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UNIVERSITÉ DU QUÉBEC EN ABITIBI-TÉMISCAMINGUE

FACTEURS INFLUENÇANT L'UTILISATION DES STRUCTURES LINÉAIRES
PAR LES PRÉDATEURS DU CARIBOU BORÉAL AINSI QUE SON
COMPÉTITEUR APPARENT

MÉMOIRE

PRÉSENTÉ

COMME EXIGENCE PARTIELLE

À LA MAÎTRISE EN ÉCOLOGIE

PAR

ARNAUD BENOIT-PÉPIN

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AVANT-PROPOS

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RÉSUMÉ

En forêt boréale aménagée, l'exploitation forestière accroît constamment le niveau de perturbation anthropique dans l'écosystème forestier. Ces perturbations rajeunissent la matrice forestière entraînant une modification de la densité et de la distribution des communautés fauniques au détriment de certaines espèces. Entre autres, l'implantation de structures linéaires anthropiques dans le paysage est un facteur prépondérant du système prédateurs-proies affectant négativement le caribou en favorisant la réponse numérique et fonctionnelle de ses prédateurs. Notre objectif est d'expliquer par des facteurs locaux et du paysage comment l'utilisation de l'habitat du loup, de l'ours noir, du lynx ainsi que du compétiteur apparent du caribou, l'orignal, varie sur différentes structures linéaires naturelles et anthropiques avec l'aide de caméras de surveillance durant la période sans neige. Dans l'ouest du Québec, au Canada, le site faunique du caribou, au sud de Val-d'Or, abrite une population isolée en voie d'extinction qui nécessite une restauration active de son habitat. Dans ce site, une sélection aléatoire stratifiée de chemins forestiers gravelés ($n = 33$) et de chemins d'hiver ($n = 28$) ainsi que du milieu riverain ($n = 19$) a été faite pour comparer leurs caractéristiques ainsi que le nombre d'utilisations de ces espèces sur chacune d'entre elles. Pour les trois prédateurs, la différence du couvert latéral entre le milieu environnant et la structure linéaire explique principalement leur nombre d'utilisations durant la période sans neige. Pour le loup gris et le lynx du Canada, l'utilisation par leur proie respective (Orignal et le lièvre d'Amérique) affecte positivement leur nombre d'utilisations. Pour celui du loup gris, il est affecté positivement par la distance à un chemin de classe supérieure (classe 1 et 2) et négativement par la distance à la ville la plus près. Un pourcentage plus élevé d'habitats du lièvre semble augmenter légèrement le nombre d'utilisations du lynx. Essentiellement, les chemins forestiers gravelés présentent un niveau d'utilisation plus élevé par toutes les espèces, mais c'est dû au couvert latéral moins élevé sur cette structure linéaire que dans son milieu environnant. Étant donné ce constat nous recommandons que les efforts de restauration liés aux démantèlements des chemins forestiers visent ceux dont les conditions de différences de couverture latérale sont favorables aux déplacements des espèces responsables du déclin du caribou.

Mots clés : Prédateurs du caribou boréal, Perturbations anthropiques, structures linéaires, chemins forestiers, utilisation, caméras de surveillance, couvert latéral, aménagement forestier.

CHAPITRE I

INTRODUCTION GÉNÉRALE

1.1 Mise en contexte en problématique

À l'heure actuelle, l'être humain est la cause de la sixième crise d'extinction de l'histoire du vivant sur la Terre (Barbault, 2005). L'accroissement constant de la population humaine ainsi que de l'économie mondiale décuple la demande en énergie, celle des terres disponibles ainsi que de la ressource en eau engendrant une perte considérable de la biodiversité indispensable aux sociétés humaines (Grooten et Almond, 2018). Plus précisément, les deux facteurs prédominants qui affectent la biodiversité sont la perte ainsi que la fragmentation de l'habitat (Fahrig, 1997 ; 2003), ceux-ci amènent directement le déclin des populations animales ainsi que de la stabilité de la chaîne trophique dans les écosystèmes forestiers (Bartlett et al., 2016).

Les écosystèmes forestiers boréaux au Canada sont aussi affectés par le déclin des populations animales. Même si cette zone forestière recèle encore de grandes portions d'écosystèmes forestiers intacts, la pression sur les ressources naturelles accroît constamment le niveau de perturbation anthropique. En effet, Imbeau et al. (2015) témoignent de la perte et de la fragmentation des forêts matures et du rajeunissement de la matrice forestière qui suit l'accès au territoire. Ils confirment que les mesures de conservation mises en place dans les territoires aménagés n'ont pas suffi pour empêcher la perte d'habitat en deçà des seuils écologiques minimums afin d'assurer le maintien de la biodiversité.

Certaines espèces à grands domaines vitaux telles que le caribou boréal (*Rangifer tarandus caribou*) sont relativement sensibles aux perturbations naturelles et anthropiques à l'intérieur de leur habitat (Lafontaine et al., 2019). L'exploitation des ressources naturelles, entre autres, réduit et fragmente considérablement les forêts matures par le biais d'activités industrielles (foresterie, hydroélectricité, exploitation des minerais et des hydrocarbures) affectant grandement les différentes populations de caribou boréal au pays (Festa-Bianchet et al., 2011). L'aire de répartition du caribou boréal a diminué de plus de 40% depuis le milieu du XIXe siècle, principalement liée à la chasse et aux modifications anthropiques de son habitat (Schaefer, 2003 ; Basille et al., 2011). La sélection d'habitat par le caribou boréal est principalement constitué de tourbières riches en arbustes et de peuplements d'épinette noire allant d'un âge intermédiaire (50-100 ans) à mature (> 100 ans) (Brown et al., 2007).

Selon l'analyse d'Environnement Canada (2011), 68% des populations du caribou boréal dans les aires étudiées sont dans la catégorie « non autosuffisante ». La difficulté que les populations ont pour maintenir leur autosuffisance est fortement associée aux perturbations anthropiques à l'intérieur de leur habitat. Les données d'Environnement Canada (2011) ont montré un lien direct entre la croissance des populations de caribou boréal et le pourcentage de perturbations naturelles et anthropiques dans leur habitat. Dans ce rapport, il en ressort un scénario de gestion cible avec moins de 35% de perturbation de l'habitat, représentant un état favorable au maintien des populations de caribou boréal.

On constate que les perturbations causées par l'activité industrielle est indirectement liée au déclin des populations du caribou boréal et montagnard. L'hypothèse selon laquelle le déclin des populations serait principalement lié à un accroissement de la prédation est suspectée depuis une quarantaine d'années (Bergerud, 1974), mais a été plus clairement mise en évidence notamment par les travaux de Wittmer et al. (2005) en Colombie-Britannique. Les plus récentes études montrent maintenant que la

compétition apparente est le phénomène expliquant le mieux le déclin de plusieurs populations de caribou boréal en Amérique du Nord (DeCesare et al., 2010 ; Festa-Bianchet et al., 2011 ; Mumma et al., 2018). Dans ce contexte, la présence accentuée de l'orignal (*Alces americanus*) nuit indirectement au caribou en provoquant l'augmentation de la prédation par le loup gris (*Canis lupus*) (Holt, 1977 ; Holt et Bonsall, 2017).

Ajoutés à ce mécanisme, le nombre et la distribution de l'ours noir ont aussi augmenté dans le paysage avec l'accroissement de la disponibilité de la ressource alimentaire (herbacées, graminées et arbustes feuillus) (Mosnier et al., 2008b) et accentué la prédation sur les faons (Latham et al., 2011a ; Pinard et al., 2012 ; Leblond et al., 2016). De plus, certaines études effectuées au Labrador montrent que le lynx du Canada (*Lynx canadensis*) peut aussi représenter un prédateur important des faons lorsque les conditions d'habitat sont favorables (Bergerud et al., 1983 ; Mahoney et al., 2016). Cette augmentation de la prédation naturelle a complètement déséquilibré la sensible balance démographique traditionnellement connue du caribou, menant éventuellement à la disparition de certaines populations et à une tendance au déclin pour presque toutes les autres en Amérique du Nord (Bergerud, 1974 ; COSEWIC, 2002 ; Festa-Bianchet et al., 2011 ; Leclerc et al., 2014).

Les perturbations anthropiques, favorisant un débalancement des conditions d'habitat pour le caribou, peuvent être temporaires ou permanentes sur le territoire. Tout comme suite à des perturbations naturelles (e.g. feux, épidémies), les aires de récolte bien régénérées entameront un processus de développement et de succession qui mèneront à des conditions plus favorables au caribou dans un délai temporel estimé à une quarantaine d'années (Courtois et al., 2007 ; Environnement Canada, 2011). Les structures linéaires anthropiques quant à elles accroissent le taux de perturbation dans l'habitat du caribou boréal de manière plus persistante dans le temps (Schneider, 2002; MFFP, 2018) et font office de corridors de déplacement pour plusieurs espèces

fauniques (Newton et al., 2017 ; Dickie et al., 2020). En effet, plusieurs études, surtout dans l'Ouest canadien, ont montré l'effet contributif des structures linéaires anthropiques telles que les chemins forestiers, les sentiers, les lignes sismiques, les pipelines et les lignes de transport d'énergie, au système défaillant prédateur-proies qui affectent négativement le caribou boréal (Dyer et al., 2002 ; Schneider, 2002 ; Whittington et al., 2005 ; Leblond et al., 2012 ; DeMars et Boutin, 2018).

Au Québec, les structures linéaires anthropiques dans l'habitat du caribou sont presque exclusivement des chemins forestiers et ceux-ci représentent un fort pourcentage de la perturbation totale (Rudolph et al., 2012 ; Rudolph et al., 2017). La voirie forestière au Québec s'étend sur une longueur d'environ 476 721 km (MFFP, 2021). Les types de chemins forestiers dans ce réseau sont principalement constitués de chemins gravelés, pour le transport de bois durant l'été et de chemins d'hiver utilisés durant la période hivernale, lorsque le sol est complètement gelé. Les chemins gravelés représentent une perturbation plus persistante dans le temps dû à la présence d'une mise en forme où le matériau granulaire est épandu et compacté pour une utilisation indépendamment des périodes saisonnières. Les chemins d'hiver, quant à eux, représentent une perturbation temporaire par l'absence de mise en forme (MRN, 2013 ; MFFP, 2018 ; 2020a).

À notre connaissance, au Québec, deux études ont quantifié l'utilisation des chemins gravelés par les prédateurs du caribou boréal afin d'identifier les variables explicatives associées à leur utilisation (Lacerte et al., 2021 ; St-Pierre et al., 2022). Il reste encore énormément d'interrogations sur l'utilisation dans le temps par les prédateurs des chemins d'hiver et du milieu riverain, dans un habitat où l'empreinte des chemins forestiers est élevée. Dans ce contexte où l'on doit concilier l'aménagement forestier et une qualité d'habitat favorable pour le maintien du caribou dans l'écosystème forestier au Québec, il pourrait être intéressant de quantifier l'utilisation des chemins gravelés et d'hiver ainsi qu'une structure linéaire naturelle de référence, le milieu riverain, par les espèces associées aux déclin du caribou. Déterminer si leur utilisation

diffère entre ces structures linéaires pourrait mieux guider l'aménagement forestier dans l'habitat du caribou et aussi fournir des retombées importantes dans notre engagement à restaurer activement l'habitat de cette espèce menacée.

1.2 État des connaissances

1.2.1 Déclin du caribou boréal

En Alberta, la modification de la dynamique forestière a complètement changé la densité et la distribution des communautés fauniques dans l'espace au désavantage du caribou boréal (Seip, 1992 ; James et al., 2004 ; Fisher et Burton, 2018). Le même phénomène se produit au Québec (Basille et al., 2011), où les coupes forestières ont modifié les interactions trophiques accentuant l'abondance de certaines proies (orignal) (Courtois et al., 1998) et de prédateurs (loup gris et ours noir) dans l'habitat du caribou (Crête et Manseau, 1996). En Ontario, le rajeunissement de la forêt boréale par l'activité de récolte forestière a aussi favorisé la colonisation et l'abondance de l'orignal (*Alces alces*) dans son habitat (Bowman et al., 2010). Ce déplacement de l'orignal semble supporter l'augmentation de la distribution et de l'abondance des populations de coyote (*Canis latrans*) et du loup gris (*Canis lupus*) au Québec (Mosnier et al., 2008a). Ces perturbations ont provoqué une amélioration de la réponse fonctionnelle et numérique des prédateurs dans l'habitat du caribou boréal et montagnard augmentant la prédation chez ces derniers et qui explique la tendance au déclin (Frenette et al., 2020 ; Fryxell et al., 2020). On fait donc référence ici au phénomène de la compétition apparente. Elle est définie par une interaction négative indirecte, plus marquée qu'à l'origine, entre les proies, qui favorise le partage de leurs prédateurs naturels (Holt et Bonsall, 2017). En d'autres mots, dans notre contexte, la compétition apparente est l'effet négatif indirect que subit une espèce (caribou) par la présence accentuée d'une autre espèce (orignal) qui partage le même prédateur (loup

gis) (Holt, 1977). Dans ce système, les deux proies vivent dans un mode de spéciation sympatrique avec une différence de productivité (Holt, 1977). Conséquemment, cette coexistence est compromise dans un écosystème forestier perturbé, car la pression de prédation sur le caribou, qui est moins productif, est accentuée par une réponse numérique et fonctionnelle du loup, qui lui est supporté par l'orignal, une proie plus productive (Holt, 1977 ; 1984 ; Holt et Kotler, 1987). La compétition apparente devient l'explication qui supportant le mieux le déclin de plusieurs populations de caribou boréal en Amérique du Nord (Holt et Kotler, 1987 ; Festa-Bianchet et al., 2011 ; Mumma et al., 2018).

