest conditions (especially in the 5-10 dbh class), followed by large forest patches and cutblock separators, and the lowest values were observed in riparian buffer strips (Fig. 2). In all forest treatments, the densities of broken snags were higher than the observed for recent or intermediate decay stages (Fig. 2).

Densities of fallen dead trees in either decay class were higher in habitat remnants (cutblock separators, riparian buffers and large forest patches) than in continuous forest conditions (Fig.3). In linear habitats the greatest density of fallen dead trees were observed principally in the medium (10-15 cm) and large (15-20 cm) diameter classes. Riparian buffer strips were the forest treatment that presented the greatest density of recent logs; while cutblock separators showed the greatest density of slightly decayed snags (Fig. 3).

Classification of forest treatments

The discriminant function analysis identified only four variables (from a total of 18 grouping variables) for the classification of the forest treatments. Total densities and basal areas of small and medium broken snags as well as small and medium recent snags were the variables that showed the highest correlation with the discriminant functions.

When considering the density of stems as the grouping variable, the first two canonical variables accounted for 99.9% of the total dispersion; 55.2% of which was represented by the first canonical variable. The selected variables for this classification were the densities of small and medium broken snags, and medium recent snags. For the first axis, small and medium broken snags densities were the most associated variables; while medium recent snags and medium broken snags densities were associated to the second axis. There was no a clear separation of the plots of the four forest treatments along either axis (Fig. 4). Forest remnant plots were more clustered than the continuous forest conditions plots, which were widely distributed along both discriminant functions (Fig. 4). The concentration ellipse of riparian buffers was the smallest; while the largest ellipses were observed for continuous forest and cutblock separators (Fig. 4).

When considering the basal areas for live and dead trees, the first two canonical variables accounted for 90.8%, and most of the spread was attributed to the first canonical variable (51.5%). Small and medium recent snags, and small and medium broken snags were considered for the classification of plots according to the basal areas. The basal areas of small and medium broken snags as well as small recent snags accounted for the first discriminant function; while the basal areas of medium recent snags and medium broken snags represented the second discriminant function. For these response variables, plots of riparian buffers strips were more clustered in the first and second discriminant functions (Fig. 5). Plots of cutblock separators, large forest patches and continuous forest conditions, were dispersed along the first discriminant function (Fig. 5). The ellipses of large forest patches, cutblock separators and continuous forest conditions showed a similar elongated form but not of similar size (Fig. 5).

Even though the first canonical variable accounted for more than 50% of the total dispersion of the plots, when considering the total densities and basal areas, the classification of the forest treatments was not as successful as expected. Only 44.5% and 47% of the total plots for all forest treatments were correctly classified when considering the density of stems and basal area, respectively. For riparian buffer strips, more than 50% of plots were correctly classified when considering density and basal area (Table 3). For cutblock separators, continuous forest conditions and large forest patches less than 50% of the original plots predicted the membership of the groups (Table 3). In all forest treatments, plots that were outside the concentration ellipses might be considered as marginal plots. Overall, concentration ellipses (Fig. 4, 5) and classification scores (Table 3) indicate that riparian buffers structure was the less variable among the forest treatments evaluated.

DISCUSSION

The principal objective of this study was to detect the possible differences in the forest structure of forest remnants, such as linear habitats, in comparison with the continuous forest conditions. This study shows that linear remnant habitats share some structural characteristics with continuous forest conditions and thus may perpetuate biological legacies in managed forests; even though linear remnant habitats do not present a sufficient core area to avoid edge effects (see Chapters 2 and 3).

Our study is one of the first studies developed in the boreal forest that documents the structural attributes of linear forest habitats in comparison with continuous forest conditions. Harper et al. (2004) examined edge effects in cutover areas and wildfire-forest interfaces in black spruce boreal forests. Even though their forest stands had a more open and discontinuous canopy cover and the adjacent clearcut areas were younger than the ones in our study; their results may provide some basis for comparison with our data set. In our study area, density values of live trees for continuous forest conditions were similar to those reported for interior forests by Harper et al. (2004). However, the density of live trees observed in the large forest patches was lower than the density observed by Harper et al. (2004) right at the edge of their forest-clearcut interfaces. In linear corridors, densities of live trees were even lower for both riparian buffers and cutblock separators. This might be the result even of the greater forest damage in linear habitats due to their narrowness or also due to forest harvesting, that selects forest stands with low tree densities. At the same time standing dead trees and fallen trees (downed logs) showed high densities in linear habitats. This might suggest that there are higher mortality rates in our study sites where edge effects such as windthrow have been acting for longer periods, increasing the density of dead trees, in comparison with sites were edges are younger.

Continuous forest conditions presented a greater stem density and a greater basal area of living trees than both types of linear corridors. Across treatments, however, these differences were spread over diameter classes maintaining in all treatments a structural diversity of live trees. The same pattern of variability was observed across treatments for dead wood where each treatment harbored a wide variety of sizes and decay classes of snags and logs. Our results show several similarities with Harper et al. (2003) findings for old-growth black spruce stands, where structural complexity is an important feature but large trees, large snags and large logs are lacking as in this ecosystem. The elevated mortality in all forest treatments was principally the result of snag breakage especially of small trees. At least in linear habitats tree breakage might be the result of wind effects due to the proximity of edges.

The forest structure of the four treatments was similar, given the high overlap between concentration ellipses in the DFA diagrams (Figs. 4 and 5). The size of the ellipses provides some indication of plots similarity within treatments. Cutblock separators, large forest patches and continuous forest conditions were more variable with regards to their structural complexity; whereas riparian buffer strips, showed a high degree of similarity among plots and hence, a low heterogeneity in their structural attributes.

Discriminant factor analysis showed that only dead trees could discriminate treatments from one another, suggesting a high degree of structural similarity among treatments. Hence, even though extensive forest management leaves narrow linear corridors in the eastern black spruce forest, these remnant habitats share many structural components with structural characteristics of the continuous forest conditions. Therefore, these linear habitats have the structural characteristics that may allow them to play an important functional role in the maintenance of the biological diversity of continuous forest conditions in these managed landscapes.

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Figure 5. Classification plot for the first two discriminant function scores for plots between 0-25 m of the forest remnants evaluated as well as plots of the continuous forest conditions, considering basal area values of small and medium recent snags, and small and medium broken snags. Concentration ellipses for each treatment are indicated as follows: continuous line = continuous forest conditions; line-dot-line = large forest patches; dotted line = cutblock separators; dashed line = riparian buffers.

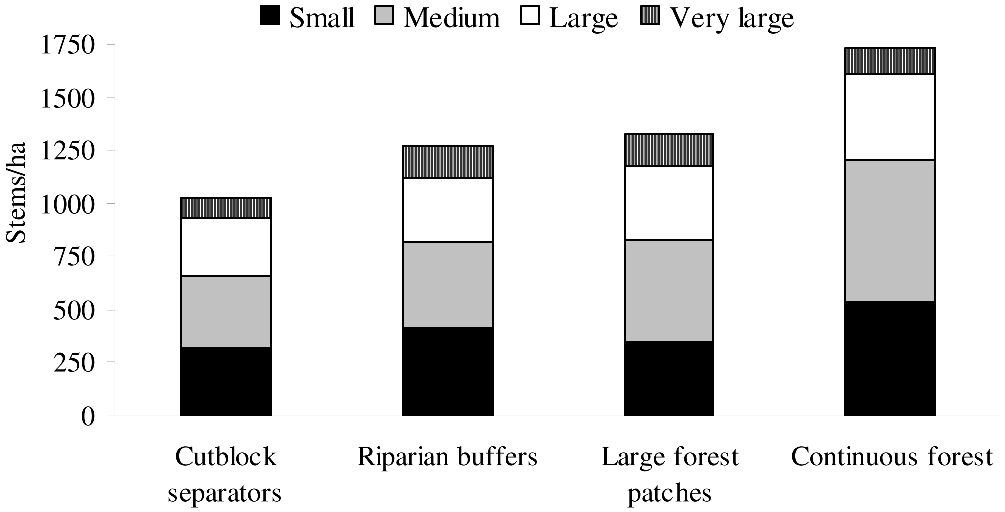


Figure 1. Mascarúa et al.

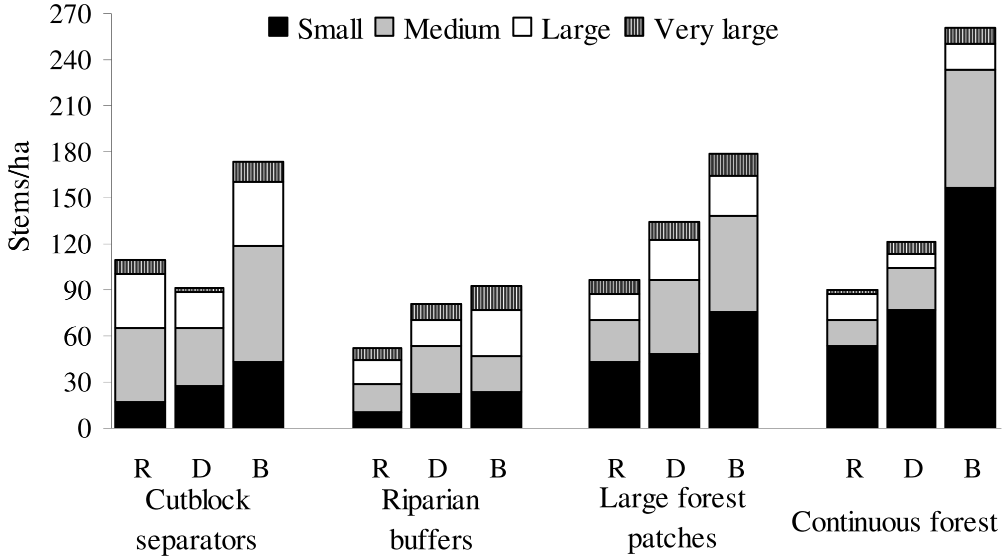


Figure 2. Mascarúa et al.