En plus de ce mécanisme, le nombre et la distribution de l'ours noir a augmenté dans le paysage avec l'accroissement de la disponibilité de la ressource alimentaire (herbacées, graminées et arbustes feuillus) (Brodeur et al., 2008 ; Basille et al., 2011). Même si l'habitat du caribou ne représente pas celui habituellement sélectionné par l'ours noir, cette espèce opportuniste montre une sélection d'habitats individuels très variable. Certains ours noirs peuvent sélectionner l'habitat du caribou, surtout l'habitat des femelles suitées, pour leur quête de nourriture et sont donc responsables d'une grande proportion de la mortalité des faons (Basille et al., 2011 ; Latham et al., 2011a ; Dussault et al., 2012). En effet, l'étude de Pinard et al. (2012) a démontré que cet omnivore opportuniste était responsable de 94% des évènements de prédation des faons de la population de Charlevoix pour laquelle les prédateurs ont été identifiés. Leblond et al. (2016) explique ce phénomène par une stratégie anti-prédatrice du loup par le caribou, qui expose alors les femelles suitées à un risque de prédation de leurs faons élevé par l'ours noir puisqu'elles sélectionnent plus fortement les habitats favorables à l'ours noir.

De plus, dans la région insulaire de Terre-Neuve-et-Labrador, en l'absence de loup, le lynx pouvait être la source probable d'une faible survie de faons. Bergerud (1971) l'avait mis en évidence, en observant une augmentation de la survie des faons avec

l'abattage de lynx dans les aires de mise bas. De plus, de récentes études de Lewis et Mahoney (2014), dans cette même région, ont montré que l'incidence de la prédation par l'ours et le lynx est plus élevée lorsque les populations de caribou sont dans leur phase de croissance (Lewis et Mahoney, 2014). La contribution du lynx à la prédation, selon cette étude, est en moyenne de 14.6 % durant la croissance de la population de caribou comparativement à 6.2 % durant la période du déclin (Mahoney et al., 2016). Ils mentionnent aussi que cette différence de prédation selon les phases de croissance des populations de caribou sont dus probablement à l'abondance de lynx qui est fonction du cycle lynx-lièvre, au changement de l'habitat de sélection du caribou (Schaefer et al., 2015), à l'abondance et/ou la compétition avec d'autres prédateurs et l'efficacité du lynx à chasser les faons selon de niveau variable de densité des populations de caribou.

Toutes ces modifications au sein de la chaîne trophique de cette communauté d'espèces liées à un accroissement continu des perturbations dans le paysage forestier au Québec ont eu comme conséquence une augmentation de la prédation naturelle menant éventuellement au déclin et l'attribution du statut d'espèce menacée pour le caribou au Canada (Bergerud, 1974 ; COSEWIC, 2002 ; Festa-Bianchet et al., 2011).

1.2.2 Effets cumulatifs des structures linéaires sur la dynamique prédateurs-proie

1.2.2.1 Effet sur les processus écologiques

Même si les structures linéaires anthropiques occupent souvent une faible portion du territoire, elles peuvent avoir un effet disproportionné sur les processus écologiques (Trombulak et Frissell, 2000). En effet, Forman (2000) affirme qu'avec une superficie d'environ 1% de structures linéaires anthropiques sur la superficie d'un territoire, celles-ci peuvent altérer les processus écologiques de manière significative. Dans

l'Ouest canadien, l'implantation de structures linéaires est un facteur prépondérant du système défaillant prédateur-proies qui affecte négativement le caribou boréal (Schneider, 2002 ; Whittington et al., 2005 ; DeMars et Boutin, 2018). Fisher et Burton (2018) ont ciblé des espèces gagnantes et perdantes dans ce paysage d'exploitation pétrolière où l'on retrouve une importante densité de structures linéaires anthropiques. Les perturbations dans ce type de région, selon cette étude, ont nettement favorisé l'expansion du cerf de virginie, de l'orignal, des grands canidés (loup et coyote) ainsi que du lynx dans le paysage forestier. En revanche elles ont fait diminuer les populations de caribou, d'ours noir, de renard roux et de pékan (*Martes pennanti*).

1.2.2.2 Structures linéaires naturelles

En l'absence de structure linéaire anthropique dans l'habitat, les prédateurs sont moins favorisés, car leurs mouvements sont surtout localisés autour des structures linéaires naturelles, notamment les ruisseaux, les rivières et les rives des grands plans d'eau (Mech et Boitani, 2010 ; Latham et al., 2011b ; Newton et al., 2017). Ces structures linéaires naturelles facilitent tout de même leurs déplacements et offrent une abondance de proies pour les prédateurs maximisant leur effort de chasse (Latham et al., 2011b). De plus, le milieu riverain, durant la saison estivale, représente un habitat où l'on retrouve une disponibilité importante de castor pour le loup (Latham, 2009). Kittle et al. (2017) ont montré aussi que le loup utilise d'une manière disproportionnée les structures linéaires naturelles favorisant ainsi leur mobilité lorsque les proies sont à faible densité.

1.2.2.3 Utilisation compensatoire des structures linéaires anthropiques

Actuellement, de récentes études ont démontré que l'utilisation des structures linéaires anthropiques a complètement modifié le patron de mouvement des prédateurs. En effet, en Alberta, dans un milieu à forte densité de structures linéaires anthropiques (e.g. lignes sismiques), Dickie et al. (2020) ont observé que les prédateurs (loup et ours) et les proies (caribou et orignal) répondent moins régulièrement aux structures linéaires naturelles. De plus, Newton et al. (2017), en Ontario, ont étudié le changement de sélection des structures linéaires par le loup. Ils ont montré que le loup fait une sélection compensatoire des chemins forestiers par rapport aux structures linéaires naturelles dans l'espace plutôt qu'une sélection additive. Terwilliger et Moen (2012) au Minnesota ont trouvé une utilisation similaire du lynx où on le retrouve plus près des routes que des plans d'eau ou des milieux humides dans son domaine vital. Bref, l'implantation de structures linéaires anthropiques dans le paysage semble orienter l'utilisation des espèces en forêt vers les chemins gravelés plutôt que vers les structures linéaires naturelles comme les cours d'eau et le milieu riverain de grands plans d'eau.

1.2.2.4 Stratégie anti-prédatrice du caribou

Tout d'abord, la ségrégation du caribou boréal de ses prédateurs et de leurs proies alternatives a bien été documentée (James et al., 2004). Cette ségrégation est un facteur déterminant dans le succès et le maintien des différentes populations de caribou boréal (Bergerud, 1985 ; Bergerud et al., 1990 ; Rettie et Messier, 2000 ; Schaefer et al., 2001). En effet, le caribou boréal dans l'Est canadien sélectionne particulièrement les milieux de faible drainage accompagné d'épinette noire (tourbières) comme milieu de refuge (Courtois et al., 2003 ; Courtois et al., 2004 ; Ferguson et Elkie, 2004). L'orignal, le

loup, et l'ours noir vont plutôt sélectionner les milieux bien drainés où l'on retrouve des forêts mixtes et des structures anthropiques (Brassard et al., 1974 ; Courtois et al., 2002 ; Brodeur et al., 2008 ; Lesmerises et al., 2012). Cette stratégie anti-prédatrice du caribou lui a permis historiquement de se maintenir dans l'écosystème forestier boréal. Toutefois, avec un habitat qui favorise les deux réponses des prédateurs par l'expansion des perturbations anthropiques liée aux activités industrielles, le caribou boréal a du mal à maintenir cette stratégie. En outre, la construction continue d'un important réseau de structures linéaires anthropiques persistantes dans l'habitat du caribou, diminue les chances de l'espèce de se séparer de ces prédateurs et donc de se maintenir dans le paysage forestier (Festa-Bianchet et al., 2011 ; Dussault et al., 2012 ; Lafontaine et al., 2019).

1.2.2.5 Modification de la réponse fonctionnelle des prédateurs

L'implantation de nouvelles lignes sismiques dans l'Ouest canadien a favorisé l'efficacité à la chasse des prédateurs (Latham et al., 2011b ; McKenzie et al., 2012). En effet, les structures linéaires anthropiques favorisent le loup et l'ours en augmentant leur vitesse de déplacement (Dickie et al., 2020) par conséquent leur taux de mouvement journalier (DeCesare, 2012). Dickie et al. (2017) montrent que le loup se déplace 2 à 3 fois plus vite sur les structures linéaires anthropiques (lignes sismiques, sentiers, routes, pipelines, lignes de transmission, voies ferrées) que dans la forêt naturelle. Conséquemment, ce déplacement amélioré augmente les probabilités de rencontre avec leurs proies (Whittington et al., 2011 ; McKenzie et al., 2012).

Les résultats de Dickie et al. (2020), dans un système qui comprend le cerf de virginie et le coyote, montre que le loup et l'ours noir sont attirés par les structures linéaires anthropiques. Implantées dans l'habitat du caribou boréal en Colombie-Britannique,

celles-ci favorisent le chevauchement spatial et donc la co-occurrence entre les prédateurs (loup gris, ours noir et grizzly (*Ursus arctos*)), augmentant nécessairement le risque de prédation du caribou (McKenzie et al., 2012 ; DeMars et Boutin, 2018 ; Mumma et al., 2018). Dans ce même système, plus le réseau de structures linéaires anthropiques est dense, plus le chevauchement spatial du loup gris et de l'ours noir dans les zones refuges du caribou est amplifié et augmente par le fait même le temps que ceux-ci passent à l'intérieur de l'habitat du caribou boréal (Whittington et al., 2011). Cette réduction de l'efficacité du caribou à se réfugier, a des implications significatives sur la survie des faons et donc sur la démographie des populations en Alberta (James et al., 2004). Dickie et al. (2017) ont démontré que les lignes sismiques favorisent le ratio de découverte de proies lorsque les prédateurs (loup et ours noir) les utilisent. Par conséquent, celles-ci vont augmenter l'efficacité à la chasse des prédateurs (Dickie et al., 2020) et exacerber cette probabilité de rencontre augmentant ainsi le risque de prédation (Mumma et al., 2018) surtout pour les populations à basse densité (McKenzie et al., 2012).

1.2.2.6 Modification de la réponse numérique des prédateurs

Les structures linéaires anthropiques induisent aussi une modification numérique des prédateurs. C'est-à-dire, qu'elles augmentent le nombre de loups en chasse dans l'habitat du caribou. En effet, McCutchen (2007), en Alberta, conclut qu'il y a plus de prédateurs comme le loup dans l'aire du caribou et que cette augmentation est liée à l'utilisation de structures linéaires anthropiques dans l'espace. L'augmentation de l'abondance du loup et de la distribution dans l'aire du caribou par l'entremise de structures linéaires anthropiques augmente le rapprochement entre le caribou boréal et ses prédateurs.

Cette utilisation compensatoire des structures linéaires anthropiques compromet la ségrégation du caribou aux espèces associées à son déclin en favorisant la réponse fonctionnelle ainsi que de la réponse numérique des prédateurs dans son habitat. Ces réponses se traduisent par une augmentation des rencontres entre le caribou et les prédateurs (Whittington et al., 2011 ; McKenzie et al., 2012), de leur succès à la chasse de ces derniers (Dickie et al., 2020) et donc du risque de prédation du caribou boréal aggravant la situation de l'espèce (Latham et al., 2011b ; Mumma et al., 2018).

1.2.3 Effet des structures linéaires anthropiques sur les espèces

1.2.3.1 Loup gris

1.2.3.1.1 Influence sur le mouvement et la sélection des ressources

Tout d'abord, la sélection des ressources est définie par la probabilité qu'un individu sélectionne une unité de ressource donnée rencontrée dans le paysage (Lele et al., 2013). D'une façon générale, la littérature sur le loup gris révèle que toute forme de perturbation anthropique modifie ses mouvements (McKenzie et al., 2012) ainsi que la sélection des ressources dans son habitat ayant des impacts significatifs sur les espèces de proies qu'il sélectionne (Muhly et al., 2019). En effet, les corridors de déplacement du loup gris ne sont donc pas distribués de manière aléatoire dans son domaine vital. Ceux-ci sont plutôt clairement associés à une sélection de facteurs biophysiques de leur environnement, particulièrement les habitats reliés aux infrastructures humaines, dont les routes (Ciucci et al., 2003). Dans le rapport de St-Laurent et Gosselin (2020), ceux-ci montrent que les chemins forestiers représentent des habitats à forte probabilité d'occurrence pour le loup gris à l'intérieur du site faunique du caribou de Val-d'Or. Les résultats de Whittington et al. (2005) suggèrent que les loups en Alberta sélectionnent ces structures non pas par une qualité d'habitat, mais plutôt puisqu'elles offrent une

facilité de déplacement sur son territoire. En effet, à plus fine échelle (0,1 km²), la sélection des routes augmente la vitesse de déplacement du loup, surtout lorsque celui-ci est en période de reproduction (Zimmermann et al., 2014 ; Dickie et al., 2017 ; Dickie et al., 2020).