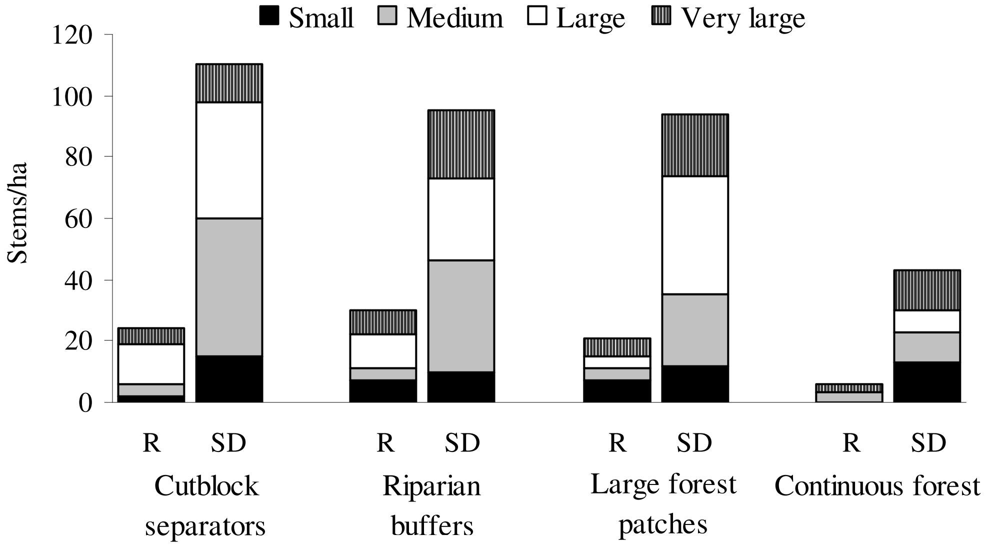
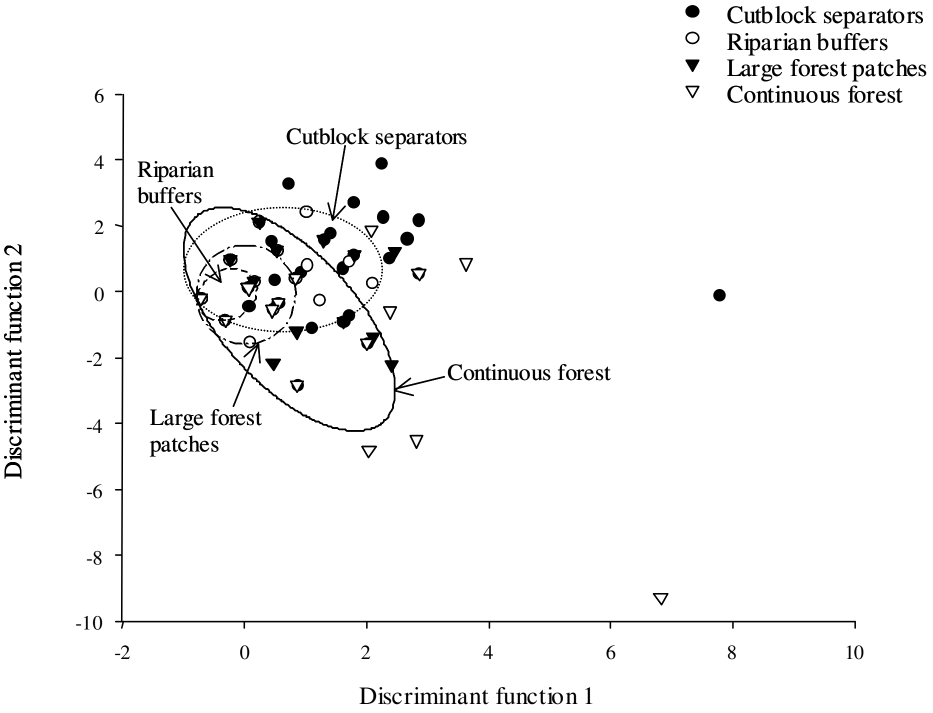


Figure 3. Mascarúa et al.



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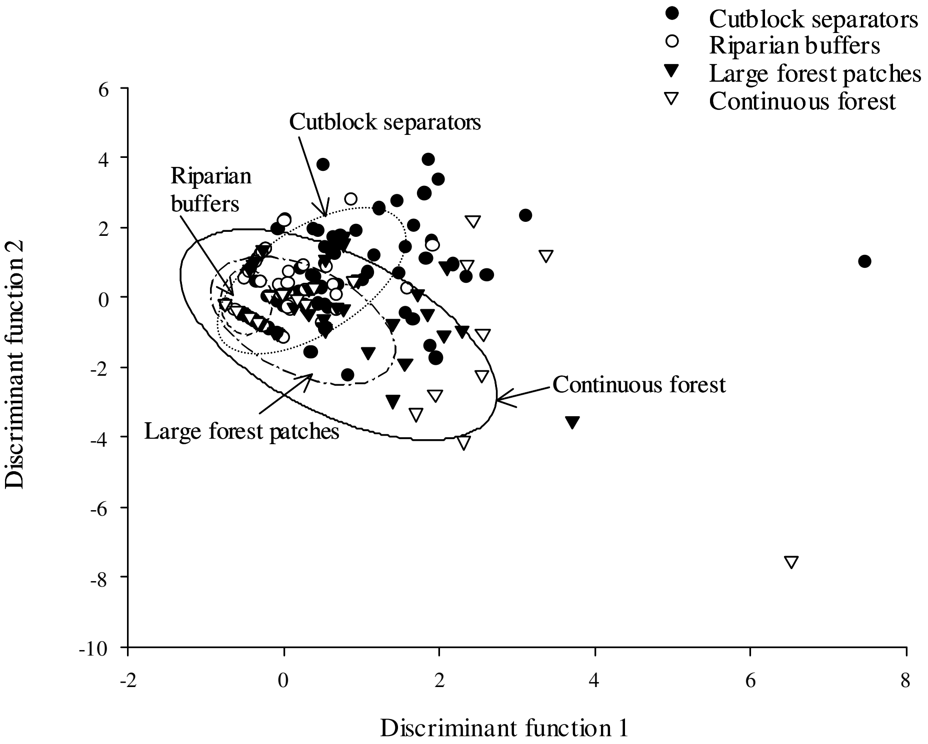

Figure 5. Mascarúa et al.

Table 1. Classification of structural groups for live trees, snags and logs by diameter and decay classes.

	Diameter (cm)	Decay class
Live trees		
1. Small trees	5 - 10	
2. Medium trees	10 - 15	
3. Large trees	15 - 20	
4. Very large trees	> 20	
Snags		
1. Small recent snags	5 - 10	3-4
2. Small decayed snags	5 - 10	5
3. Small broken snags	5 - 10	6
4. Intermediate recent snags	10 - 15	3-4
5. Intermediate decayed snags	10 - 15	5
6. Intermediate broken snags	10 - 15	6
7. Large recent snags	15 - 20	3-4
8. Large decayed snags	15 - 20	5
9. Large broken snags	15 - 20	6
10.Very large recent snags	> 20	3-4
11.Very large decayed snags	> 20	5
12. Very large broken snags	> 20	6
Logs		
1. Small recent logs	5 - 10	1
2. Small slightly-decayed logs	5 - 10	2
3. Intermediate recent logs	10 - 15	1
4. Intermediate slightly-decayed logs	10 - 15	2
5. Large recent logs	15 - 20	1
6. Large slightly-decayed logs	15 - 20	2
7. Very large recent logs	> 20	1
8. Very large slightly-decayed logs	> 20	2

Table 2. Characteristics of the forest remnants and transects studied including edge age and orientation, stand age, tree density, basal area and species composition.

Transect	Edge age[a] (years)	Stand age* (years)	Edge orientation[b] (degrees)	Density[c] (stems/ha)	Basal area[c] (m^2/ha)		Tree spp. composition[c] (% of tree density)			
					Live	Dead	*Picea*	*Pinus*	*Abies*	Other
Cutblock separators										
1	5	70	150, 330	1808	21	7	99	0	1	0
2	5	90	110, 290	1717	15	11	72	0	26	2
3	5	120	150, 330	1675	16	8	100	0	0	0
4	5	120	120, 300	1942	25	7	89	9	1	1
5	5	120	120, 300	1242	8	16	100	0	0	0
6	5	120	170, 350	1442	17	7	83	0	15	2
7	5	120	100, 280	1077	11	10	97	2	1	0
8	8	120	120, 300	957	15	8	97	0	3	0
9	8	120	150, 330	2031	15	6	100	0	0	0
10	7-8	120	150, 330	1525	16	4	97	3	0	0
Mean values				1542	16	8	93	1	5	1
Riparian buffers										
1	7	90	30, 210	1325	15	8	91	8	0	1
2	7	90	0, 180	2260	36	6	96	2	0	2
3	7	120	130, 310	1315	13	9	99	0	0	1
4	9	90	20, 200	2193	27	6	95	3	0	2
5	10	120	70, 250	1158	18	3	97	1	2	0
6	10	120	170, 350	1138	13	7	98	1	0	1
7	10-11	90	130, 310	1309	12	13	89	7	0	4
8	10-11	120	120, 300	1283	19	9	94	3	1	2
9	11	90	30, 210	2188	17	4	95	4	0	1
10	11	90	20, 200	1109	22	1	82	5	0	13
Mean values				1528	19	7	94	3	0	3
Large forest patches										
1	7	90	298	1808	29	6	97	1	0	2
2	7	90	318	2808	16	6	94	6	0	0
3	7	90	184	1508	26	11	98	0	0	2
4	7	120	110	2517	28	9	100	0	0	0
5	7	120	240	2042	11	18	88	0	12	0
6	8	70	270	1050	20	10	97	0	3	0
7	8	90	338	1233	27	9	98	0	2	0
8	8	120	314	2492	27	4	100	0	0	0
9	9	70	290	1867	16	7	92	1	1	6
10	9	120	190	1225	22	2	79	14	7	0
Mean values				1855	22	8	94	2	3	1
Continuous forest conditions										
1		70		3167	38	10	69	8	2	21
2		70		4667	32	8	98	0	0	2
3		90		2633	28	6	100	0	0	0
4		90		2933	33	10	100	0	0	0
5		90		900	19	4	100	0	0	0
7		90		1800	16	6	71	0	23	6
6		120		2033	32	3	64	0	27	9
8		120		1133	16	2	100	0	0	0
9		120		1333	17	3	87	0	8	5
10		120		1933	18	4	96	0	4	0
Mean values				2253	25	6	89	1	6	4

[a] Data are from ecoforestry maps (1:20 000, Ministère des Ressources Naturelles du Québec).

[b] Orientation was measured looking into the forest from the edge. The orientations for both edges of the corridors are given.

[c] Mean of all plots (5 x 20 m) per transect per treatment.

Table 3. Classification values of group membership for each forest treatment evaluated, considering density and basal area.

	Predicted group membership (%)									
	Cutblock separators		Riparian buffers		Large forest patches		Continuous forest		Total (%)	
Forest treatment	Density	Basal area	Density	Basal area	Density	Basal area	Density	Basal area	Density	Basal area
Cutblock separators	**39.2**	**43.3**	38.3	35.0	13.3	9.2	9.2	12.5	100	100
Riparian buffers	15.0	17.5	**72.5**	**70.0**	5.8	6.7	6.7	5.8	100	100
Large forest patches	25.0	21.7	51.7	38.3	**8.3**	**20.0**	15.0	20.0	100	100
Continuous forest	13.3	23.3	50.0	46.7	10.0	6.7	**26.7**	**23.3**	100	100

Edge influence on forest structure in large forest remnants, cutblock separators and riparian buffers in managed black spruce forests*

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ABSTRACT

Remnants of old forests left on the landscape following forest harvesting, especially corridors, provide benefits of connectivity and facilitation of movement or dispersal, which may be hindered by the presence of edges. Our objective was to determine the extent of edge influence on forest structure in these forest remnants in black spruce boreal forest. We sampled the density of trees, snags, and logs, and canopy cover along clearcut edge-forest gradients in large forest patches, cutblock separators and riparian buffers. The distance of edge influence was determined by comparing values at different distances from the edge to values in continuous forest using randomization tests. Forest remnants had lower live tree density and canopy cover, and higher mortality and windthrow than continuous forest. Distance of edge influence on forest structure extended 10-30 m from the edge, and was slightly more extensive into cutblock separators where two edges are in close proximity, but less extensive in riparian buffers possibly due to the presence of internal edges near the stream. Because of edge influence, the structure near the edges of forest remnants and across narrow corridors is modified; wider corridors would be required to provide a core habitat of continuous forest conditions.