1.2.3.1.2 Échelle et période d'utilisation

La densité des chemins influence aussi la réponse du loup sur plusieurs échelles spatiotemporelles. À l'échelle locale (1km de rayon), la sélection des structures linéaires anthropiques dans le milieu de l'été est diminuée lorsque la densité de chemins augmente (période de rendez-vous et nomade), mais pas durant la période de mise bas (printemps) (Houle et al., 2010). À l'échelle du domaine vital cependant, durant toute l'année, les loups augmentent l'utilisation des chemins gravelés lorsque leur densité augmente, particulièrement durant la période d'élevage (Houle et al., 2010 ; Zimmermann et al., 2014).

1.2.3.1.3 Type de comportement observé

Au point de vue comportemental, Ehlers et al. (2014) ont étudié le comportement du loup gris près des structures linéaires anthropiques. Leurs analyses ont démontré que les loups sont soit en comportement de chasse ou en comportement de recherche de proies sur ces structures linéaires. Ces comportements se traduisent par une utilisation temporelle accrue des structures linéaires anthropiques expliquées par une augmentation de leur ratio de déplacement et de mouvement linéaire, surtout en présence d'une densité de routes élevée. On constate donc que le loup a su s'ajuster

devant le développement constant des infrastructures humaines sur le territoire. Le développement d'un comportement cryptique a permis d'éviter les risques associés à ceux-ci, sans pour autant nuire à sa capacité de combler ses besoins vitaux. Cette plasticité comportementale est donc un important facteur qui illustre le succès de l'espèce dans les milieux perturbés par l'activité humaine (Zimmermann et al., 2014).

1.2.3.1.4 Effet de la végétation sur l'utilisation

La végétation sur et autour des chemins agit sur le déplacement et sur l'utilisation de l'espace du loup gris. Avec l'absence d'entretien, les structures linéaires subissent une fermeture graduelle par la végétation. Une étude de Dickie (2015), entre autres, a montré l'effet de la hauteur de la végétation sur le déplacement du loup. Les résultats de cette étude illustrent le fait que lorsque la végétation est basse, elle n'a aucun effet sur le déplacement du loup gris. Toutefois, lorsqu'elle dépasse 1m de hauteur, elle réduit de 23% la vitesse de déplacement en été. En revanche, en hiver (accumulation 1.5 m de neige par année), la végétation diminue la vitesse de déplacement seulement lorsque la hauteur de celle-ci excède 5 m (Dickie, 2015).

1.2.3.2 Ours noir

Un nombre moins élevé d'études se sont intéressées à l'utilisation des routes par l'ours noir. Cependant, le nombre d'études existant montre quand même que les structures linéaires anthropiques peuvent affecter de différentes manières la distribution et le comportement de l'ours noir. En effet, une étude illustre que l'ours noir utilise plus les lignes sismiques que la forêt d'intérieur (Tigner et al., 2014). Ces chercheurs laissent

sous-entendre qu'elles influencent leur habilité à localiser et à capturer des caribous et autres ongulés. Ils ont aussi noté que cette différence d'utilisation par l'ours noir est atténuée lorsque les lignes sismiques ont une largeur inférieure à 2 m. Dickie et al. (2020) ont aussi montré que l'ours noir est attiré par toute forme de structures linéaires et qu'il se déplace plus rapidement sur ce type de structures. En présence d'activité humaine, Schwartz et al. (2010) ont trouvé que l'activité de l'ours noir et du grizzly semblait être plus prononcée près des routes (1km) durant la nuit que le jour. Comme pour le loup, l'ours noir semble tirer profit de ces structures linéaires pour la sélection de ses ressources (Latham et al., 2011a) ce qui pourrait avoir des conséquences notables sur la conservation du caribou boréal plus précisément la survie des faons (Brodeur et al., 2008 ; Basille et al., 2011 ; Latham et al., 2011a ; Pinard et al., 2012 ; Leblond et al., 2016).

1.2.3.3 Lynx du Canada

Une étude, à long terme sur la densité de la communauté des mammifères dans un paysage dominé par l'exploitation des sables bitumineux (Skatter et al., 2020) a montré que la densité du lynx augmente par la présence de larges structures linaires telles que les routes, des pipelines ainsi que des lignes d'hydroélectricité. Nous avons trouvé quelques recherches axées spécifiquement sur le lynx du Canada. Au Minnesota, Terwilliger et Moen (2012) ; Terwilliger (2016) ont interprété par GPS radio télémétrique l'utilisation des routes et de sentiers par le lynx du Canada. Dans ces études, ils ont trouvé que seulement à fine échelle, soit à l'intérieur de 50 m de la route, l'espèce sélectionne les routes et les sentiers. À une échelle plus large, il ne semble pas avoir de distinction entre les relevés GPS et une localisation aléatoire. Ils ont aussi trouvé que la vitesse de déplacement entre un petit nombre d'emplacements consécutifs sur une route ou un sentier était 60 m/h plus rapides que le taux de déplacement entre

des endroits successifs ne se trouvant pas sur une route ou sur un sentier. Ces résultats suggèrent que les routes et les sentiers peuvent augmenter l'efficacité du déplacement du lynx à petite échelle, mais selon leur résultat la présence de routes ne veut pas nécessairement signifier une augmentation du taux de déplacement à l'échelle de son domaine vital. Selon les chercheurs, le lynx peut être ralenti par des opportunités de prédation, des interactions des compétiteurs interspécifiques (coyote, lynx roux [*lynx rufus*]) (Bayne et al., 2008) et l'activité humaine.

1.2.3.4 Orignal

Un nombre important d'études ont permis de mieux comprendre l'effet des structures linéaires anthropiques sur l'orignal. En Ontario, Rempel et al. (1997) ; Bowman et al. (2010) ont montré qu'à grande échelle ce cervidé est favorisé dans les paysages avec une densité de chemins forestiers modérée puisqu'associé à une jeune matrice forestière où l'on trouve un meilleur accès aux ressources alimentaires disponibles. En Alberta, dans des écosystèmes tourbeux, McCutchen (2007) a lui aussi noté que les structures linéaires anthropiques ont le potentiel d'augmenter l'utilisation de l'orignal dans ce genre d'écosystème. À plus fine échelle cependant, l'orignal ne répondra pas favorablement aux structures linéaires anthropiques. Au sud de son aire de répartition géographique, au Massachusetts, dans un paysage routier, Wattles et al. (2018) ont montré que les routes nuisent de façon notable au déplacement et à l'utilisation de son habitat. Dans ces zones avec une activité humaine intense, ils ont observé que l'orignal évite presque toutes les routes et le milieu adjacent, sauf celles avec une faible circulation humaine (<10 véhicules/jour), et que cet évitement est positivement relié à la circulation humaine sur la route. Dussault et al. (2007), dans le parc National de la Jacques-Cartier, ont observé le même patron où l'orignal évite les routes et les traverse rapidement pour se déplacer vers d'autres parcelles d'habitat.

Avec cette différence d'effet selon l'échelle spatiale d'analyse, cela laisse sous-entendre que l'orignal fait nécessairement un compromis entre les coûts et les bénéfices associés aux routes. En effet, Beyer et al. (2013) ont déterminé un seuil (0.2 km/km² en hiver et un seuil de 0.4 km/km²) de densité routes qui modifie son comportement. Dans cette étude, ils ont mis en évidence que la réponse aux routes est surtout soutenue par l'intensité de la circulation humaine plutôt que l'évitement de ces prédateurs puisqu'ils ont observé dans les zones, là où la chasse est interdite et où la circulation humaine est contrôlée, que l'orignal n'évite pas les routes à deux voies, même si celle-ci peut améliorer l'efficacité de déplacement des loups. La plus récente étude est celle de Dickie et al. (2020), en Alberta, dans une région avec une activité humaine et une pression de chasse relativement faible, qui ont quantifié ce compromis et déterminé que pour l'orignal, celui-ci perçoit les lignes sismiques et les chemins d'hiver et le milieu riverain comme un risque de prédation puisqu'ils les évitent en général. Lorsqu'utilisé comme corridor de déplacement, celui-ci s'y déplace beaucoup plus rapidement. En bref, ces études révèlent que les structures linéaires anthropiques affectent négativement l'orignal à petite échelle, mais montrent tout de même globalement que cette espèce de par sa réponse comportementale a su s'adapter à leur présence et combler ainsi ses besoins vitaux (Muhly et al., 2011 ; Wattles et al., 2018).

1.2.4 Méthode de détection de l'utilisation de l'habitat par la grande faune

Quantifier les relations des organismes avec leur environnement représente un élément central pour comprendre l'écologie des populations et des communautés animales. Les interactions entre les espèces influencent la manière dont les organismes se distribuent dans l'espace et dans le temps (Fleming et al., 2014). Récemment, l'utilisation des caméras de surveillance pour inventorier la faune a considérablement augmenté, car elle représente un outil analytique extrêmement utile et discret pour des fins de

recherches et ainsi mieux comprendre l'écologie de la faune terrestre (O'Connell et al., 2010). Elle permet entre autres de quantifier l'utilisation d'une ressource, une métrique plus précise que la sélection de la ressource. La sélection et l'utilisation sont différentes puisqu'une unité de ressources hautement recherchée par une espèce résulte d'une sélection élevée. Toutefois, elle peut avoir une faible utilisation si elle n'est pas facilement accessible dans l'espace (Lele et al., 2013). Dans son champ de détection, la caméra de surveillance permet d'enregistrer des données sous forme de photos d'animaux en fournissant des informations sur la date, l'heure et la localisation des détections qui confirme son utilisation (Fleming et al., 2014). Les images peuvent donc fournir des informations explicites sur l'identité, le comportement, la distribution spatiale des animaux dans des lieux définis. L'avantage de l'utilisation des caméras de surveillance est qu'elle constitue une méthode non invasive permettant de continuellement échantillonner les communautés animales dans l'espace sur une très longue période (Keim et al., 2019). Selon la méthode employée, les caméras de surveillance peuvent être utilisées pour inventorier la faune, étudier le comportement, estimer la probabilité d'occupation de sites, l'intensité d'utilisation d'une ressource et même la densité de plusieurs espèces fauniques (Rovero et al., 2013 ; Burton et al., 2015 ; Rovero et Zimmermann, 2016 ; Pettigrew, 2017).

1.3 Objectif de l'étude et hypothèse de travail

1.3.1 Objectif de l'étude

L'objectif du projet de recherche vise à quantifier l'utilisation de structures linéaires naturelles et anthropiques durant la période sans neige par les prédateurs du caribou boréal (loup gris, ours noir et lynx) ainsi que son compétiteur apparent, l'orignal avec l'aide de caméras de surveillance en Abitibi-Témiscamingue, dans le domaine bioclimatique de la sapinière à bouleau blanc. Autrement dit, de comprendre par des

facteurs locaux et de paysages comment le nombre d'utilisations varie sur une diversité de structures linéaires naturelles et anthropiques. Les structures linéaires étudiées sont les chemins forestiers gravelés (classe 3 et 4 selon la classification fonctionnelle au Québec) et les chemins d'hiver d'une largeur variant de 5 à 8 m ainsi que du milieu riverain, comme structure linéaire naturelle. En réalisant une sélection aléatoire stratifiée de ces structures linéaires à l'intérieur du site faunique du caribou de Val-d'Or, et avec des observations répétées d'espèces fauniques sur chaque structure linéaire étudiée, il sera possible de déterminer le nombre d'utilisations du loup gris, de l'ours noir, du lynx et de l'orignal sur ces trois types de structures linéaires. Nous expliquerons ces résultats avec les caractéristiques locales et de paysages propres à chacune des structures linéaires. Il sera donc possible de définir si les espèces ont une préférence pour un certain type de structures linéaires. Le nombre d'utilisations par jour d'échantillonnage est un indicateur qui nous informe indirectement sur les interactions prédateurs-proies. Le décompte des prédateurs sur chacune des structures linéaires étudiées réfère ultimement au risque réel pour la proie d'emprunter la structure linéaire et son milieu voisin. Donc, dans un contexte où l'habitat du caribou boréal est façonné par divers chemins forestiers, le résultat concret de l'étude est de cibler les structures linéaires et leurs variables explicatives qui favorisent excessivement les espèces associées au déclin du caribou boréal. Avec ces informations, il sera possible d'identifier ceux à risque pour le caribou, afin de mieux guider l'efficacité des activités de démantèlement des chemins forestiers dans des zones retenues. Ces informations sont nécessaires afin de commencer un long processus de restauration active de l'habitat des populations de caribou boréal (Ray, 2014).

1.3.2 Hypothèses de travail

Nos hypothèses ont été construites sous la base suivante :

- En Ontario, Newton et al. (2017) ont déterminé que la sélection des structures linéaires anthropiques est compensatoire. C'est-à-dire que les prédateurs ne se déplacent plus sur les structures linéaires naturelles, mais sélectionnent maintenant les structures linéaires anthropiques pour leurs déplacements.
- Dickie (2015) ont vu que la végétation lorsqu'elle dépasse 1m de hauteur, elle réduit de 23% la vitesse de déplacement des prédateurs en été.
- Abrahms et al. (2016) qui a montré que chez le lycaon (*Lycaon pictus*), la sélection des chemins augmente surtout lorsque la densité végétale dans le milieu environnant est élevée.
- Fuller et al. (2003) ; (Keim et al., 2011) ont conclu que les prédateurs sélectionnent leurs proies plutôt que l'habitat de leurs proies.
- L'ours noir suit la disponibilité des plantes les plus digestibles (Mosnier et al., 2008). L'orignal s'alimente de préférence dans les broussailles à haute productivité et les forêts en début de succession (Dussault et al., 2005 ; Crum et al., 2017).