Keywords: cutblock separators, distance of edge influence, edge effects, forest structure, forest management, riparian buffers.

Nomenclature: Marie-Victorin, 1995.

INTRODUCTION

In fragmented landscapes, populations living in remnant habitats can be altered by negative edge effects on their survival and reproduction resulting in population declines on local and regional scales (Robinson et al., 1995; Donovan et al., 1997; Rheault et al., 2003). The effects can be exacerbated by the shape of remnants; linear habitats, in particular, are more likely to be strongly affected given their high edge ratio (Temple, 1986).

The effectiveness of linear remnants on fragmented landscapes as movement and dispersal corridors, as habitat or as buffers remains controversial, in part due to edge influence (Saunders et al., 1991; Lindenmayer & Nix, 1993; Naiman et al., 1993; Castelle et al., 1994; Beier & Noss, 1998). In harvested forests, the role of remnants might be diminished due to the presence of a greater surface exposed to edges. The influence of the clearcut area may result in greater windthrow, and therefore lower tree density and canopy cover, and greater log abundance in the adjacent forest near the edge (Esseen & Renhorn, 1998; Harper & Macdonald, 2002b; Harper et al., 2004). As a result of edge influence on forest structure, the core area of continuous forest conditions (Laurance, 1991) is less than patch size per se. In linear remnant habitats, it may be too small for corridors to be effective. Most studies on linear corridors have focused on their use by fauna (e.g., Beier & Noss, 1998; Hannon et al., 2002; Hannon & Schmiegelow, 2002), on environmental gradients (Brosofske et al., 1997; Dignan & Bren, 2003), or on their function as buffers for nutrient loading (Gregory et al., 1991); but their capacity to protect the forested environment has received very little attention (Castelle et al., 1994). One of the first steps in assessing their effectiveness is to determine if the forest structure within remnant habitats is compromised by edge influence, a subject that few studies have addressed for linear corridors (but see Hairston-Strang & Adams, 1998; Ruel et al., 2001).

Forests of linear shape are the most common remnants in harvested boreal forests in Quebec, as the result of intensive clearcutting that leaves cutblock separators between large clearcuts, and riparian buffer strips at the sides of permanent watercourses. In addition, these corridors are often the only remnants of older seral stages left in the harvested landscape. Although edge influence usually only extends up to 10 m in the boreal forest (Esseen &

Renhorn, 1998; Harper & Macdonald, 2002b; Harper et al., 2004), edge influence on forest structure and composition is likely to be more prominent in linear corridors given their narrowness (e.g., windthrow, Ruel et al., 2001).

In this paper, our objectives were: (1) to determine the extent of edge influence on forest structure at clearcut forest edges in large forest patches, cutblock separators and riparian buffers, and (2) to compare edge influence on forest structure between cutblock separators and riparian buffers in order to determine if the presence of a stream can mitigate edge influence in narrow corridors. Our results will provide an assessment of the effective width of continuous forest habitat in linear corridors in Quebec boreal forest.

METHODS

Study area

Research was conducted in the west bioclimatic zone of black spruce and feather moss in the Abitibi region in northwestern Quebec (Saucier et al., 1998). The area is part of the Clay Belt of Ontario and Quebec, where the topography is generally flat and organic soils are present on clay, glaciolacustral and till deposits (Gauthier et al., 2000). In the study area (49°00’- 49°45’ N, 76°00’- 77°30’ W), forest stands were dominated by *Picea mariana*, in co-dominance with *Pinus banksiana* and *Abies balsamea*, with sparsely distributed trees of *Betula papyrifera*, *Populus tremuloides* and *Larix laricina*.

In the study region, natural forest dynamics are associated with wildfires of cycles averaging 139 years (Bergeron et al., 2001) and with various intensities (Grondin, 1996). As result of harvesting by Domtar and Abitibi Co. companies since the early 1970s, the landscape matrix consists of clear-cut areas and forest remnants, including linear corridors. In 1986, the Quebec Government forest regulations prescribed that clearcut areas should not exceed 150 ha and should be a minimum of 60 m apart, for clearcuts less than 100 ha, or 100 m apart for clearcuts 100-150 ha, thereby creating cutblock separators either 60 or 100 m wide. Riparian buffers were also required with a minimum width of 20 m on both sides of streams, lakes or other surface water bodies.

Sampling design

We evaluated edge influence on forest structure at clearcut edges of three different types of forest remnants (treatments): (1) large forest patches (at least 300 m wide), adjacent to a single forest edge; (2) 60 m wide cutblock separators; (3) 20-70 wide riparian buffers surrounding streams. Forest remnants were dominated by black spruce (*Picea mariana* > 80% of canopy trees), and were 70-120 years old and 12 m or taller (Ministère des Ressources Naturelles du Québec, 1994; Table 1). Forest remnants were sampled near 5-10 year old edges created by forest harvesting between 1993 and 1998 (Table 1). Edge influence was evaluated for all treatments without considering edge orientation, because of the lack of edges that were perpendicular (exposed) to the prominent wind direction in cutblock separators and large forest patches.

Ten transects perpendicular to the clearcut edge for each treatment extended into the interior of the forest remnant and were at least 100 m apart from each other. Transects were 60 m long in cutblock separators and in large patches, and varied between 45 m to 75 m in riparian buffers, due to the variability of the buffer width. Continuous forest conditions were sampled along ten 100 m long transects located near each transect in the large patches, but at least 100 m away from any edge.

Data on forest structure were collected in summer 2003 in contiguous rectangular plots (5 x 20 m, long axis parallel to the forest edge) every 5 m along all transects in the three treatments, and in three plots 50 m apart each other, along the transects in continuous forest. All live trees, standing dead trees (snags) and fallen trees (logs) ≥ 5 cm dbh (diameter at breast height, 1.3 m) were inventoried within each plot. Live trees were classified according to diameter into four classes: small trees (5-10 cm dbh), medium trees (10-15 cm dbh), large trees (15-20 cm dbh) and very large trees (> 20 cm dbh). We recorded decay classes for snags (Thomas et al., 1979) and logs (Maser et al., 1979). We only sampled logs of decay classes 1-2 (See Fig. 1) with stems originating within the plot, since the objective of the study was to detect forest damage due to recent harvesting. Canopy cover was measured using a convex spherical densiometer at the center of each plot.

Data analysis

Edge influence on forest structure was evaluated in the three treatments (cutblock separators, riparian buffers, and large forest patches) for each response variable. Since the transects in the linear corridors spanned the entire width and therefore had two plots for every distance from the edge, data from these two plots were averaged for each distance from the edge prior to the analysis. Response variables included canopy cover, densities of total live trees, snags and logs; densities of trees of different sizes; densities of snags and logs in different decay classes; and mortality and windthrow. We estimated mortality as the proportion of the number of dead trees (snags and logs) to the number of all trees (dead and live), and windthrow as the number of logs to the number of all trees.

We estimated the distance of edge influence (DEI) for all response variables in each treatment using an updated version of the critical values approach (Harper and Macdonald 2001, 2002a). The original method compared the mean value at the edge to critical values based on randomization of continuous forest data; in some instances this approach might lead to Type I error. Herein, we employed a randomization method which compares the mean difference between the continuous forest values and values at a given distance from the edge to a distribution of mean differences created by randomizing the entire data set (continuous forest values and values for a given distance from the edge). For each distance from the edge, we used the following steps: (1) Ten values were randomly selected from a data set which included all thirty continuous forest values and ten values at the given distance from the edge. For the edge of large forest remnants, where variation among transects was controlled by blocking (edge and continuous forest plots were located along the same transects), one value was randomly selected from the four values for each transect. Randomization was not restricted in any way for the corridor treatments. (2) The difference between the mean of the values selected in (1) and the mean of the remaining (unselected) values was calculated. (3) These first two steps were repeated for a total of 5000 permutations to create a distribution of mean differences of the randomized data. (4) Critical values were the 2.5 and the 97.5 percentiles of the sorted 5000 permuted differences (two-tailed test, $\alpha = 0.05$). The difference between the mean value at a given distance from edge and the reference continuous forest was considered significant if it was outside the critical values. The distance of edge influence (DEI) was determined as the set of two or more contiguous distances from the edge with significant differences from the reference continuous forest (Harper and Macdonald 2002a,b).

Forest structure in the first 25 m from the clearcut edge was compared among the three treatments using an analysis of variance (ANOVA). Forest treatment and distance to edge were fixed factors, and distance to edge was also considered as a repeated measure. Multiple comparisons among treatments were performed for the observed means of all plots between 0-25 m, using the Tukey post hoc test. ANOVA models were performed with SPSS version 10.0 (SPSS Inc., 1999).

RESULTS

Distance of edge influence

Forest structure near the clearcut edge of large forest patch treatment was affected by edge influence (Fig. 2). The most extensive edge influence was for lower canopy cover and greater windthrow, which extended 25 m from the edge (Table 3). There were fewer densities of live trees in all diameter classes than in continuous forest; however significant differences were registered only for large live trees near the clearcut edge with DEI extending to 10 m (Tables 2, 3). Significant edge influence for the density of small trees and for mortality was observed for this treatment at further distances from the clearcut edge (Tables 2, 3). There was no significant edge influence on snags in any decay class in any of the forest remnants. Positive edge influence on total log density and mortality extended 0-10 m (Fig. 2).

Cutblock separators had slightly more extensive edge influence than large forest patches. Lower canopy cover and total live tree density, and higher mortality and windthrow, extended across most or almost all their width compared to continuous forests (Fig. 2). As in the large forest patches, edge influence on large trees was also significant but not as extensive (Table 2). Greater densities of logs were observed near the edge (DEI = 0-10 m) for total logs and logs in decay class 2 (Table 2, 3).

Significant edge influence in riparian buffer strips was detected only for few variables, and did not extend as far as in the other treatments. Lower canopy cover and overall tree density, and higher mortality and windthrow, had DEIs of up to 15 m (Fig. 2, Table 2). There was no significant edge influence for snags or logs in any decay class in this treatment (Table 2, 3).

Differences among forest remnants

There were no significant differences among the three forest remnants in the first 25 m from the clearcut edge for canopy cover, the density of live trees (except for very large trees which were significantly greater in large forest patches than in cutblock separators), the density of logs (in either decay class) and windthrow (Table 3). The density of snags in riparian buffer strips was significantly lower in comparison with the other two treatments; this was also observed for snags in decay classes 4 (except the difference between riparian buffers and large patches was not significant) and 6. Lower mortality was observed in riparian buffers, but only the difference between riparian buffers and cutblock separators was significant (Table 3).

DISCUSSION

The structural damage that we observed at the edges of linear corridors, and in large forest patches, is common in many ecosystems (Laurance et al., 1998; Chen et al., 1992). In our study, the most important changes were increased mortality (especially in cutblock separators), and the resulting reduction in canopy cover in linear corridors in comparison with large forest patches (except for mortality) as well as with continuous forest. After edge creation, increased tree mortality leads to decreased tree density and canopy cover, and a greater deadwood abundance (Chen et al., 1992; Brosofske et al., 1997; Harper & Macdonald, 2002b; Harper et al., 2004). In the black spruce forest, greater tree mortality near clearcut edges is most likely the result of windthrow rather than exposure to environmental factors (Harper et al., 2004). This is evident in our study as an increased proportion and densities of logs, as well as similar or lower densities of snags near clearcut edges in comparison with the continuous forest. Some of these logs were probably snags at time of harvesting.

Our results showed that the distance of edge influence on forest structure extends 10-25 m from the clearcut edge into large forest remnants in black spruce forest. The smaller distance of edge influence of a maximum of 5 m detected by Harper et al. (2004) at clearcut edges in black spruce forest might be due to younger edges next to older forests. Older black spruce forests are more open with a discontinuous canopy cover and are therefore accustomed to a greater penetration of light and wind; after forest fragmentation, these forest stands seem relatively unaffected by an extensive edge influence (Harper et al., 2004). Changes following edge creation would have more impact in our denser forest stands with a more closed canopy, and at edges of older clearcuts where edge influence has had more time to develop. Nonetheless, our estimates of DEI in black spruce forest provide more evidence that edge influence is less extensive in boreal forests (Harper & Macdonald, 2002b; Harper et al., 2004), compared to other ecosystems (e.g. Chen et al., 1992; Laurance et al., 1998; Burton, 2002).

In answer to our first objective, we found that edge influence extended 10-25 m from the clearcut edges of large forest remnants, and across the entire width of approx. 60 m wide cutblock separators. Linear corridors are naturally long and thin, and therefore have potentially more exposed area to edge influence than square or round shape fragments (Saunders et al., 1991). Other studies in forested strips have also found that strips less than 50 m are entirely edge habitats (Brosofske et al., 1997; Hylander et al., 2002; Dignan & Bren, 2003). In our study, these edge habitats consist of fewer large live trees, reduced canopy cover and more logs compared to continuous forest and large forest patches. In the harvested black spruce forest, these narrow cutblock separators (< 60 m) are not wide enough to maintain a core area with structural conditions similar to those in continuous forest.

After the creation of clearcuts, one might expect that both types of corridors would exhibit a similar response. However, riparian buffer strips differ from cutblock separators due to the presence of a stream and an even greater exposed area from inherent edges next to the stream. With respect to our second objective, we found that edge influence was mitigated in riparian buffers. Edge influence of structural damage was either absent or did not extend into the center of riparian buffers. Resistance of trees in riparian buffers that were already adapted to the edge environment near a stream might result in low mortality near the pre-existing edge (Harper et al. in prep.). Although edge influence on snag density compared to continuous forest was not significant, snag density in riparian buffers did show a significant difference compared to cutblock separators. The relatively low densities of standing dead trees observed in riparian buffers in our study and in other studies could be the result of the resistance or adaptation of this ecosystem to frequent natural disturbances associated with the stream such as beaver damage.

In theory, forest linear corridors play an important ecological role in fragmented forest landscapes and are left following harvesting to reduce the visual impacts of logging activities (Machtans et al., 1996; Naiman et al., 1993). In order to provide habitat for plant and animal species associated with continuous forests, we recommend wider forested linear corridors. This recommendation is consistent with other studies that suggest wider buffers to ensure a sufficient continuous forested habitat to maintain and preserve forest interior species (Brosofske et al., 1997; Pearson & Manuwal, 2001; Hannon et al., 2002; Hylander et al., 2002; Dignan & Bren, 2003; Potvin & Bertrand, 2004). The minimum critical area that for a forest remnant to support quality habitat has been difficult to quantify (Castelle et al., 1994; Chen et al., 1996; Jorgensen et al., 2000; Hylander et al., 2002; Potvin & Bertrand, 2004). We show, however, that in the managed black spruce forest of northwest Quebec, forest strips < 60 m wide are not enough to preserve continuous forest habitat with structural characteristics that form the biological legacies of older forests. Our results also suggest that riparian corridors may be preferable since they reduce some of the edge influence on forest structure; however, conserving wider corridors of both types will ensure a variety of forest structural types on the landscape.

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Figure 1. Classes of decomposition for snags and logs sampled in this study.

Figure 2. Mean values ± 1 SE of forest structure along the clearcut edge-to-interior gradient in forest remnants: (A) Canopy cover, (B) Mortality, (C) Windthrow, (D) Total live tree density, (E) Total snag density, and (F) Total log density. Symbols represent large forest patches (triangles), cutblock separators (squares), and riparian buffer strips (circles). Filled symbols indicate values that are significantly different from continuous forest (see methods). Dashed lines represent mean values of continuous forest conditions. Standard errors for continuous forest were: % Canopy cover = 4.54; % Mortality = 0.03; % Windthrow = 0.007; Total live tree density = 139.14; Total snag density = 104.82; Total log density = 13.35.

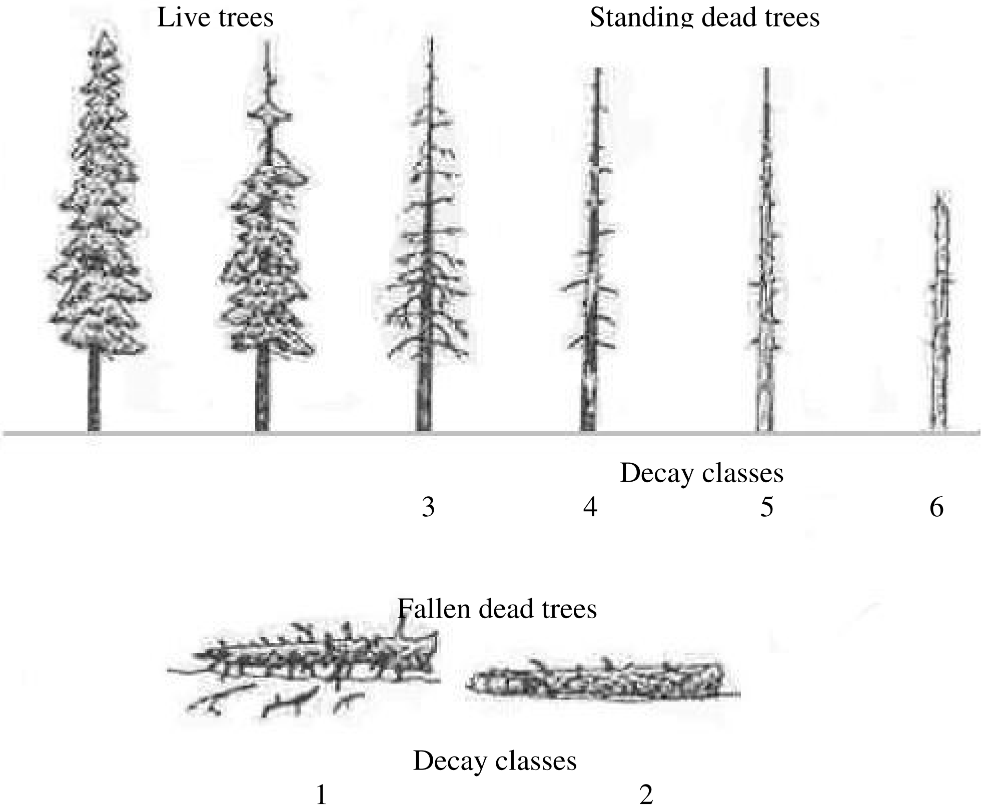

Figure 1. Mascarúa et al.

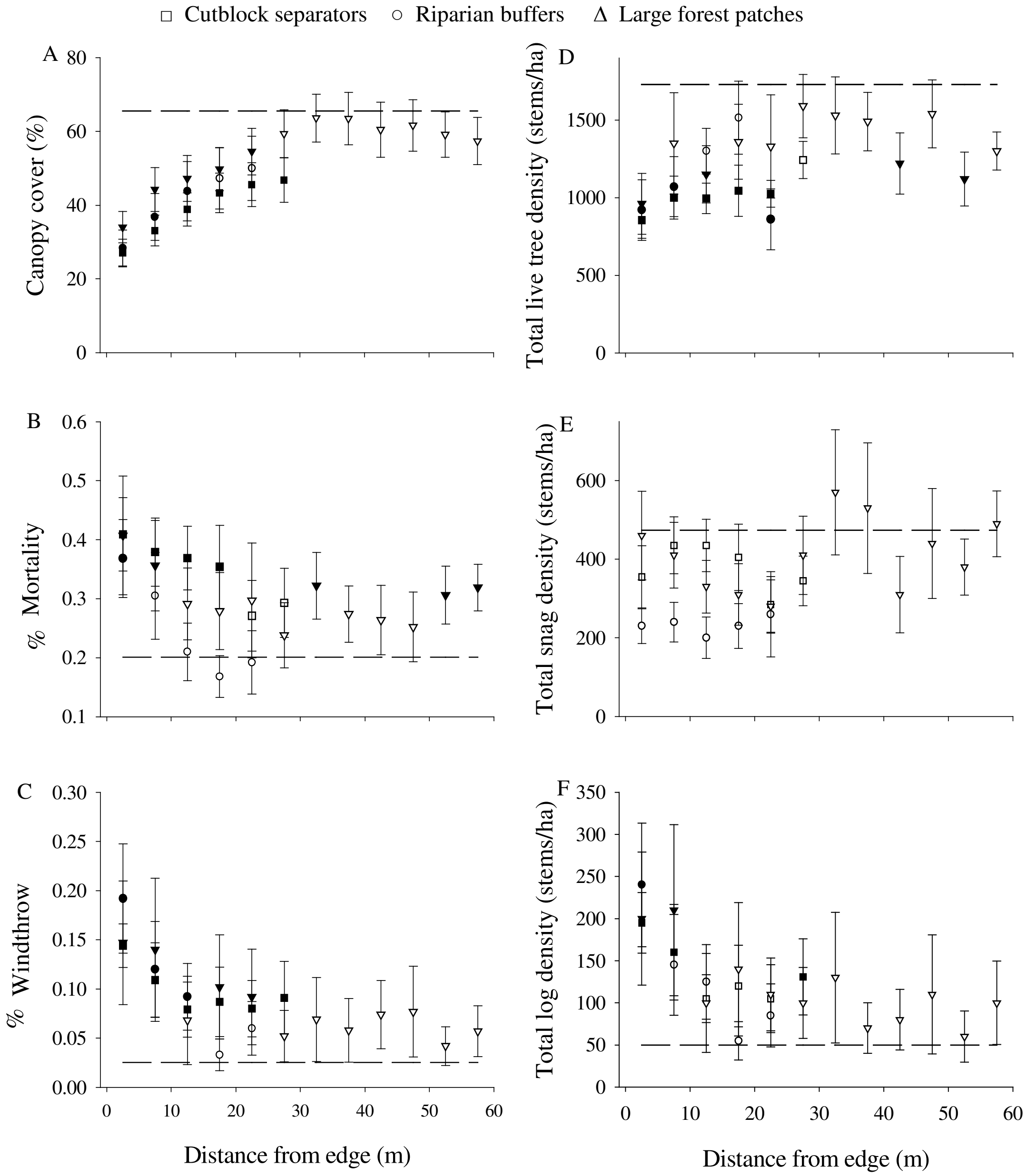

Figure 2. Mascarúa et al.