Nous émettons ainsi l'hypothèse que les chemins gravelés auront un nombre d'utilisations plus élevées par les grands mammifères que les deux autres structures linéaires, car nous supposons que les conditions de différence du couvert latéral entre le milieu environnant et la structure linéaire y seront plus propices au déplacement, l'utilisation par les proies y sera plus fréquente et la quantité de plantes comestibles y sera également plus élevée. La figure. 1.1 représente une illustration des trois types de structures linéaires comparées dans cette étude.

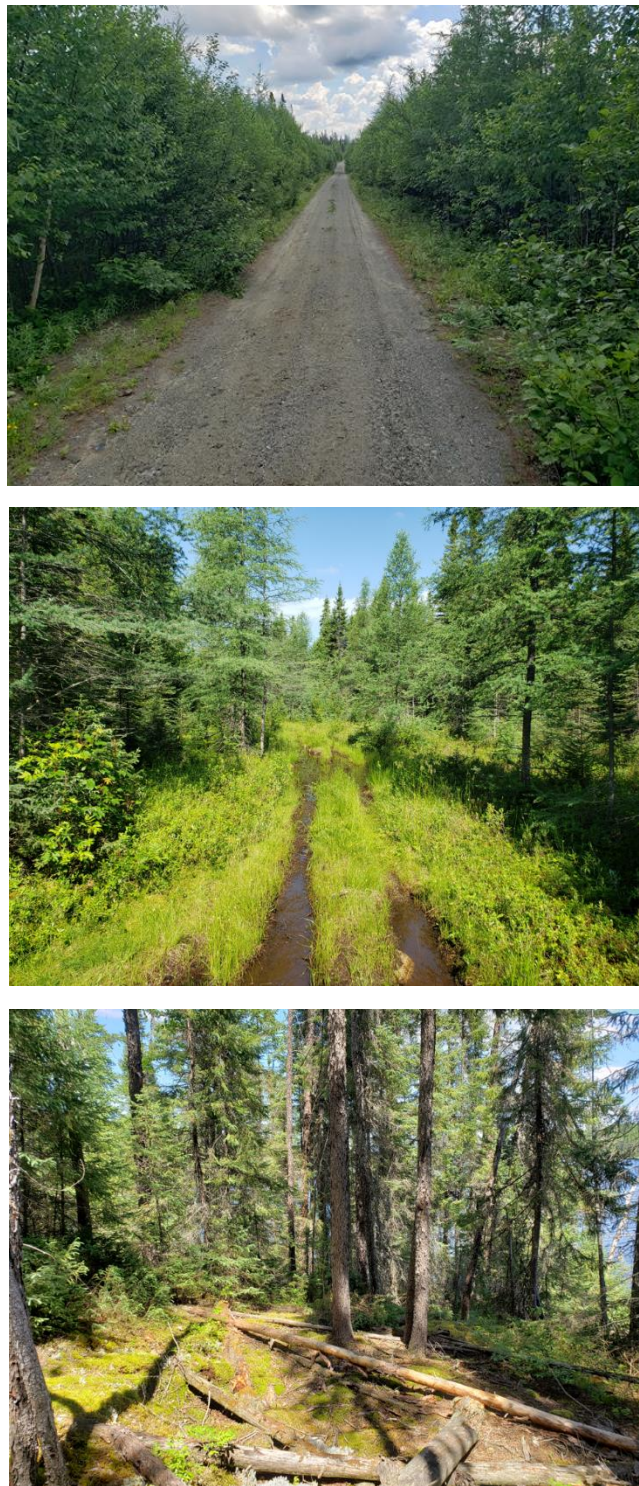


Figure 1.1 Photos des trois types de structures linéaires comparées dans cette étude, chemins gravelés de classe 3 et 4 (A), chemins d'hiver (B) et milieux riverains (C).

CHAPITRE II

USE OF LINEAR FEATURES BY WOODLAND CARIBOU PREDATORS AND HIS APPARENT COMPETITOR

Ce chapitre a été rédigé en anglais sous forme de manuscrit scientifique afin d'être soumis à la revue *Forest Ecology and Management*

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Arnaud Benoit-Pépin^{ab}, Mariano Javier Feldman^{ab}, Valeria Osvaldo^{abc}, Louis Imbeau^{ab}

^a Institut de recherche sur les forêts, Université du Québec en Abitibi-Témiscamingue, 445, boul. de l'Université, Rouyn-Noranda, Québec, Canada, J9X 5E4.

^b Chaire en aménagement forestier durable UQAT-UQAM, Université du Québec en Abitibi-Témiscamingue. 445, boul. de l'Université, Rouyn-Noranda, Québec, J9X 5E4.

^c Hémera Centro de Observación de la Tierra, Escuela de Ingeniería Forestal, Facultad de Ciencias, Universidad Mayor, Camino La Pirámide 5750, Huechuraba, Santiago, 8580745, Chile.

Corresponding author : Arnaud Benoit-Pépin, Université du Québec en Abitibi-Témiscamingue, 445 Boulevard de l'Université, Rouyn-Noranda, Québec, Canada, J9X 5E3, Arnaud.Benoit-Pepin@uqat.ca

2.1 Abstract

In managed boreal forests, logging operations are constantly maintaining the level of anthropogenic disturbances in the forest ecosystem. These disturbances rejuvenate the forest matrix resulting in a modification of the density and distribution of wildlife species causing the decline of Woodland caribou in North America. Furthermore, the establishment of anthropogenic linear features such as logging roads in the landscape is a major factor in the predator-prey system that is negatively affecting caribou by promoting the numerical and functional response of its predators. Our objective is to explain through local and landscape factors how the number of habitats use in snow-free season by wolves, black bears, lynx and the apparent competitor of caribou, moose, varies on different natural and anthropogenic linear features with the help of camera traps. In the western part of Quebec, Canada, the caribou wildlife site south of Val-d'Or is enclosing an isolated population at the edge of extinction requiring an active restauration of their habitat. In this site, we used a stratified random design to select lower-class gravel forest roads ($n = 33$), winter forest roads ($n = 28$) and riparian areas ($n = 19$) to compared their characteristics and the number of used by these four species. For the three predators, the difference in the lateral cover between the surrounding area and the linear feature mainly explains their number of uses. For wolf and lynx, use by their respective prey (moose and snowshoe hare) positively affects their number of uses. The number of gray wolf uses is also positively affected by distance to a higher forest road class (class 1 and 2) and negatively by distance to the nearest urban area. A higher percentage of hare habitat appears to slightly favor lynx number of uses. Essentially, gravel forest roads have the highest number of uses by all species but this is due to the less important lateral cover on these roads than in surrounding area. From these results, we recommend that restoration efforts related to forest road closures targeted all forest roads with favorable conditions in lateral cover difference. These

roads favour the movement of species responsible for the decline of the boreal caribou population.

Keywords: Woodland Caribou predators, anthropogenic disturbances, linear features, forest road, habitat use, camera traps, lateral cover, forest management.

2.2 Résumé

En forêt boréale aménagée, l'exploitation forestière accroît constamment le niveau de perturbation anthropique dans l'écosystème forestier. Ces perturbations rajeunissent la matrice forestière entraînant une modification de la densité et de la distribution des communautés fauniques au détriment de certaines espèces. Entre autres, l'implantation de structures linéaires anthropiques dans le paysage est un facteur prépondérant du système prédateurs-proies affectant négativement le caribou en favorisant la réponse numérique et fonctionnelle de ses prédateurs. Notre objectif est d'expliquer par des facteurs locaux et de paysages comment le nombre d'utilisations de l'habitat en période sans neige du loup, de l'ours noir, du lynx ainsi que du compétiteur apparent du caribou, l'original, varie sur différentes structures linéaires naturelles et anthropiques avec l'aide de caméras de surveillance. Dans l'ouest du Québec, au Canada, le site faunique du caribou, au sud de Val-d'Or, abrite une population isolée en voie d'extinction qui nécessite une restauration active de son habitat. Dans ce site, une sélection aléatoire stratifiée de chemins gravelés ($n = 33$) et de chemins d'hiver ($n = 28$) de classe inférieure ainsi que du milieu riverain ($n = 19$) a été faite pour comparer leurs caractéristiques ainsi que le nombre d'utilisations de ces espèces. Pour les trois prédateurs, la différence du couvert latéral entre le milieu environnant et la structure linéaire explique principalement leur nombre d'utilisations par 100 jours. Pour le loup gris et le lynx du Canada, l'utilisation par leur proie respective (Original et le lièvre d'Amérique) affecte positivement leur nombre d'utilisations. Le nombre d'utilisations du loup gris est affecté positivement par la distance à un chemin forestier de classe supérieure (classe 1 et 2) et négativement par la distance à la ville la plus près. Un pourcentage plus élevé d'habitats du lièvre semble augmenter légèrement le nombre d'utilisations du lynx. Essentiellement, les chemins forestiers gravelés présentent le nombre d'utilisations le plus élevé par toutes les espèces, mais c'est dû au couvert latéral moins élevé sur cette structure linéaire que dans son milieu environnant. De par

ces résultats, nous recommandons que les efforts de restauration liés aux démantèlements des chemins forestiers visent ceux dont les conditions de différences de couverture latérale sont favorables aux déplacements des espèces responsables du déclin des populations de caribou boréal.

Mots clés : Prédateurs du caribou boréal, perturbations anthropiques, structures linéaires, chemins forestiers, utilisation de l'habitat, caméras de surveillance, couvert latéral, aménagement forestier.

2.3 Introduction

The constant growth of the human population as well as the world economy is causing a considerable loss of biodiversity on the planet (Grooten et Almond, 2018). In general, this decline is primarily due to the loss and fragmentation of the habitat (Fahrig, 1997; 2003). Although still relatively intact, boreal forest ecosystems in Canada are also being impacted. Constant exploitation of natural resources through industrial activities (forestry, hydroelectricity, mineral and hydrocarbon extraction) is maintaining a high level of anthropogenic disturbance and is also compromising the maintenance of biodiversity (St-Laurent et al., 2009 ; Imbeau et al., 2015). These disturbances are rejuvenating the forest matrix, resulting in a change in the forest dynamic, composition, structure and fragmentation level. Such changes affect the density and spatial distribution of wildlife species to the detriment of certain species associated to mature forests with large home ranges such as the woodland caribou (*Rangifer tarandus caribou*) (Seip, 1992 ; Crête et Manseau, 1996 ; James et al., 2004 ; Bowman et al., 2010 ; Fisher et Burton, 2018 ; Lafontaine et al., 2019).

The most recent studies on caribou show that apparent competition is the phenomenon that best supports the hypothesis of declining populations in North America (DeCesare et al., 2010 ; Festa-Bianchet et al., 2011 ; Mumma et al., 2018). It is defined by the indirect negative effect that one species (woodland caribou) is suffering by the enhanced presence of another species (*Alces americanus*) that shares the same predator (*Canis lupus*) (Holt, 1977 ; Holt et Bonsall, 2017). Predation pressure on the less productive caribou is thus accentuated by a numerical and functional response of wolves in its habitat, which in turn are supported by the more productive moose prey in rejuvenating forests (Holt, 1977 ; 1984 ; Holt et Kotler, 1987). In addition, the number and distribution of black bears (*Ursus americanus*) has also increased on rejuvenating landscapes with the greater availability of its food resources (Mosnier et

al., 2008b), which raise predation on calves (Latham et al., 2011a ; Pinard et al., 2012; Leblond et al., 2016). Some studies in Labrador show that Canada lynx (*Lynx canadensis*) may also represent a significant predator of fawns (Bergerud et al., 1983 ; Mahoney et al., 2016). This increase in predation indirectly due to disturbance led to caribou being assigned a threatened species status in Canada in 2002 (Bergerud, 1974; Thomas et Gray, 2002 ; Festa-Bianchet et al., 2011 ; Leclerc et al., 2014).

Anthropogenic disturbances may be categorized as temporary or almost permanent on the land. The duration of the impact on anthropogenic disturbance is more of a gradient. As with natural disturbances (e.g. fires, insect epidemics), forest harvesting will initiate a process of development and succession that will lead to more favourable conditions for caribou within an estimated time frame of 40 years (Courtois et al., 2007 ; Environnement Canada, 2011). Anthropogenic linear features, on the other hand, increase the rate of disturbance in caribou habitat over a longer temporal period. Although its anthropogenic linear features often occupy a small portion of the land area, they can have a disproportionate effect on ecological processes (Trombulak et Frissell, 2000). Several studies in western Canada assert that the placement of anthropogenic linear features in the landscape, such as gravel forest roads and seismic lines, are overriding factors that alter predator-prey dynamics favoring predators at the expense of caribou (Schneider, 2002 ; Whittington et al., 2005 ; DeMars et Boutin, 2018). When present in its habitat, anthropogenic linear features induce an increase in functional and numerical response from predators. Functionally, anthropogenic linear features increase the hunting efficiency of predators, thereby increasing predation on caribou. Specifically, they promote spatial overlap of gray wolves and black bears in caribou refuge areas (undisturbed or mature forest) (McKenzie et al., 2012 ; DeMars et Boutin, 2018 ; Mumma et al., 2018), facilitate movement by increasing their travel speed (Dickie et al., 2017 ; Dickie et al., 2020) and thus their daily movement which necessarily creates a higher co-occurrence between predators and caribou (Whittington et al., 2011 ; McKenzie et al., 2012). As for the numerical response, it simply means

that the number of predators hunting in caribou habitat increases (McCutchen, 2007). Both of these responses cause an increase in natural predation that changes the sensitive demographic balance traditionally known for caribou (Bergerud, 1974 ; Leclerc et al., 2012). Although the demographic effect of linear features on large wildlife is well known, from a woodland caribou habitat restoration perspective, it would be relevant to identify which anthropogenic linear features are most likely to favor species associated with caribou decline. To do so, it is necessary to know the level of use of a variety of natural and anthropogenic linear features in the managed forest landscape to find the factors that explain a decrease or an increase in the number of uses of a linear feature. Knowing these factors is particularly important in the context of active caribou habitat restoration.