Table 1. Characteristics of the forest remnants and transects studied including edge age and orientation, stand age, tree density, basal area and species composition.

Transect	Edge age[a] (years)	Stand age[a] (years)	Edge orientation[b] (degrees)	Density[c] (stems/ha)	Basal area[c] (m^2/ha)		Tree spp. composition[c] (% of tree density)			
					Live	Dead	Picea	Pinus	Abies	Other
Large forest patches										
1	7	90	300	1808	29	6	97	1	0	2
2	7	90	320	2808	16	6	94	6	0	0
3	7	90	180	1508	26	11	98	0	0	2
4	7	120	110	2517	28	9	100	0	0	0
5	7	120	240	2042	11	18	88	0	12	0
6	8	70	270	1050	20	10	97	0	3	0
7	8	90	340	1233	27	9	98	0	2	0
8	8	120	310	2492	27	4	100	0	0	0
9	9	70	290	1867	16	7	92	1	1	6
10	9	120	190	1225	22	2	79	14	7	0
Cutblock separators										
1	5	70	150, 330	1808	21	7	99	0	1	0
2	5	90	110, 290	1717	15	11	72	0	26	2
3	5	120	150, 330	1675	16	8	100	0	0	0
4	5	120	120, 300	1942	25	7	89	9	1	1
5	5	120	120, 300	1242	8	16	100	0	0	0
6	5	120	170, 350	1442	17	7	83	0	15	2
7	5	120	100, 280	1077	11	10	97	2	1	0
8	8	120	120, 300	957	15	8	97	0	3	0
9	8	120	150, 330	2031	15	6	100	0	0	0
10	7-8	120	150, 330	1525	16	4	97	3	0	0
Riparian buffers										
1	7	90	30, 210	1325	15	8	91	8	0	1
2	7	90	0, 180	2260	36	6	96	2	0	2
3	7	120	130, 310	1315	13	9	99	0	0	1
4	9	90	20, 200	2193	27	6	95	3	0	2
5	10	120	70, 250	1158	18	3	97	1	2	0
6	10	120	170, 350	1138	13	7	98	1	0	1
7	10-11	90	130, 310	1309	12	13	89	7	0	4
8	10-11	120	120, 300	1283	19	9	94	3	1	2
9	11	90	30, 210	2188	17	4	95	4	0	1
10	11	90	20, 200	1109	22	1	82	5	0	13
Continuous forest										
1		70		3167	38	10	69	8	2	21
2		70		4667	32	8	98	0	0	2
3		90		2633	28	6	100	0	0	0
4		90		2933	33	10	100	0	0	0
5		90		900	19	4	100	0	0	0
7		90		1800	16	6	71	0	23	6
6		120		2033	32	3	64	0	27	9
8		120		1133	16	2	100	0	0	0
9		120		1333	17	3	87	0	8	5
10		120		1933	18	4	96	0	4	0

[a] Data are from ecoforestry maps (1:20 000, Ministère des Ressources Naturelles du Québec).

[b] Orientation was measured looking into the forest from the edge. The orientations for both edges of the corridors are given.

[c] Mean of all plots (5 x 20 m) per transect per treatment.

Table 2. Mean values ± 1 SE of trees of different sizes, and snags and logs in different decay stages at different distances from the clearcut edge in large forest patches (n = 10), cutblock separators (n = 20), and riparian buffers (n = 20), and in continuous forest (n = 10).

Distance from	Live tree density (stems/ha)				Snag density (stems/ha)			Log density (stems/ha)	
edge (m)	Small	Medium	Large	Very large	Class 4	Class 5	Class 6	Class 1	Class 2
Large forest patches									
0-5	310 ± 99	360 ± 93	**180 ± 66**	110 ± 38	120 ± 47	140 ± 54	200 ± 60	40 ± 16	160 ± 76
5-10	480 ± 190	450 ± 169	**230 ± 62**	190 ± 48	150 ± 50	130 ± 45	130 ± 33	50 ± 34	160 ± 96
10-15	400 ± 161	320 ± 104	250 ± 67	180 ± 44	50 ± 22	100 ± 33	180 ± 65	0 ± 0	90 ± 59
15-20	350 ± 119	420 ± 155	440 ± 102	150 ± 60	90 ± 50	140 ± 48	**80 ± 20**	10 ± 10	130 ± 80
20-25	370 ± 109	510 ± 192	350 ± 101	100 ± 39	50 ± 22	80 ± 36	150 ± 40	30 ± 21	80 ± 39
25-30	320 ± 90	570 ± 148	500 ± 97	200 ± 67	140 ± 45	110 ± 38	160 ± 56	30 ± 15	70 ± 42
30-35	450 ± 179	520 ± 145	390 ± 89	170 ± 37	140 ± 83	180 ± 70	250 ± 65	0 ± 0	130 ± 78
35-40	360 ± 92	600 ± 129	360 ± 60	170 ± 65	180 ± 105	130 ± 37	220 ± 81	10 ± 10	60 ± 31
40-45	**280 ± 96**	380 ± 126	430 ± 108	130 ± 45	50 ± 27	140 ± 69	120 ± 66	20 ± 13	60 ± 34
45-50	**220 ± 57**	670 ± 187	490 ± 99	160 ± 37	40 ± 16	140 ± 70	260 ± 90	20 ± 20	90 ± 71
50-55	**290 ± 62**	450 ± 128	300 ± 76	80 ± 49	60 ± 34	110 ± 41	210 ± 72	40 ± 22	20 ± 13
55-60	330 ± 83	500 ± 125	310 ± 85	160 ± 67	90 ± 28	210 ± 35	190 ± 59	10 ± 10	90 ± 41
Cutblock separators									
0-5	380 ± 96	**230 ± 49**	**165 ± 25**	80 ± 29	155 ± 31	95 ± 29	105 ± 28	**45 ± 22**	**145 ± 27**
5-10	375 ± 94	330 ± 66	**210 ± 32**	85 ± 27	155 ± 39	95 ± 25	185 ± 35	20 ± 11	**140 ± 53**
10-15	270 ± 63	355 ± 65	290 ± 48	80 ± 24	135 ± 24	115 ± 33	185 ± 34	15 ± 8	90 ± 26
15-20	290 ± 60	335 ± 88	310 ± 65	110 ± 32	80 ± 20	95 ± 21	230 ± 62	25 ± 11	95 ± 40
20-25	275 ± 61	360 ± 55	320 ± 46	70 ± 23	70 ± 19	85 ± 26	130 ± 28	25 ± 8	80 ± 34
25-30	410 ± 68	485 ± 80	390 ± 49	135 ± 36	80 ± 22	85 ± 28	245 ± 29	13 ± 7	**117 ± 40**
Riparian buffers									
0-5	390 ± 158	**275 ± 67**	**175 ± 47**	80 ± 30	45 ± 17	75 ± 23	110 ± 28	**65 ± 28**	**175 ± 50**
5-10	385 ± 111	325 ± 97	260 ± 74	100 ± 23	70 ± 23	90 ± 28	75 ± 23	30 ± 15	110 ± 57
10-15	310 ± 64	435 ± 74	385 ± 66	170 ± 43	30 ± 13	95 ± 29	75 ± 28	**40 ± 12**	85 ± 43
15-20	485 ± 84	435 ± 105	375 ± 61	220 ± 48	60 ± 17	65 ± 20	90 ± 22	5 ± 5	50± 24
20-25	290 ± 90	290 ± 89	**195 ± 64**	85 ± 27	65 ± 27	75 ± 36	80 ± 30	25 ± 13	60 ± 26
Continuous forest									
	533 ± 75	673 ± 109	407 ± 50	117 ± 24	90 ± 23	120 ± 34	260 ± 67	7 ± 5	43 ± 12

Notes: Values that were significantly different from continuous forest conditions are in bold. Data from the two clearcut edges were combined for cutblock separators and riparian buffers.

Table 3. A comparison of forest structure at clearcut edges in different types of forest remnants including means ± 1 SE for the first 25 m and distance of edge influence (DEI), and a summary of the results of the analysis of variance (F- and p-values) for the treatment effects. Superscripts are the results of post-hoc Tukey tests, where different letters indicate significant differences among treatments.

	Large forest patches		Cutblock separators		Riparian buffers			
	Mean ± SE	DEI (m)	Mean ± SE	DEI (m)	Mean ± SE	DEI (m)	F	p
Canopy cover (%)*	46.0 ± 2.66	0-25	37.6 ± 1.77	0–30 (All)	40.4 ± 2.42	0-15	2.99	0.052
Mortality (%)	0.326 ± 0.04^{ab}	0-10, 50-60	0.356 ± 0.03^{a}	0-20	0.249 ± 0.03^{b}	0-5	3.43	0.035
Windthrow (%)	0.110 ± 0.02	0-10, 15-25	0.100 ± 0.01	0-30 (All)	0.100 ± 0.02	0-15	0.09	0.917
Live tree density (stems/ha)								
Total	1230.0 ± 115.29	ns	984.0 ± 54.70	0-25	1133.0 ± 89.58	0-10	2.28	0.104
Small trees	382.0 ± 60.52	40-55	318.0 ± 41.69	ns	372.0 ± 53.65	ns	0.41	0.668
Medium trees	412.0 ± 63.93	ns	322.0 ± 32.11	ns	352.0 ± 42.76	ns	0.86	0.425
Large trees	290.0 ± 37.50	0-10	259.0 ± 19.78	0-10	278.0 ± 36.37	ns	0.25	0.780
Very large trees	146.0 ± 20.64^{b}	ns	85.0 ± 12.31^{a}	ns	131.0 ± 17.43^{ab}	ns	3.55	0.032
Snag density (stems/ha)								
Total	358.0 ± 37.04^{a}	ns	383.0 ± 27.64^{a}	ns	222.0 ± 24.56^{b}	ns	9.01	0.000
Decay class 4	92.0 ± 18.26^{ab}	ns	119.0 ± 13.92^{a}	ns	54.0 ± 9.13^{b}	ns	5.37	0.006
Decay class 5	118.0 ± 19.10	ns	97.0 ± 14.67	ns	80.0 ± 13.55	ns	1.34	0.266
Decay class 6	148.0 ± 20.85^{a}	ns	167.0 ± 20.53^{a}	ns	86.0 ± 12.38^{b}	ns	5.31	0.006
Log density (stems/ha)								
Total	150.0 ± 32.86	0-10	137.0 ± 17.33	0-10	127.0 ± 21.12	ns	0.17	0.842
Decay class 1	26.0 ± 8.99	ns	26.0 ± 5.24	ns	33.0 ± 7.14	ns	0.35	0.705
Decay class 2	124.0 ± 31.50	ns	110.0 ± 15.07	0-10	96.9 ± 18.45	ns	0.42	0.655

* Arcsine transformed (Arcsine $x^{0.5}$) for the ANOVA analysis.

Interaction of edge effects in linear corridors of black spruce boreal forests

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ABSTRACT

In managed black spruce boreal forests, linear corridors are often the main remnants of continuous forests left on the landscape after harvesting. Forest structure in linear corridors might be influenced by the presence of two or more edges that occur in close proximity. Models of edge influence were used to evaluate forest structure responses in cutblock separators and riparian buffers to the presence of two close edges. The models evaluate the presence of either: 1) simple edge influence (no edge interaction), or 2) combined edge influence (edge interaction). All trees, snags and logs ≥ 5cm dbh, as well as canopy cover, were inventoried in rectangular plots (100 m^2) along transects perpendicular to the edge. The magnitude of edge influence (*MEI*), a function of the difference in the mean value of a response variable near the edge compared with continuous forest conditions, was used as the response variable in the models. Data from forest remnants presenting one edge were used to construct the models. For all variables, except live tree density, interactions of two close edges in the linear corridors were possible, according to the models. Predictions from the two alternative models were compared with empirical data from the linear corridors. For canopy cover, there was evidence of edge interaction in cutblock separators and riparian buffers. For snag and log density, no edge interaction in cutblock separators was detected. In both types of linear corridors, lower density of live trees and canopy cover and greater density of dead trees near clearcut edges were detected compared to the continuous forest conditions. Greater forest damage in 60 m wide corridors was predicted due to the combination of edge effects. Therefore, to avoid the interaction of two close edges, wider linear corridors should be left in order to provide sufficient interior habitat in linear corridors for the organisms associated with continuous forest conditions.

Key words: edge influence; magnitude of edge influence; forest remnants; linear habitats; timber harvesting.

INTRODUCTION

In managed forests, linear habitats such as cutblock separators and riparian buffers are left to reduce the visual impacts of forest harvesting or to protect water quality of aquatic systems. Additionally, although not specifically designed for that purpose, linear corridors may play an important role in the maintenance of biodiversity. In the resulting fragmented landscape, they may also function as dispersal routes, movement corridors, habitat for many forest species and improve landscape connectivity (Saunders et al. 1991; Lindenmayer and Nix 1993; Naiman et al. 1993; Machtans et al. 1996; Beier and Noss 1998; Hannon and Schmiegelow 2002).

In linear habitats, clearcut edges are important features that occur in close proximity. Due to edge proximity, the forest vegetation of these linear habitats might become more exposed to changes in the environmental factors (e.g. wind, humidity and temperature) following edge creation than those that occur at one edge (Saunders et al. 1991; Chen et al. 1992; Murcia 1995; Cadenasso et al. 1997; Dignan and Bren 2003). Following forest harvesting, important changes in the forest structure and dynamics of forest remnants may depend on the interaction of the close created edges (Malcolm 1994; Harper et al. unpublished).

The interaction among edges in forest remnants has been documented by only a few studies (Malcolm 1994; Fernández et al. 2002; Harper et al., unpublished). The influence of more than one edge has been conceptualized as either: (1) the total influence in a patch that incorporates the additive nature of edge effects along the border in relation to the distance from the edge (Malcolm 1994; Fernández et al. 2002); or (2) different possible interactions of edge effects (Harper et al. unpublished).

The analysis of the influence and interaction of different types of edges in linear corridors is an important issue, since these linear remnants are often the only unharvested forests in quite large regions of harvested landscapes. Also, it is important to demonstrate if the forest structure has been affected by edge influence or if linear corridors in the harvested boreal forest present the appropriate structural characteristics to act as habitat or movement corridors for the flora and fauna associated with the interior conditions of continuous forests.

The influence of two close edges on the forest structure of linear habitats in managed black spruce boreal forests was evaluated in order to characterize the interaction of edge effects. Models of edge influence developed by Harper et al. (unpublished) were used to determine the nature of the edge interaction on the forest structure of cut-block separators and riparian buffer strips. A combination of edge effects for light penetration and windthrow risk from two edges in close proximity was expected; such additive effects might represent important changes for the forest structure of the linear corridors evaluated.

METHODS

Study area

Study sites were located in the black spruce boreal forest in the Abitibi region in northwestern Quebec (Lebel sur Quévillon 49° 00’ - 49° 45’ N, 76° 00’ - 77° 30’W). The study area is found in the black spruce - feather moss bioclimatic zone of the northern Clay Belt of Ontario and Quebec (Saucier et al. 1998). Glaciolacustral deposits with a generally flat topography characterize the zone. Soils are predominantly organic, with clay and till deposits (Gauthier et al. 2000). The region has a boreal climate with mean annual temperatures between 0 and -2.5°C and mean annual precipitations between 600 mm and 1000 mm (Robitaille and Saucier 1998).

Boreal forest dynamics have been associated with natural disturbances of diverse intensities and frequencies (Grondin 1996). Human disturbances like timber harvesting have been performed in the area since the 1970s by Abitibi Consolidated and Domtar forestry companies. In the study area, the landscape matrix is dominated by clearcuts in which small forest remnants and linear corridors are embedded. Since 1996, clearcut areas less than 100 ha are separated by linear forest remnants known as cutblock separators of 60 m width minimum, and cutblock separators of 100 m width separate clearcut areas between 100 and 150 ha. Riparian buffers are left on all sides of streams, rivers or lakes, with a minimum width of 20 m on each side.

Forest stand selection was based on the following criteria: (1) forest stands had at least 80% dominance of Black spruce (*Picea mariana*), were 12m or more in height and were between 70 and 120 years old (Ministère des Ressources Naturalles du Québec. Cartes écoforestières 1/20000: 32 C16, 32 F01, 32 F06, 32 F16, 32 K01, 32 K02, 33 F01, 34 F01; Direction des inventaires forestieres); and (2) clearcuts next to forest remnants were between 5 and 10 years old. In all forest stands *P. mariana* was found in co-dominance with *Pinus banksiana* and *Abies balsamea* (L.) Mill. with sparsely distributed trees of *Betula papyrifera* Marsh., *Populus tremuloides* Michx., and *Larix laricina* (Du Roi) K. Koch.

Sampling design

Forest structure was sampled for four treatments: a) Cutblock separators aprox. 60 m wide; b) Riparian buffers, 45-70 m wide and with a minimum width of 20 m on both sides of streams; c) Large forest patches adjacent to a single forest edge (at least 300 m wide); and continuous forest conditions 100 m away from any boundary or clearcut area, located near the large forest patches (Fig. 1). In ten independent sites for each treatment, one transect per treatment was established to evaluate the forest structure. For cutblock separators, riparian buffers and forest-clearcut boundaries, transects were established perpendicular to the forest edge (considered as the limit of the uncut mature trees) and extended into the forest remnants. Transect length was 60 m in cutblock buffers and at large forest patches; for riparian buffers, only data within 20 m from the edge were used, due to the variability of the corridor width. Continuous forest conditions were sampled with transects 100 m long.

Vegetation data were collected from 5 x 20 m (100 m^2) plots, with their long axes parallel to the forest edge. Plots were located contiguously every 5 m along transects in the forest remnants (cutblock separators, riparian buffers, and large forest patches). On the continuous forest transects, three plots (5 x 20 m) were located 50 m apart from each other.

Data collected

Sampling was conducted in summer, 2003. At each site, all live trees and snags ≥ 5 cm dbh (diameter at breast height = 1.3 m) within each 5 x 20 m plot were inventoried. We also sampled fallen trees (logs) with stems originating within the sample plot, which was easy to detect in our study area. We only considered logs in decay stages 1 and 2 (according to Maser et al. 1979) because the objective of our study was to record forest damage due to recent harvesting. At the center of each plot, canopy cover was measured using a convex spherical densiometer.

Models of edge effects interaction

To predict the possible interaction of edge influence for a response variable at a location where two edges are in close proximity, the models of edge influence conceptualized and developed by Harper et al. (unpublished) were used. For this study we used models for two types of edge influence: (1) no edge interaction, edge influence is restricted to the strongest effect from only one edge, either edge of the forest strip that has the strongest influence; and (2) combination of edge influence, both edges in the linear corridor exert an edge influence.

To quantify edge influence we used the metric Magnitude of the Edge Influence (*MEI*) for the response variables evaluated. *MEI*, considered as a measure of the strength of edge influence (Harper et al. 2005), is a function of the proportional increase or decrease (due to edge influence) in a response variable average value at a given distance from edge, compared to the reference continuous forest conditions.

MEI is calculated according to the following equation:

$$MEI = (\bar{x}_d - \bar{x}_i) / (\bar{x}_d + \bar{x}_i)$$

Where, $\bar{x}_d$ = mean value of a response variable at distance *d* from the clearcut edge, $\bar{x}_i$ = mean value of the same response variable in the continuous forest conditions (three plots at 100 m from the clearcut edge).

MEI standardizes edge response so that it can vary between –1 (negative edge influence, lower values at the edge than in continuous forest conditions) and +1 (positive edge influence, greater values at the edge than in continuous forest conditions); and equals 0 when there is no edge influence (Harper et al. unpublished).

In each forest treatment, *MEI* was calculated for every sampled distance from the edge for live tree density, snag density, log density, and canopy cover. For cutblock separators and riparian buffer strips, distances from both edges sampled were combined, to obtain the respective *MEI* at each distance from the clearcut edge.

We developed curves of *MEI* from the clearcut edge to the interior of the forest remnant using *MEI* with exponential equations for each sampled distance of the large forest patches. Then, the resulted *MEI* values were applied in Models 1 and 2 to predict *MEI*, within 25 m from the clearcut edge, for linear corridors.

Model of no edge interaction: for a given distance, *MEI* is equal to the maximum absolute value of *MEI* from whichever edge:

$M^{e1,e2}$ = Max [M^{e1} or M^{e2}], where

$M^{e1,e2}$ = *MEI* at distance $d1$ from the first edge and distance $d2$ from the second edge,

M^{e1} = *MEI* at distance $d1$ from the first edge (e_1),

M^{e2} = *MEI* at distance $d2$ from the second edge (e_2).

Model of edge influence combination: for each distance the response is greater than the influence from only one edge, because influence of both edges (e_1 and e_2) is combined:

$M^{e1,e2} = (M^{e1} + M^{e2}) / (1 + M^{e1} \times M^{e2})$, where,

$M^{e1,e2}$ = *MEI* at distance $d1$ from the first edge and distance $d2$ from the second edge,

M^{e1} = *MEI* at distance $d1$ from the first edge (e_1),

M^{e2} = *MEI* at distance $d2$ from the second edge (e_2).

The two models were constructed with the *MEI* predicted values for each response variable. Then the predicted values were compared with the *MEI* values obtained from empirical data from cutblock separators and riparian buffers.

RESULTS

Model predictions

The models used in this study predicted negative edge influence (*MEI* < 0) for all variables, except for log density, in cutblock separators and riparian buffers (Fig. 2). For all variables, the greatest absolute values of *MEI* were always predicted near the edges compared to the middle of the linear corridors. The edge combination model generally predicted greater absolute values of *MEI* than the no edge interaction model for all variables. However, for live tree density, no interaction of edge influence was predicted because both models showed identical trends. For this last variable, the similarity of trends between both models was observed because the distances of edge influence from both edges do not overlap. The greatest edge influence (absolute values of *MEI*) was predicted for log density by both models all across the corridors width, compared to other variables; while the lowest absolute values of *MEI* were predicted for live tree densities (Fig. 2).