Over the past several years, models have been developed that provide information on the distribution and number of uses of large mammal species in their ecosystems with the help of camera traps. The site occupancy models developed by MacKenzie et al. (2002) are extremely useful for wildlife habitat management and conservation purposes. Indeed, these models allow us to know, among other things, the proportion of areas, the proportion of habitats or the probability of occupancy of a resource by species of interest considering even imperfect detection of individuals (MacKenzie et al., 2002 ; MacKenzie et al., 2017). To accommodate the imperfect detection, these models allow for the inclusion of multiple variables that affect the detection probability among sites, including temporal variables such as day, month or year during the sampling period. Occupancy thus attempts to answer whether or not a resource will be used and at what probability level. The intensity of use or counting model, on the other hand, informs whether a particular resource will be used more or less frequently over time (Keim et al., 2019). The outcome thus directly refers to the expected number of events in which the species uses a particular resource. The major distinction between the occupancy and counting models is that the probability of occupancy may remain constant over time as the intensity of use varies (Keim et al., 2011 ; Keim et al., 2019).

In the context of woodland caribou habitat restoration, we believe that, on linear features, it is more relevant to know the intensity of use or the number of uses per days of species related to caribou decline, as it indirectly informs us about species interactions. This model therefore allows us to directly quantify the actual risk experienced by caribou using the space near a linear feature also frequented by these predators.

Our objective is therefore to explain using local and landscape factors how the number of uses of woodland caribou predators, including gray wolves, black bears, and Canada lynx, as well as its apparent competitor, moose, varies along different natural and anthropogenic linear features during the snow free season. The literature shows little information in North America on the level of use of winter forest roads and riparian areas by these species. To compare the number of uses of different linear features, wildlife monitoring was conducted May to September 2020-2021 on gravel forest roads and winter forest roads ranging in width from 5-8 m , as well as the riparian area, which is used as a natural travel corridor (Newton et al., 2017 ; Dickie et al., 2020). Combining the number of uses for the snow-free season is relevant to forest management and is justifiable because of similar abiotic conditions on linear features in these periods. In addition, these large mammal species have large home ranges and by avoiding the effect of fall hunting, it is assumed that there will be a negligible change in habitat pattern or on linear features studied during this period for these species. We hypothesized that gravel forest roads have higher number of used by large mammals than the other two linear features. We assume that the difference in lateral cover conditions between the surrounding area and the linear feature is more conducive to movement on gravel forest roads. Also, we expected that prey use is more frequent, and the availability of edible plants is also higher on gravel forest roads. Predicting the number of uses of these species by their explanatory factors in a context of managed forest landscape is essential to guide woodland caribou habitat restoration initiatives (Rempel et al., 1997 ; Muhly et al., 2019).

2.4 Methodology

2.4.1 Study area

The study area is located in western Quebec, in the administrative region of Abitibi-Témiscamingue. Forestry is an important activity for this region. The forest ecosystem is mainly located in the northern part of the white birch – balsam fir bioclimatic domain (Saucier et al., 2009 ; Ministère des Forêts de la Faune et des Parcs (MFFP), 2016a). The average annual temperature is 1.5 °C and the average annual precipitation is 874.8 mm (Environnement Canada, 2010). The highest point in the study area is approximately 421 m and the lowest point is 308 m from mean sea level. The study area is located within the Forest Management Units (FMU) 08351 (Ministère des ressources naturelles (MRN), 2020b) and includes the caribou wildlife site south of Val-d'Or (47°53'20"N, 77°39'15"W), designated in 2013-2018, covering approximately 2145 km² (MFFP, 2018) (Figure 2.1). This caribou wildlife site was delimited by historical and recent telemetry surveys of tagged Val-d'Or caribou individuals (MRN, 2013). For several years, a gray wolf depredation program has been conducted in the northeastern part of the caribou wildlife site. The construction of the gravel and winter road in the wildlife site was carried out between 2004 and 2008. The wildlife site is primarily composed of softwood species including black spruce (*Picea mariana* (Miller) BSP.), jack pine (*Pinus banksiana* Lamb.) and balsam fir (*Abies balsamea* (L.) Mill.) with white birch (*Betula papyrifera* Marsh.). Mammals such as moose, gray wolf, black bear, lynx and snowshoe hare (*Lepus americanus*) are also present (Saucier et al., 2009).

2.4.2 Linear feature selection

In Quebec, the forest industry is the actor responsible for the construction of most of the anthropogenic linear features in the forest landscape with approximately 476,721 km of forest roads established in 2020. High class gravel forest roads (Quebec functional classes 1 and 2) represent a small percentage of all forest roads combined (13,082 km). These classes of forest roads, with a width of 8 to 9 m, are designed to have an almost permanent life span because it has multiple uses. The economic and social importance of these higher gravel forest road class make its dismantling too constraining. Narrow gravel forest roads (Quebec functional class 3 and 4) and winter forest roads built near logging areas represent about half of those established in Quebec with 165,875 km and 67,703 km respectively (MFFP, 2021). Such narrow anthropogenic linear features are more suitable to be dismantled for boreal caribou habitat restoration purposes. This study has therefore focused on these two types of anthropogenic linear features. Class 3 and 4 gravel forest roads have an estimated life span of 10 to 15 years for the transportation of wood mainly during the summer period. Gravel forest roads are regulated by using higher construction standards with compacted gravel and a rigorous drainage system (culvert) that allows a higher transport performance than winter forest roads. For example, their sub-grade consists of gravel and has a high compaction rate, which allows the roads to perform better while preventing degradation from occurring quickly. Narrower- to medium-width roads such as winter roads do not meet these standards; their construction is based upon a shorter-term vision and, therefore, their sub-grade consists of mineral soil, organic soil or woody debris. Gravel forest roads are considered a long-lasting disturbance in the forest landscape (Girardin et al., 2022). Winter forest roads, on the other hand, are used to transport wood when frozen ground conditions are met during the winter period. Low regulated standards for such roads imply a status of temporary disturbances (MRN, 2013 ; MFFP, 2018 ; 2020a). We also studied a natural linear feature used by

large wildlife, the riparian area. This natural edge constrains and concentrates movement and provides a quality environment for many prey species (Newton et al., 2017 ; Dickie et al., 2020).

Selection of linear features was done with the help of a geographic information system (ArcGIS Pro, 2.6.0). Geographic data for forest roads in the study area were provided by the Quebec Ministry of Energy and Natural Resources (MERN, 2014). In this same area, we also received from the Ministère des Forêts de la Faune et des Parcs (MFFP) the location of gravel and winter forest roads that were scheduled for dismantling in 2022 for the purpose of habitat restoration for the caribou wildlife site. To select the riparian area, we excluded the shorelines of water bodies less than 20 ha, since small water bodies are less likely to negatively impede movement (Newton et al., 2017). The entire wildlife site was thus covered with a grid of points, all spaced 150 m apart, to consider also small section of roads at the end of forest road network. We applied 5 spatial constraints before randomly drawing the final sample. The first constraint is the application of a 20 m buffer zone around all linear features studied to extract potential observation points. This 20 m zone corresponds, among other things, to the zone of influence of a logging road affecting the vegetation (Zhou et al., 2020) and to the minimum width of residual forest left around water bodies after a cut as a protection measure. Thus, this area represents a connectivity space that can be used as a travel corridor by wildlife. The second constraint is that all points located more than 500 m from a drivable forest road were discarded. This is a justifiable compromise between a fairly large number of points and sampling efficiency. The third accessibility constraint is to prioritize the points on roads that were scheduled to be dismantled due to their rarity to assure a long-term study. We apply a 3 km radius zone around these roads for sampling efficiency because some points are located too far away of dismantled roads. The points located within these radii allow us to obtain those with a potential to be randomly drawn for the purpose of our study. In order to distribute our sample spatially, the fourth constraint separates the study area into two sub-areas according to the degree

of recent use by Val-d'Or caribou and the intensity level of recent depredation. Thus, the sample is the result of a stratified random selection according to 5 groups of linear features (gravel forest roads with and without scheduled to dismantled, winter forest roads with and without scheduled to dismantled, and riparian areas). Finally, a minimum distance of 1 km between each observation point was established to promote the independence of sites within the same group. We therefore formed clusters located in the two sectors, i.e. 44 observation points in the north-eastern depredation sector (1698 km²) and 38 points in the south-western sector without depredation (447 km²). This process resulted in a distribution of sites presented in Figure 2.1 where we find 33 observation points on gravel forest roads, 30 on winter forest roads and 19 on riparian areas.

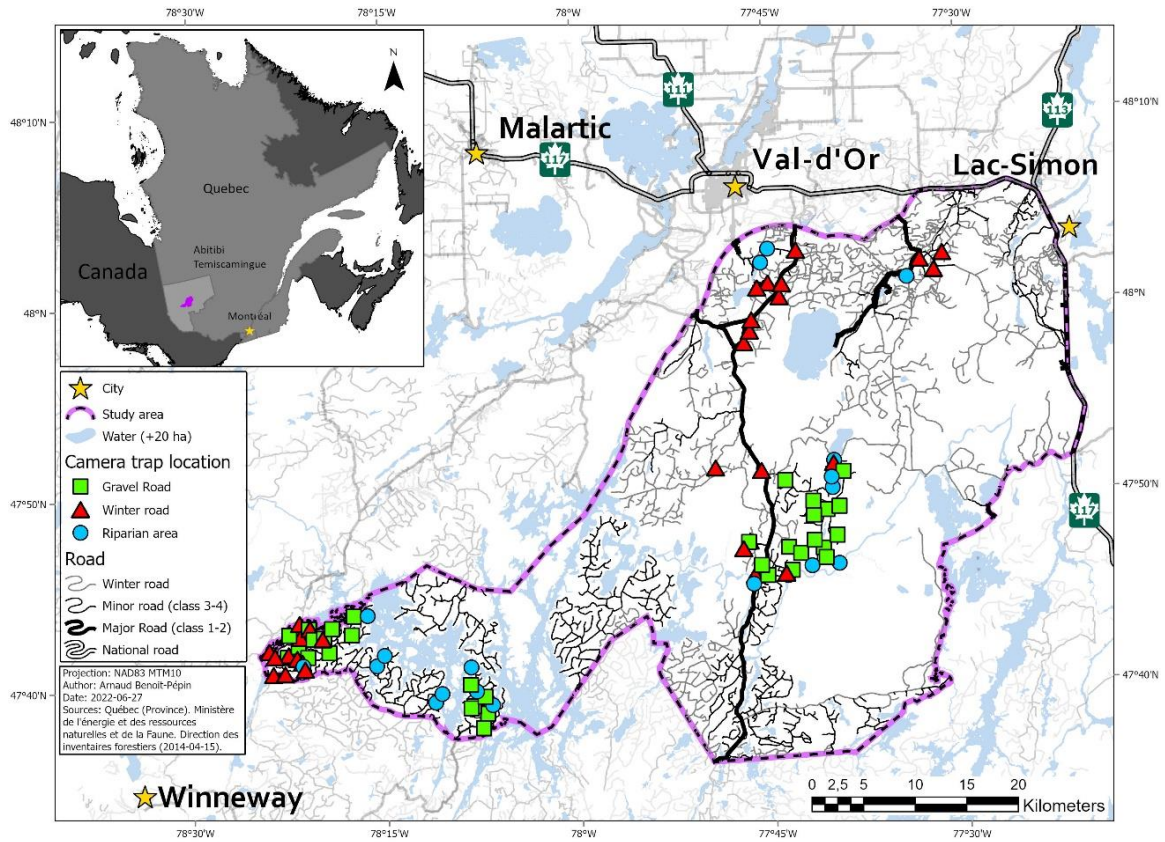


Figure 2.1 Location of the 33 gravel forest roads, 30 winter forest roads and 19 riparian areas surveyed by camera traps in the summer of 2020 and 2021 in the caribou wildlife site south of Val-d'Or, western Quebec, Canada.

2.4.3 Camera trap installation

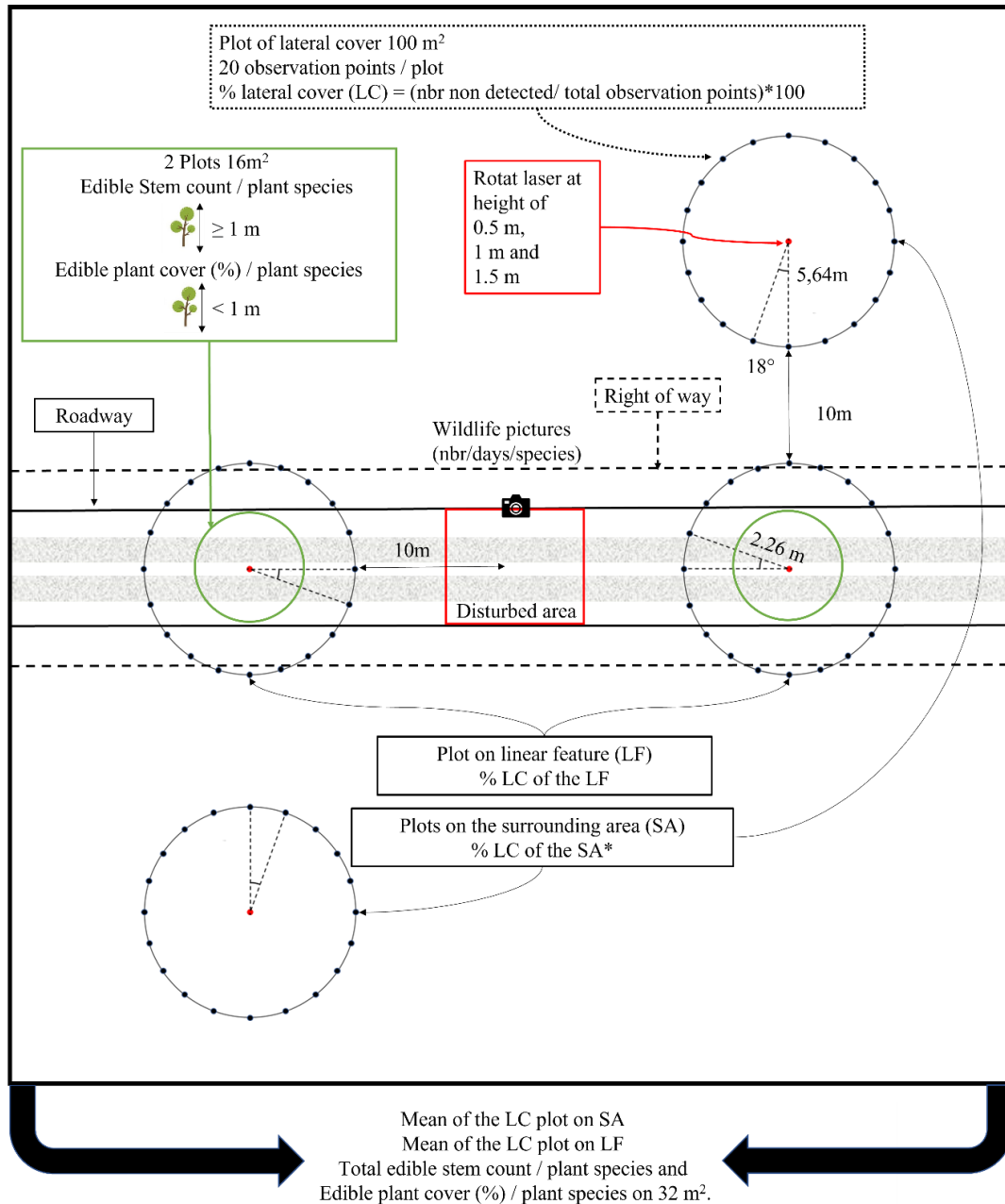
This survey required the use of 87 camera traps for the 82 linear features studied (30 models #119876CN: Trophy Cam HD Brown, 40 models #119776: Trophy Cam Aggressor brown, Bushnell, Overland Park, Kansas, USA, 7 models #119875: Trophy Cam Camo, 5 models #119977: Core DS). Some cameras had to be replaced which led to the purchase of other newer models to complete the tracking of linear features (5 models #119837 Trophy Cam E3). Sampling was conducted from June 9th to October 6th (93 days) in 2020 and from May 14th to September 17th (135 days) in 2021. Cameras were programmed to capture 3 photos per event to facilitate identification and a 5-second capture interval between each event. We positioned the cameras about 50 cm above ground level and aimed them as far north as possible for best image clarity with a 30-degree angle to the forest roads or to the estimated location on the riparian area to capture moving animals. For the riparian area, we used Rovero et Zimmermann (2016) as a guide to determine the most likely wildlife passage near the shoreline around a 0-20 m radius of the pre-selected station. We were forced to modify the environment by cutting branches in the field of view of the cameras to avoid false triggers. Photo and memory card retrieval was done at approximate intervals of 24-30 days. We used Wild ID software (Rovero et Zimmermann, 2016 ; Team Network, 2017), to annotate images in preparation for analysis.

2.4.4 Linear feature characteristics

2.4.4.1 Local variables

To quantify lateral cover, the method of Collins et Becker (2001), was adapted to increase the accuracy and efficiency of the measurement. Given the variable field of

view of the studied species, lateral cover was measured at 50 cm, 100 cm and 150 cm above ground level. For each sampling unit (Figure 2.2), we had two distinct micro-habitats (surrounding area and the linear feature) characterized by their own composition and plant cover. We therefore arranged two 100 m² (5.64 m radius) plots per micro-habitat. The plots in the surrounding area excluded vegetation within 10 m of the forest road right-of-way to avoid the edge effect (Zhou et al., 2020). On the linear feature, the plots were located on both sides of the camera at a distance of 10 m to avoid the vegetation area disturbed during the camera placement. Each of the plots had 20 observation points systematically distributed around its periphery, i.e. at an angle of 18° between each observation point. For each point, the observer, with the help of a pole, must position the detector device in order to capture the rotary laser signal (Bosch GRL900-20HVK). The percentage of lateral cover is calculated by counting the number of times the rotary laser signal was obstructed over the total number of observation points in the plot. We thus obtained, for each plot, three values of the lateral cover according to three measured heights. The average for each height (50 cm, 100 cm and 150 cm) was calculated for each environment. The average lateral cover value of each height of the linear feature is subtracted from the surrounding area to obtain the difference in lateral cover between the two micro-habitats. Thus, the possible values of the difference in lateral cover between the surrounding area and the linear feature are between -100% and 100% for each linear feature sampled. A positive value means that the linear feature is less obstructed than the surrounding area, a value of 0 means that there is no difference between the surrounding area and the linear feature, and a negative value means that the linear feature is more obstructed than the surrounding area.



*For the riparian areas, LC plots to the surrounding area were placed on the same side, at the opposite of the water body.

Figure 2.2 Visual representation of each vegetation measurement in a single linear feature sampling in the summer of 2020 and 2021 in the caribou wildlife site south of Val-d'Or, Québec.

To test the effect of food quantity on linear features for bear and moose, we applied 2 circular plots (16 m²) on the linear feature within the lateral cover plots at a distance of 10 m from the camera location (St-Pierre et al., 2021) (Figure. 2.2). A count of the number of stems (≥ 1 m height) and an assessment of the percentage of plant cover (< 1 m) in this plot were made. Next, we counted and cumulated for black bear and moose the total number of edible stems (Table. A2.3) as well as the average edible plant cover (Table A2.2) in both plots (32 m²).

For predators, habitat use is strongly associated with the habitat use of their prey (Fuller et al., 2003 ; Keim et al., 2011). The possible effect of respective prey number of uses on predators is a potentially favorable factor that affect their number of uses on linear feature. The prey considered are snowshoe hare for Canada lynx, American beaver (*Castor canadensis*) and moose for gray wolf and black bear. Then, from the prey events captured by the cameras, we extracted the events of prey use on each of the linear features. We also extracted for these same linear features the events of human activity to test whether the human uses causes species avoidance on the linear feature (Oberosler et al., 2017). Next, because species number of uses depend on the sampling effort of the cameras, we divided the obtained events of each prey and human activity by the camera sampling effort (days) on each linear feature. The result gives a rate of use for snowshoe hare, beaver, moose and human activity that will be used for the analysis.

2.4.4.2 Landscape variables

Using ArcGIS Pro and MRNF data (5th ecoforestry inventory of Southern Quebec), we also extracted landscape variables that we assumed to be important for explaining mammal distribution (Table 2.1). On different radii (250 m, 500 m, 750 m and 1000

m) around each camera trap, we calculated the density of all forest road classes (km/km^2), the percentage of the area of forests less than 20 years old (harvested or not) compared to the total land area. In the case of lynx, the percentage of dense cover stands (cover density higher than 50%) over the total productive area was considered. Finally, the distance to a higher-class forest gravel road (class 1 and 2) and the distance to nearest urban area was calculated for each camera trap position.

Table 2.1 Variables and hypothesis related to each species (gray wolf, Canada lynx, black bear, and moose) that could explain the number of uses on linear features (gravel forest and winter roads and the riparian areas) in the caribou wildlife site south of Val-d'Or, Québec. The expected effect for each species is represented by (+) for positive effect, (-) for a negative effect, (+/-) for varying effects and (NA) indicates that the covariate was not used in the generalized linear mixed-effect model for that species.

Group variables	Variables	Short form	Species-specific effect	Hypothesis
Local	Difference in lateral cover between the surrounding area and the linear feature (%) at 50 cm for predator and 150 cm for moose	DifLateralCover	(+) Wolf (+) Lynx (+) Black bear (+) Moose	The difference in lateral cover between the surrounding area and the linear feature could reflect the number of uses. Number of uses increases with increasing difference in lateral cover (Abrahms et al., 2016).
	Count of edible stems (\geq 1m)	EdibleStems	(NA) Wolf (NA) Lynx (+) Black bear (+) Moose	Availability of most digestible plants are affecting the displacement patterns for Black bear (Mosnier et al., 2008b). Moose preferentially forages in high productivity scrubland-early successional forests (Dussault et al., 2005 ; Cnum et al., 2017).
	Edible plants (<1 m) cover (%)	EdiblePlantCover	(+) Moose	
	Rate of human use (count/sampling effort)	Human	(-) Wolf (-) Lynx (-) Black bear (-) Moose	For all species, local human activity can cause a voidance of linear features and their adjacent zone (Oberosler et al., 2017).
	Rate of prey use (count/sampling effort)	Prey (Moose, Beaver, Snowshoe hare)	(+) Wolf (+) Lynx (NA) Black bear (NA) Moose	Predators such as wolf and lynx are positively related to prey density (Fuller, 1989 ; Fuller et al., 2003 ; Keim et al., 2011 ; King et al., 2020).
Landscape	Percentage of dense cover stands (more than 50% cover) in 1000 m radius	Densecoverstand	(NA) Wolf (+) Lynx (NA) Black bear (NA) Moose	Dense to closed canopy stands are important components of lynx habitat in northern boreal forests (Poole et al., 1996).
	Percentage of regeneration stands (20 years) in 250 m radius	Regenation-Stands	(+) Wolf (NA) Lynx (+) Black bear (+) Moose	Wolf selects regenerating stands based on its prey habitat preference (i.e., moose) (Houle et al., 2010). Black bear and moose select regenerating stands for forage opportunities (Brodeur et al., 2008 ; Mosnier et al., 2008b).
	Density (km / km ²) of forest roads (all classes) in 250m radius for Alces and 1000m radius for wolf, black bear, and lynx	DensityRoad	(+/-) Wolf (+/-) Lynx (+/-) Black bear (-) Moose	Density of anthropogenic linear features can negatively affect lynx and wolf occupancy (Mech et al., 1988 ; Mladenoff et al., 1995 ; Marrotte et al., 2020) or positively improve movement and hunting (Thurber et al., 1994 ; Whittington et al., 2005 ; Fisher et Burton, 2018 ; Dickie et al., 2020). Bears use anthropogenic linear features to facilitate movement (Dickie et al., 2020) or perceive this type of landscape as a risk due to high level of human disturbance (Gould et al., 2019). Moose tends to avoid anthropogenic linear features (Laurian et al., 2008 ; Grosman et al., 2011 ; Beyer et al., 2013 ; Thomas, 2018).
	Distance (km) to a higher forest road class	NearRoad	(+/-) Wolf (-) Lynx (+) Black bear (-) Moose	Distance to a higher forest road class (1 and 2) has a positive spatial effect by promoting movement for wolf (McKenzie et al., 2012 ; St-Laurent et Gosselin, 2020). However, in regions with high level of human activity, wolves tend to avoid anthropogenic disturbances (Lesmerises et al., 2012). Higher forest roads class may negatively affect lynx due to habitat loss, fragmentation and mortality risks (Bayne et al., 2008 ; Walpole et al., 2012). Black bears have a high tolerance of human activity, especially since anthropogenic linear features are often correlated with a availability of high quality food (Ladle et al., 2018). Disturbed areas with high human activity can be attractive to moose because it represents a refuge habitat from his predator (Rempel et al., 1997 ; Muhly et al., 2019).
	Distance (km) to nearest urban area	NearUrbanArea	(-) Wolf (-) Lynx (-) Black bear (+/-) Moose	The spatial urban area has an effect on density and space use of large mammal wildlife species (Berger, 2007 ; Bayne et al., 2008 ; Mcdonald et al., 2009 ; Muhly et al., 2011 ; Olsson et al., 2011)

2.4.5 Statistical analyses

All statistical analyses were performed with the help of R version 4.0.2 (R Core Team, 2020). For all statistical analyses, we considered the results to be significant at a threshold value of $p = 0.05$.

2.4.5.1 Local and landscape characteristics of linear features

We compared local and landscape variables by linear feature type that did not differ between years (excluding species interaction variables). For this analysis, 32 gravel forest roads, 27 winter forest roads, and 19 riparian areas were selected. We used two-factor ANOVA according to the several heights (50 cm, 100 cm, 150 cm) of the difference in lateral cover, and the different radii (250 m, 500 m, 750 m, 1000 m) of the percentage of dense cover stand, percentage of regeneration stand and the density of forest road. For the variables quantifying the food available on the linear feature for black bear and moose (count of edible stems (≥ 1 m) and edible plants (< 1 m) cover) and the two distance variables (distance to higher forest road class and distance nearest urban area), we used the one-way ANOVA. For all these ANOVA test, a Bonferroni adjustment ($p < 0.05/10 = 0.005$) was applied. Only the lateral cover difference variable met normality and homoscedasticity without transformation. The remaining variables required a square root transformation. Tukey's test was performed for each variable to find if any of the means differed between the three types of linear features.