Empirical results

In cutblock separators and riparian buffers, edge influence was negative (*MEI* < 0) for all variables except log density throughout cutblock separators and riparian buffers and live tree density > 5 m from the clearcut edges of riparian buffers.

Both types of linear corridors showed similar trends as model predictions for all response variables: greater edge influence near the clearcut edges, as compared to elsewhere in the corridors (Fig. 2). Only canopy cover and live tree density showed continuous trends from greater absolute values of *MEI* near clearcut edges to lower absolute *MEI* values in the middle of the linear corridors; except that live tree density in riparian buffers switched from negative to positive *MEI* values (Fig. 2a, b). For snags and logs, non-monotonic trends were observed in both types of linear corridors: absolute values of *MEI* were high near edges and in the middle of the corridors, but lower at 10-15 m from the clearcut edge (Fig. 2c, d).

Greater densities of live trees as well as a greater canopy cover amounts were observed all across riparian buffers than in cutblock separators (Fig. 2). Also riparian buffers showed greater log density and a lower snag density near edges (0-15 m), compared to the values observed in cutblock separators (Fig. 2).

For canopy cover, empirical absolute values of *MEI* across both types of corridors were greater than both model predictions (Fig. 2a). For live tree density, cutblock separators showed greater *MEI* absolute values than both model predictions (Fig. 2b). In riparian buffers, greater absolute values of *MEI* for snag density were registered near the clearcut edges (< 15 m) than both model predictions. In cutblock separators absolute values of *MEI* for snag density were lower than the combination model predictions all across the corridor and also lower to the no interaction model predictions between 5 m - 20 m from clearcut edge (Fig. 2c). For the log density lower absolute values of *MEI* than the edge combination model predictions were observed across both linear corridors. When comparing absolute values of *MEI* for log densities with the no edge interaction model predictions, greater values were observed near edges (< 15 m) in riparian buffers, and at the edge (0-5 m) and in the middle (20-30 m) in cutblock separators (Fig. 2d).

DISCUSSION

The magnitude of edge influence (*MEI*) in linear corridors might be stronger if edge effects are combined; therefore, the forest structure of linear corridors is likely to become highly affected by new environmental conditions, such as an increase in wind activity, humidity and air temperature, that were not present before the creation of two close edges. In our study, the combination of edge effects in cutblock separators and riparian buffers was predicted for canopy cover as well as for the density of snags and logs. For live trees both models showed very similar trends, therefore it was not possible to predict an edge interaction. One possibility of the similarity of models trends for this variable is that the distances of edge influence did not overlap within the width of the corridors when constructing the models. Another possibility could be the similar densities of live trees between large forest patches and the continuous forest conditions, which resulted in very low *MEI* values. Therefore, when constructing the models no differences were observed in the models predictions.

The interaction of edge influence across cutblock separators and riparian buffer strips was observed as a reduction in the canopy cover in comparison with the edge interaction model predictions. In riparian buffer strips the decrease in canopy cover at 20-25 m could suggest an additional edge effect of the “natural old” edge, as result of the stream presence in the middle of the buffer, but that has a weaker influence than the new created clearcut edge. All across riparian buffer strips, the greater amount of canopy cover was due to the greater densities of live trees in comparison with the cutblock separators (Chapter 2). The high density of live trees in the riparian buffer strips might be the result of the lack of tree density reduction right at the edge due to the resistance of riparian buffers to the creation of a new edge. This resistance might be developed by the forest trees due to the presence of an older edge, which existed before the creation of the new clearcut edge, rather than an interaction of two close edges (Harper et al. unpublished). For the density of live trees, greater absolute values of the *MEI* than both model predictions were observed only in the cutblock separators, suggesting an interaction of edge effects that results in a greater damage of the forest structure for this corridor type.

In riparian buffers, a combination of edge effects was observed for the density of snags only at the nearest distances from the clearcut edge. In the middle of the riparian buffers (15–25 m from clearcut edge) the presence of an old and natural edge probably counteracts the clearcut edge interaction (Harper et al, unpublished). The lower densities of snags near the clearcut edge in riparian buffer strips than the predictions of the edge interaction model, might be due to an increase in snags densities that have fallen from wind, which is evident as a greater log density (Fig. 2). In cutblock separators, edge influence was observed as an increase in snag density at the edge; however, the interaction of edge effects was not observed, since the edge combination model predicted greater densities of snags than those observed.

We found no evidence of a combination of edge influence for the density of fallen trees in either type of linear corridor. However, greater log density was observed in riparian buffer strips than in cutblock separators near the clearcut edge. The high densities of fallen trees near the clearcut edges in riparian buffers might suggest a greater susceptibility to forest damage, as a result of windthrow (Ruel 2000; Ruel et al. 2001; Acker et al. 2003) than stream floodings or beaver activity (Malanson and Kupfer 1993). Even if the greatest edge influence was observed near the clearcut edges for both types of linear habitats, the non-monotonic trends observed for the densities of snags and logs were due to the high variability of densities observed in the forested strips (Chapter 2).

We had predicted greater forest damage in 60 m wide linear corridors due to the combination of the influence of two close edges. We found evidence of a combination of edge effects in linear corridors as a greater opening of the canopy. No edge influence combination was detected for the density of snags and logs; except for snags at the nearest distances from the clearcut edge in riparian buffer strips.

Due to the close clearcut edges proximity, we found that linear corridors consist principally of edge habitat. However, we observed that cutblock separators were more affected by the creation of two close edges than riparian buffer strips. In riparian buffer strips, forest structure showed an adaptation or resistance to the influence of a new created edge. This resistance to edge effects might be provided by the presence of a stream in the middle of riparian buffers which has an inherent edge that is older than the clearcut edges surrounding the corridor (Harper et al. unpublished). Our results suggest that riparian buffers may provide more stable forest structure than cutblock separators, because of their resistance to the interaction of edge effects. This could in turn offer forest conditions that are closer to continuous forest conditions that have become highly limited in even-aged managed forests to the plant and animal species associated with this type of forests. In the case of cutblock separators, wider corridors are required in order to diminish the combination of edge effects.

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List of figures

Figure 1. Sampling design for assessing edge influence in forest remnants: a) Cutblock separators, b) Riparian buffer strips, c) Forest-clearcut boundaries, and d) Continuous forest conditions.

Figure 2. Models predictions and empirical results for the possible interaction of edge influence in linear corridors for: a) canopy cover, b) live tree density, c) snag density, and d) log density. Symbols represent average of *MEI* at each distance from clearcut edge for Cutblock separators (solid squares) and Riparian buffer strips (open circles). Lines represent model predictions of the no edge interaction model (solid line) and edge influence combination model (dotted line).

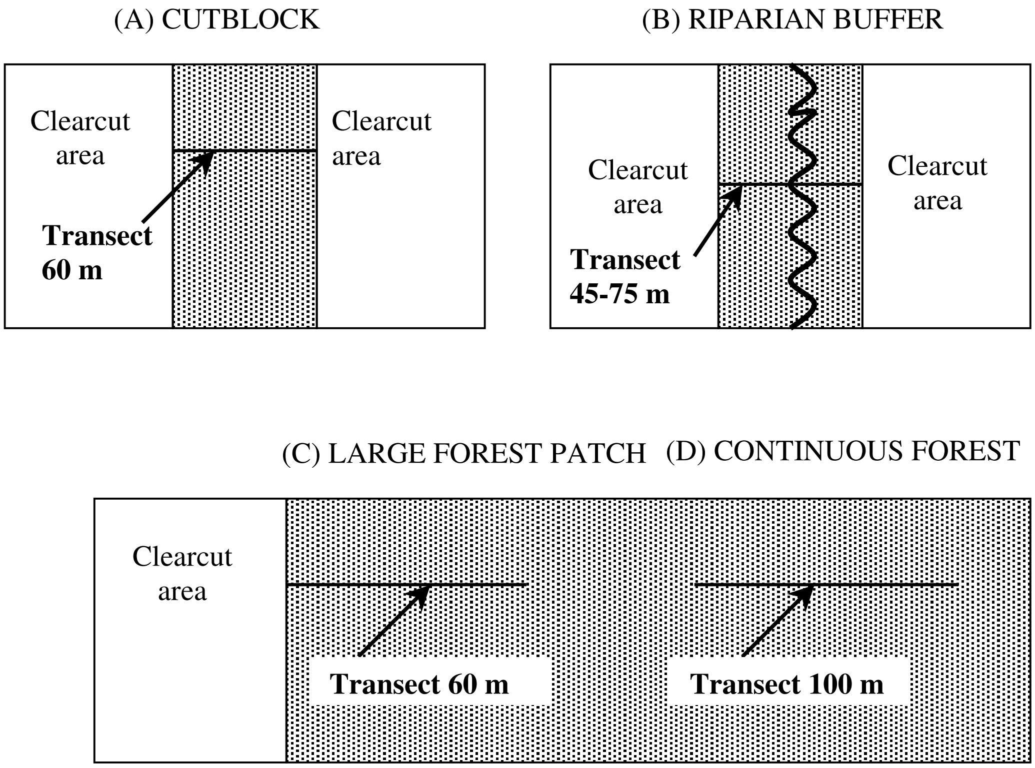

Figure 1. Mascarúa et al.

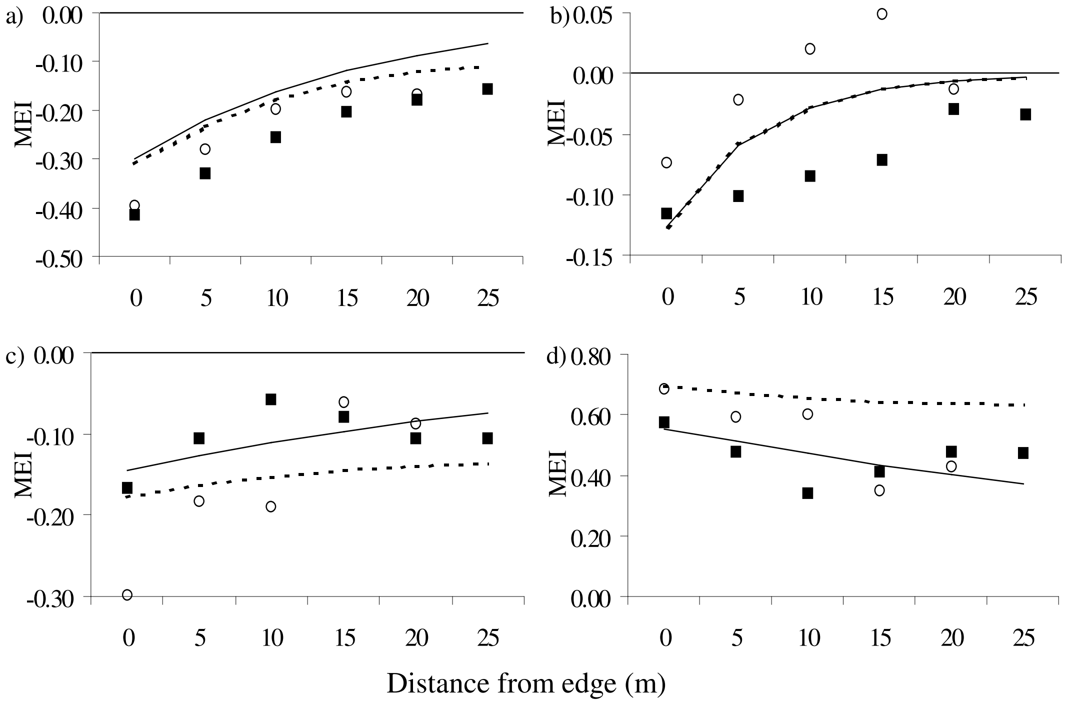

Figure 2. Mascarúa et al.