2.4.5.2 Number of uses model

Prior to analysis, we removed linear feature sampling with dysfunctional camera traps (loss by theft, destruction by bears, leaf movements) from the dataset (Hamel et al., 2013). We thus selected only those that performed the full tracking of linear features. In 2020 and 2021 respectively, we remove from the data set 6-11 camera traps on gravel forest roads, 7-3 cameras on winter roads and 3-2 cameras on riparian areas. Note that the data on the same linear feature but in different years, were processed independently.

To determine the number of uses, the calculation is based on the number of use events corrected by the number of days of monitoring at each site with camera (offset). To avoid multiple events of the same individual passing and returning to the detection field of the camera traps on the same station, we specified a time interval of 10 minutes as a criterion for independence between 2 events of the same species at the same site (Keim et al., 2019). The use of a generalized linear mixed-effects model with Poisson distribution is appropriate in our case to calculate the number of uses of a species for the whole snow free period. To do this, the use events for each species are used as a response variable. This type of model then considers site variables, specific to each species, and random variables that can affect the number of uses of gray wolves, black bears, Canada lynx and moose. To do so, all numerical variables were standardized before the analysis. First, for fixed effects, we included in all models the year factor to control its effect. Secondly, for some fixed effect variables, a variable reduction filter was necessary due to the presence of correlations among some of the variables. This is the case for the different measurements of lateral cover at 50 cm, 100 cm, and 150 cm from the ground as well as for the calculations of the density of forest roads (DR), the percentage of dense cover forest (DS) and the percentage of regenerating forest (RS) at different radii (250 m, 500 m, 750 m, 1000 m from the location of camera traps). With the help of Akaike's information criterion corrected for small samples and

overdispersion (AICc) (Burnham et Anderson, 2002), model comparison for each previous variable taken at different scales allowed for the selection of the most parsimonious one for each species (Leblond et al., 2011). The fixed effect variables selected for further analysis are therefore presented in Table 2.1. The Schloerke et al. (2018) graphic tool of the fixed-effect variables found a strong correlation in lynx between distance to an higher forest road class and the percentage of dense cover forest (> 0.6). To overcome this problem, we retained only the more parsimonious one between these two variables (Leblond et al., 2011) and selected the percentage of dense cover forest. Note that for model moose, it was impossible to include the distance to nearest urban area because it led to estimation problems. For random effects, we included the database ID of the linear feature as a random effect in each model to account for the effect caused by the two repeated year measurements on the linear features (St-Pierre et al., 2022).

Since the effect of some local and landscape variables are strongly influenced by the type of linear features, separating the number of uses models into groups for all species was more appropriate. This means that the first group of models considered only the local and landscape variables in fixed effects which takes into account the biological aspect of the species. The effect of type of linear feature was excluded from the averaging of the first group so that the model would be predictive of local and landscape variables only. The second group and third group of models are relevant from a management perspective. The second group was used to predict and compare the number of uses and the type of linear features. So, we included in fixed effect only, the type of linear features (gravel forest roads, winter forest roads and riparian areas). Lastly, a third group of models compared for each species the best models of the first two groups to determined whether the type of linear feature is sufficient to identify restoration priorities.

We use R package lme4 (version 1.1-29) to build the models (Bates et al., 2011). For the first group, we generated, for each species and their respective variables, a global model and models with a single fixed effect variable. The second group considered only the linear feature type in fixed effect and the third is the comparison of the best models by species of the first two groups. All groups of models were compared to a null model. The goodness of fit of the global model for each group was performed following Mazerolle (2020). This test showed for the first group of models that the global lynx model is fitted to the observed data ($\hat{c} = 0.99$). However, there is a slight under dispersion for the wolf, bear and moose global models ($\hat{c} < 1$). For the global species models, the prediction result of 1000 simulations with 95% prediction interval show a good representation of the data (Figure A2.1). Then, the pseudo-R-square for Generalized Mixed-Effect models was calculated for all models in comparison to their null model. For each species, we used a model selection and multi-model inference based on AICc (Burnham et Anderson, 2002), using the AICcmodavg package (Mazerolle, 2020) to the first and the second group of models. With the help of the Shrinkage estimator function, we assessed the presence or absence of effect of local and landscape variables under all models. Prediction of the number of uses on the snow-free season was calculated with the modavgPred function by Mazerolle (2020).

To determine if there was a spatial bias in the use data for the 4 species of interest, we performed a neighborhood analysis per year with the geographic coordinates location of the camera traps (Bivand et al., 2013). To build the neighborhood list, the function Graph based spatial weights was used with the Gabriel graph method. To add a spatial dependence in the generalized mixed effect models, we used the fitme function of the package spam (Rousset, 2023). Only for the complete model of each species, the Moran's test was performed and showing that the location of the camera traps in 2020-2021 respectively was not correlated with the number of uses of wolves (p-value 2020-2021 = 0.89 – 0.92), lynx (p-value 2020-2021 = 0.28 – 0.68) and moose (p-value 2020-2021 = 0.70 – 0.43). Therefore, in the presence of only one spatial bias for black bear

(p-value 2020-2021 = 0.01 – 0.39) in 2020 related to the location of camera traps in the study area, we did not include the spatial location of the camera trap in the further analysis of number of use models.

2.5 Results

2.5.1 Characteristics of local and landscape variables of linear feature

2.5.1.1 Local variables

The difference in lateral cover (Figure 2.3 and Table A2.4) shows an effect of linear feature type (F-value = 26.806; p-value < 0.001) and the interaction with lateral cover measured at different heights (F-value = 3.967; p-value = 0.004). The difference in lateral cover between the gravel forest roads and the two other linear features is larger at 50 cm and decreases as the height value increases. At 50 cm, 100 cm and 150 cm above ground level, we obtain a difference of 38%, 18% and 8% respectively between graveled forest roads and winter forest roads. Between graveled forest roads and riparian areas, the difference is 35%, 18% and 11% respectively. The interaction indicates that the difference in lateral cover on the inside vs. outside of gravel roads differs by height stratum, but this pattern does not appear to be present for the other two linear features. (Figure 2.3). The difference in lateral cover is similar between the winter forest roads and the riparian areas, regardless of the height measured. These two linear features are very close to 0% signifying the absence of difference between the cover on the surrounding area and the linear feature. On the graveled forest roads, especially at 50 cm and 100 cm above ground level, the mean is 36 and 22% respectively. The lateral cover is therefore significantly lower on the graveled forest roads than in the surrounding areas.

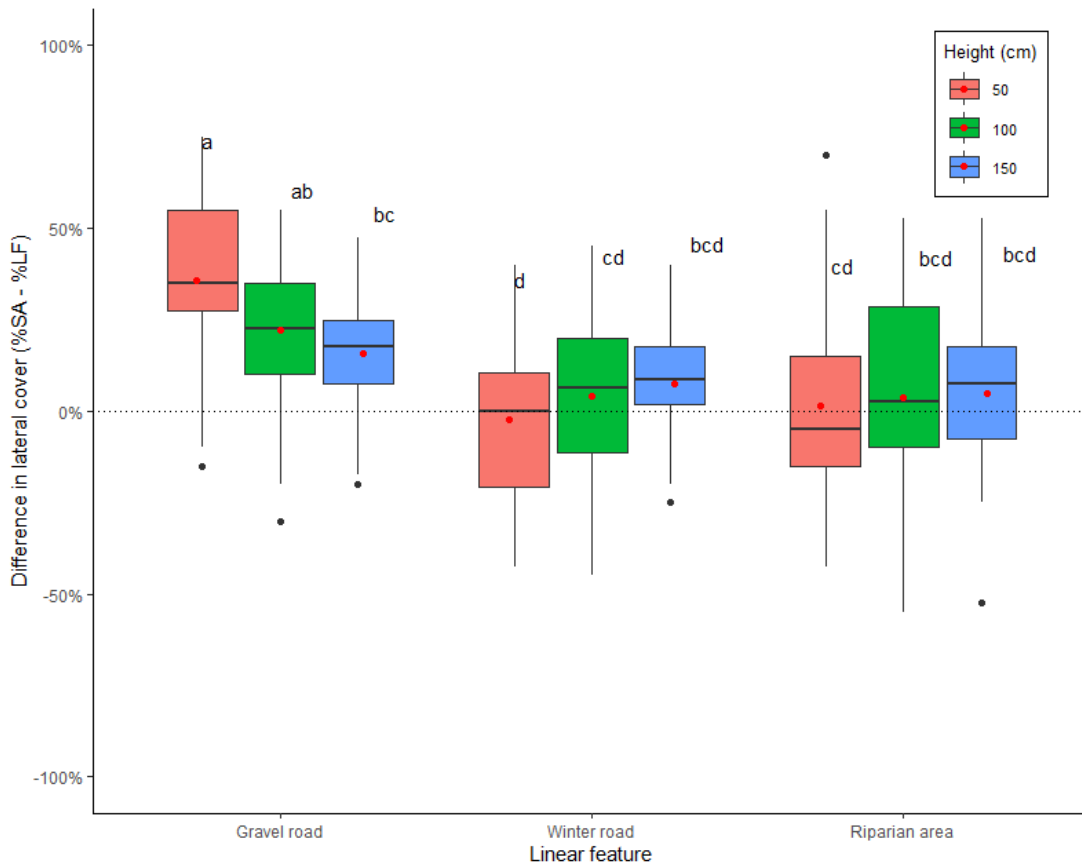


Figure 2.3 Distribution of the difference in lateral cover between the surrounding area (SA) and the linear feature (LF) measured at 50 cm (red boxplots), 100 cm (green boxplots) and 150 cm (blue boxplots) above the ground for 33 graveled forest roads, 29 winter forest roads and 18 riparian areas, in western Quebec, Canada. The mean values are represented by a red dot on the boxplots. The dotted horizontal line represents the absence of difference between the SA and the LF. Positive value means that the LF has less cover than the SA and a negative value means that the LF has more cover than the SA. The comparisons were conducted with a two-way Anova without transformation. Letters indicate significant differences between linear features and their respective height, with $a > b > c > d$ (Tukey tests).

As for the 2 variables representing the food available for black bear and moose, it is only in the proportion of edible plant cover (plants < 1 m) for black bear (F-value = 4.614; p-value < 0.001) that we observe a significant difference between the 3 types of linear features. For bear, there is respectively 17% and 18% less edible plant cover on graveled forest roads than on winter forest roads and riparian areas (Table A2.4).

2.5.1.2 Landscape variables

The landscape variables around the location of camera traps according to the type of linear features are presented in Figure 2.4 and Table A2.5. The proportion of regenerating stands (20-year class) differs between the three types of linear features (F-value = 35.32; p-value < 0.001). On average, 16% and 13% less regenerating stands are found around winter forest roads than around graveled forest roads and riparian areas respectively (Figure 2.4F). For the proportion of dense cover stands this variable differed between type of linear features (F-value = 12.9; p-value < 0.001) and the comparison differentiated winter forest roads from the two other linear features (Figure 2.4G). On average, we observed more dense cover stands around winter forest roads than around graveled forest roads (13% less) and riparian areas (16% less). For forest road density (km / km²), this variable differs according to the type of linear features (F-value = 81.1; p-value < 0.001) and to the different radii measured (F-value = 12.4; p-value < 0.001). Also, there is an interaction between the type of linear feature and radii selected (F-value = 13.28; p-value < 0.001), resulting in a negative relationship for graveled and winter forest roads, whereas the relationship is positive for riparian areas. At the 250 m and 500 m radii, the difference in density is greatest between the riparian areas and the two other linear features. At these radii, on average, the density of forest roads is lower around riparian areas compared to winter forest roads (2.84 km/km² and 1.45 km/km² higher respectively) and graveled forest roads (2.36 km/km² and 0.8

km/km² higher respectively). At an average of 750 m, the distinction is only present between winter forest roads and the riparian areas. At this distance, the density of all forest roads classes around the location of camera traps on winter forest roads is higher than for riparian areas (0.97 km/km² less) and around graveled forest roads (0.33 km/km² less). At a radius of 1000 m, no difference is observed between the three types of linear features. Overall, only by type of linear feature, the density of forest roads is 2.3 times higher on winter forest roads and 1.8 times higher on graveled forest roads than around riparian areas (Figure 2.4H). For the distance to a higher forest road class, this variable differs between the three types of linear features (F-value = 17.76; p-value < 0.001). We obtained an average distance to the camera traps of 3.6 times and 2.8 times higher for riparian areas and graveled forest roads than on winter forest roads respectively (Figure 2.4I).