CONCLUSION GÉNÉRALE

Dans la forêt boréale aménagée, les séparateurs de coupe et les bandes riverains sont souvent les seules types habitat d'origine laissées après la récolte forestière. Actuellement, les pratiques de rétention n'ont pas été développées dans l'esprit de préserver et de conserver des legs biologiques des forêts d'origine, pour maintenir dans les paysages aménagés des conditions qui s'apparentent à celles qui résultent de perturbations naturelles (Bunnell et al. 1999; Bergeron et al. 2002). Ces habitats linéaires ont davantage été laissés à des fins de maintien de la qualité de l'eau ou d'écrans visuels. La présente étude montre que ces habitats présentent quelques attributs structurels similaires aux conditions des forêts continues. Ce sont les bandes riveraines le type d'habitat résiduelle qui présentent une plus faible variabilité dans la structure forestière en comparaison avec les séparateurs secs (Chapitre 1). Par contre, ces habitats linéaires voient d'autre parte leurs caractéristiques structurales affectées par les effets de lisières associés à la fragmentation du couvert forestier d'origine. Ce dans le cas des séparateurs secs, où l'influence des bordures est étendu sur une aire plus grande (Chapitre 2). Aussi, l'interaction des effets des bordures dans des corridors linéaires pourrait affecter significativement son structure forestière et influencer son rôle écologique (Chapitre 3).

2.1 Structure forestière des forêts résiduelles

L'épinette noire, *Picea marianna*, était l'espèce d'arbre dominante dans tous les peuplements forestiers que nous avons étudié; la présence du pin gris, *Pinus banksiana*, du peuplier faux-tremble, *Populus tremuloides*, et du sapin baumier, *Abies balsamea* étant marginale. Nos peuplements forestiers d'étude avaient un recouvrement de la 'canopée' relativement continu, haut (> de 17 m), avec moins de trouées que ce que Harper et al. (2003) ont décrit pour les très vieux peuplements dans cette portion de la forêt boréale de l'Est du Canada. Toutes ces caractéristiques indiquent que la forêt d'origine correspondait à une forêt de deuxième cohorte (*sensu* Bergeron et al. 1999), soit une forêt qui correspond à l'étape intermédiaire de développement vers le stade de vielle forêt où l'ouverture du couvert forestier et en corollaire le nombre de trouées sont davantage importants (Harper et al. 2003).

Les conditions forestières continues ont présenté une densité de tiges plus grande et une surface terrière plus grande que les deux types d'habitats linéaires et l'interface forêt-coupe. Ces différences dépendent donc du degré de perturbation induit par la coupe forestières au pourtour de la forêt d'origine. Bien que la densité des tiges vivantes soit plus élevée dans les forêts continues que dans les interfaces forêt-coupe, les bandes riveraines et les séparateurs secs de coupe, la distribution des classes de diamètre des arbres vivants dans tous les traitements ne montre pas des différences substantielles, indiquant ainsi que les habitats résiduels maintiennent au moins certaines caractéristiques structurales des forêts d'origine.

Il est souvent rapporté dans la littérature que les forêts enclavées dans une matrice des milieux ouverts sont plus affectées par des conditions météorologiques adverses (exposition accrue aux vents, assèchement en raison du changement des conditions locales d'humidité, entre autres). Cela se manifeste souvent par une mortalité accrue des arbres et par conséquent par un recrutement plus élevé d'arbres morts sur pied dans ces habitats par rapport à des peuplements enclavées dans une matrice forestière (Chen et al. 1992; Young and Mitchell 1994; Ferreira and Laurance 1997). Nos résultats montrent également une mortalité plus forte des arbres, non pas pour les tiges mortes sur pied mais plutôt sous la forme de tiges renversées et couchées au sol. Ruel (2000) obtient des résultats similaires pour des forêts de l'Est du Québec et conclut que la vélocité accrue du vent aux interfaces forêt résiduelle-parterres de coupe ainsi que pour des bandes riveraines, expose davantage les arbres aux risques de chablis.

Par conséquent la foresterie extensive pratiquée dans la forêt d'épinette noire du Québec crée des habitats linéaires dont la structure forestière, sans atteindre de façon optimale les conditions des forêts continues, comporte encore des conditions structurelles d'habitats qui s'en rapprochent. Ces habitats linéaires peuvent donc jouer un rôle fonctionnel dans le maintient de la diversité biologique et structurelle dont la flore et la faune associées aux vieilles forêts ont besoin.

2.2 Effets de bordures sur la structure des forêts résiduelles

En raison de la superficie étendue des aires de récolte en forêt boréale, la structure des forêts résiduelles, particulièrement pour les habitats linéaires, est fortement exposée aux effets de bordure. Dans notre étude, nos résultats indiquent que l'altération du couvert forestier observés près des bordures a été associée à une mortalité accrue des arbres et peut être aussi associée à une exposition plus grande aux facteurs environnementaux locaux adverses. Cette mortalité se reflète davantage toutefois par une densité plus forte d'arbres au sol que d'arbres encore sur pied. Les arbres couchés sont à la fois constitués des tiges préalablement mortes (stade 2 de décomposition au sol) et vivantes qui après la coupe on été renversés par le vent. La densité plus grande d'arbres morts tombés a été aussi détectée près de bordure en comparaison à des conditions forestières continues dans autres études (Chen et al. 1992; Harper and Macdonald 2002b; Harper et al. 2004).

Par ailleurs avec notre étude, nous n'avons pas détecté une plus grande densité d'arbres morts sur pied (chicots) près des bordures de nos habitats résiduels comparativement aux conditions forestières continues. Cependant, il y avait une densité plus grande d'arbres tombés près des bordures des forêts résiduelles, et ce particulièrement quant au nombre élevé de tiges dans la classe 2 de décomposition. Ces dernières étaient probablement déjà au moment de la coupe et ils ont été ainsi affectés par des vitesses de vent plus hautes après la création des bordures, réduisant ainsi leur temps de résidence comme arbres morts sur pied. La densité plus grande d'arbres morts tombés a également été observée près des bordures en comparaison à des conditions forestières continues.

Nos résultats indiquent que la distance d'influence de bordure s'est étendue à 30 m de la lisière dans les forêts résiduelles. Étant donné la largeur des habitats linéaires, l'influence de bordure s'étend sur l'ensemble de ces habitats. Les attributs structuraux associés aux forêts continues sont donc, par conséquent, altérés sur l'ensemble de la superficie de ces habitats résiduels. D'autres études dans des bandes boisées ont aussi constaté que l'on peut entièrement considérer des bandes moins de 50 m comme des habitats de bordure (Brosofske et al. 1997; Hylander et al. 2002; Dignan and Bren 2003). En général, nous avons observé une diminution dans la densité d'arbres vivants et une augmentation de la densité d'arbres morts particulièrement d'arbres tombés au sol dans les séparateurs de coupe et les bandes riverains. Cela se traduit par une réduction du recouvrement de la canopée dans les deux types de habitats linéaires. Donc, dans la forêt d'épinette noire coupée, ces habitats linéaires (< 60 m) ne sont pas assez larges pour mitiger les effets de bordures et ainsi préserver des conditions structurelles identiques à celles observées dans les grands massifs des forestiers continues.

2.3 Interaction des effets de bordures dans les habitats linéaires

Le troisième chapitre montre l'effet combiné de deux bordures sur la structure forestière des habitats linéaires résiduels des aires de récolte en la forêt d'épinette noire. Nous avons émis l'hypothèse que l'ampleur de l'influence de la bordure (*MEI*) dans les habitats linéaires pourrait être plus forte si l'influence de deux bordures proches aboutit à une interaction de leurs effets. Ainsi, la structure forestière des habitats linéaires va probablement devenir fortement affectée par des nouvelles conditions environnementales (augmentation de l'activité du vent, l'humidité et la température de l'air). Contrairement aux habitats résiduels non-linéaires qui, exposés sur l'ensemble de leur périmètre à des effets de bordures, n'ont pas de bordures rapprochées. Dans notre étude, la combinaison d'effets de bordures dans les séparateurs de coupe et les bandes riverains a été possible pour le recouvrement de la canopée, pour la densité des chicots et la densité des arbres tombés au sol.

Les résultats empiriques dans les séparateurs de coupe et les bandes riveraines révèlent qu'il existe effectivement un effet d'interaction d'influence de bordure pour le recouvrement de la canopée. Dans le deux types des corridors la diminution du recouvrement de la canopée est plus forte que ce que le modèle ne prévoit quant aux effets additifs d'effets de bordures rapprochées. Par ailleurs, dans les bandes riveraines la diminution dans le recouvrement de la canopée à 25 m pourrait suggérer un effet de bordure complémentaire de la "vieille bordure", comme résultat de la présence d'un cours d'eau au milieu de la bande, mais cela a une influence plus faible que la nouvelle bordure créée (Harper et al. non publiée).

Nos résultats empiriques ne montrent aucune évidence d'un effet combiné d'influence de bordure pour les densités d'arbres tombés au sol dans l'un ou l'autre de nos habitats linéaires. Cependant, une plus grande influence de bordure (MEI) quant aux arbres tombées au sol a été observée dans les bandes riveraines que dans les séparateurs de coupe près de la bordure. Ces plus hautes densités d'arbres tombés au sol dans les bandes riverains pourraient suggérer une sensibilité plus grande à l’action du vent en raison de la plus faible largeur de ces habitats linéaires résiduels.

La proximité des bordures et les effets qui en découlent sur la structure du couvert forestier conduisent à considérer les habitats linéaires résiduels comme étant particulièrement vulnérables. Cependant, nous avons observé que les séparateurs de coupe ont été plus affectés par la création de deux bordures proches que les bandes riveraines. Nos résultats suggèrent que les bandes riverains puissent fournir une structure forestière plus stable que les séparateurs de coupe, à cause de leur résistance à l'interaction d'effets de bordure. Cela pourrait à son tour offrir les conditions forestières qui sont plus similaires des conditions des forêts continues, qui sont devenues fortement limitées dans le paysage aménagé du Nord-ouest du Québec. Finalement, nos résultats indiquent que pour mieux répondre à des objectifs écologiques de maintien de l’hétérogénéité des conditions structurales des forêts d’origine à des fins de protection de legs biologiques, ces habitats devront être plus larges pour non seulement éviter les effets de bordures mais aussi la combinaison potentielle de ces effets qui altère davantage la forêt résiduelle.

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