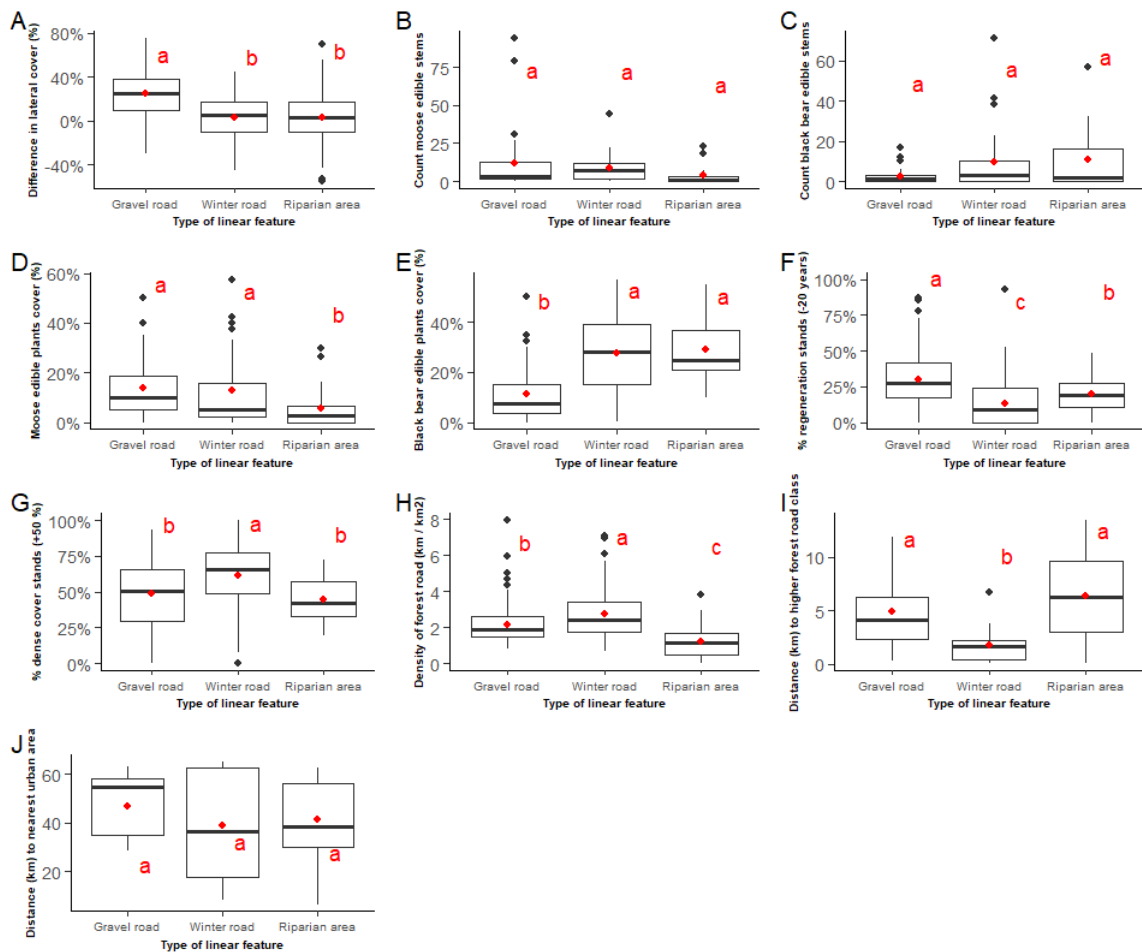


Figure 2.4 Distribution of local and landscape variables for 33 graveled forest roads, 29 winter forest roads and 18 riparian areas in western Quebec, Canada. The comparisons were conducted using one-way Anova for all the variables with square root transformation. The mean density values are represented by a red dot on the boxplots. Red letters indicate significant differences between linear features, with $a > b > c > d$ (Tukey tests).

2.5.2 Number of uses

For 5589 sampling days in 2020 and 7906 days in 2021, the cameras detected 21 mammal species on all linear features combined. Those most common were, in descending order of total mentions, snowshoe hare, red fox, human, Canada lynx, red squirrel, moose, American beaver, black bear and gray wolf (Table A2.1). For all the species of interest and models, the results of model selection and the marginal and conditional R-square for the three groups of models are presented in Tables 2.2, 2.3 and 2.4.

Table 2.2 Model selection based on the Akaike Information Criterion corrected for small samples and overdispersion (AIC_c) explaining the number of uses of linear features (gravel forest roads, winter forest roads and riparian areas) according to linear feature characteristics (first group of models) by gray wolf, black bear, Canada lynx and moose in the caribou wildlife site south of Val-d'Or, western Québec, Canada, in 2020 and 2021. The models for each species were compared to a null model. Only the two best models of each species are represented with respective Akaike weights (ω_i), log likelihood (LL), the number of estimated parameters (K), the marginal (R²M) and conditional R-square (R²C).

Models	LL	K	AIC _c	Δ AIC _c	ω_i	R ² M	R ² C
Gray wolf ~							
DifLateralCover50cm + Human + Moose + Beaver + RegenerationStands250m + DensityRoad1000m + NearRoad + NearUrbanArea + Year + (1 LinearFeatureID)	-224.70	11	473.59	0.00	0.97	0.51	0.94
DifLateralCover50cm + Year + (1 LinearFeatureID)	-236.19	4	480.69	7.09	0.03	0.33	0.94
Black bear ~							
DifLateralCover50cm + Year + (1 LinearFeatureID)	-275.60	4	559.51	0.00	0.77	0.16	0.45
DifLateralCover50cm + EdibleStems + EdiblePlantsCover + Human + Moose + Beaver + RegenerationStandS250m + DensityRoad1000m + NearRoad + NearUrbanArea + Year + (1 LinearFeatureID)	-266.48	13	562.04	2.53	0.22	0.26	0.45
Canada lynx ~							
DifLateralCover50cm + Human + SnowshoeHare + DenseCoverStands1000m + DensityRoad1000m + NearUrbanArea + Year + (1 LinearFeatureID)	-355.65	9	730.78	0.00	0.99	0.40	0.75
DifLateralCover50cm + Year + (1 LinearFeatureID)	-365.86	4	740.04	9.26	0.01	0.32	0.76
Moose ~							
DifLateralCover150cm + EdibleStems + EdiblePlantsCover + Human + RegenerationStands250m + DensityRoads250m + NearRoad + Year + (1 LinearFeatureID)	-303.12	10	628.06	0.00	0.47	0.15	0.50
DifLateralCover150cm + Year + (1 LinearFeatureID)	-310.76	4	629.84	1.77	0.19	0.06	0.47

Table 2.3 Model selection based on the Akaike Information Criterion corrected for small samples and overdispersion (AICc) explaining the number of uses of linear features (gravel forest roads, winter forest roads and riparian areas) according to type of linear features (second group of models) by gray wolf, black bear, Canada lynx and moose in the caribou wildlife site south of Val-d'Or, western Quebec, Canada in 2020 and 2021. The models for each species were compared to a null model. All models are represented with respective Akaike weights (ω_i), log likelihood (LL), the number of estimated parameters (K), the marginal (R^2M) and conditional R-square (R^2C).

Models	LL	K	AICc	$\Delta AICc$	ω_i	R^2M	R^2C
Gray wolf ~							
TypeLinearFeature + Year + (1 LinearFeatureID)	-236.82	5	484.11	0.00	1.00	0.32	0.94
Null + Year + (1 LinearFeatureID)	-249.14		504.47	20.36	0.00	0.001	0.002
Black bear ~							
TypeLinearFeature + Year + (1 LinearFeatureID)	-274.66	5	559.79	0.00	1.00	0.17	0.45
Null + Year + (1 LinearFeatureID)	-285.61	3	577.41	17.61	0.00	0.0001	0.0003
Canada lynx ~							
TypeLinearFeature + Year + (1 LinearFeatureID)	-369.84	5	750.16	0.00	1.00	0.25	0.77
Null + Year + (1 LinearFeatureID)	-383.33	3	772.85	22.7	0.00	0.004	0.01
Moose ~							
TypeLinearFeature + Year + (1 LineraFeatureID)	-303.08	5	616.64	0.00	1.00	0.17	0.49
Null + Year + (1 LinearFeatureID)	-314.23	3	634.65	18.01	0.00	0.0005	0.002

Table 2.4 Model selection based on the Akaike Information Criterion corrected for small samples and overdispersion (AICc) of the two best model (third group of models) explaining the number of uses of linear features (gravel forest roads, winter forest roads and riparian areas) by gray wolf, black bear, Canada lynx and moose in the caribou wildlife site south of Val-d'Or, western Quebec, Canada in 2020 and 2021. The models for each species were compared to a null model. All models are represented with respective Akaike weights (ω_i), log likelihood (LL), the number of estimated parameters (K), the marginal (R^2M) and conditional R-square (R^2C).

Models	LL	K	AICc	$\Delta AICc$	ω_i	R^2M	R^2C
Gray wolf ~							
DifLateralCover50cm + Human + Moose + Beaver + RegenerationStands250m + DensityRoad1000m + NearRoad + NearUrbanArea + Year + (1 LinearFeatureID)	-224.70	11	473.59	0.00	0.99	0.51	0.94
TypeLinearFeature + Year + (1 LinearFeatureID)	-236.82	5	484.11	0.00	1.00	0.32	0.94
Null + Year + (1 LinearFeatureID)	-249.14	3	504.47	20.36	0.00	0.001	0.002
Black bear ~							
DifLateralCover50cm + Year + (1 LinearFeatureID)	-275.60	4	559.51	0.00	0.54	0.17	0.45
TypeLinearFeature + Year + (1 LinearFeatureID)	-274.66	5	559.79	0.29	1.00	0.17	0.45
Null + Year + (1 LinearFeatureID)	-285.61	3	577.41	17.90	0.00	0.0001	0.0003
Canada lynx ~							
DifLateralCover50cm + Human + SnowshoeHare + DenseCoverStands1000m + DensityRoad1000m + NearUrbanArea + Year + (1 LinearFeatureID)	-355.65	9	730.78	0.00	1.00	0.40	0.75
TypeLinearFeature + Year + (1 LinearFeatureID)	-369.84	5	750.16	19.38	0.00	0.25	0.77
Null + Year + (1 LinearFeatureID)	-383.33	3	772.85	42.08	0.00	0.004	0.01
Moose ~							
TypeLinearFeature + Year + (1 LineraFeatureID)	-303.08	5	616.64	0.00	1.00	0.17	0.49
DifLateralCover150cm + EdibleStems + EdiblePlantsCover + Human + RegenerationStands250m + DensityRoads250m+ NearRoad + Year + (1 LinearFeatureID)	-303.12	10	628.06	11.42	0	0.15	0.49
Null + Year + (1 LinearFeatureID)	-314.23	3	634.65	18.01	0	0.0005	0.002

The first group of models takes into account the local and landscape variables for each species, the effect of year and a random effect of the identifier of the linear features (Table 2.2). At the level of local variables, we observed a positive effect of the difference in lateral cover between the surrounding area and the linear feature on the number of use of all predators during the snow-free season (Table 2.5 and Figure 2.5). Note that the measured height of the most parsimonious lateral cover difference was 50 cm for predators and 150 cm for moose. There was a significant positive effect on the number of uses of gray wolf and Canada lynx associated with the number of uses of their respective prey (Table 2.5, Figure 2.6A and Figure 2.6B). The number of human activity variable did not have an effect on the number of uses of any of the species investigated. No effect was found on the two variables quantifying food quantity on linear feature for black bear and moose. For landscape variables, the number of Canada lynx uses seems to increase marginally as the percentage of dense cover stands increases near the linear feature (Table 2.5 and Figure 2.6C). We found no evidence that the percentage of regenerating stands within 250 m affected the number of uses for wolf, bear and moose (Table 2.5). None of the four species responded to the forest road density within a radius of 1000 m (Table 2.5). Furthermore, we observed that distance to a higher forest road class (Table 2.5 and Figure 2.6D) and the distance to the nearest urban area (Table 2.5 and Figure 2.6E) respectively had a positive effect and negative effect on the number of uses for gray wolf.

Table 2.5 Multimodel inference explaining the number of uses during the snow-free season according to the characteristics (first group of models) of linear features (gravel forest roads, winter forest roads and riparian areas) by gray wolf, black bear, Canada lynx and moose in the caribou wildlife site south of Val-d'Or, western Québec, Canada in 2020 and 2021. Estimates of the fixed effect explanatory variables on the number of use (λ) are presented with their 95% confidence intervals. All candidate models were used for multimodel inference.

Parameters	Estimate	SE	Lower limit	Upper limit	Parameters	Estimate	SE	Lower limit	Upper limit
Gray wolf					Canada Lynx				
<u>DifLateralCover50cm</u>	<u>0.85</u>	<u>0.2</u>	<u>0.46</u>	<u>1.25</u>	<u>DifLateralCover50cm</u>	<u>0.78</u>	<u>0.12</u>	<u>0.55</u>	<u>1.02</u>
Human	0.03	0.01	-0.16	0.22	Human	0.01	0.05	-0.09	0.11
<u>Moose</u>	<u>0.29</u>	<u>0.13</u>	<u>0.04</u>	<u>0.54</u>	<u>SnowshoeHare</u>	<u>0.17</u>	<u>0.05</u>	<u>0.06</u>	<u>0.27</u>
Beaver	0.04	0.11	-0.17	0.26	<u>DenseCoverStands1000m*</u>	<u>0.25</u>	<u>0.13</u>	<u>0.04</u>	<u>0.46</u>
RegenerationStands250m	0.24	0.21	-0.17	0.65	DensityRoad1000m	-0.18	0.13	-0.43	0.07
DensityRoad1000m	0.17	0.22	-0.26	0.60	NearUrbanArea	-0.14	0.13	-0.39	0.11
<u>NearRoad</u>	<u>0.54</u>	<u>0.23</u>	<u>0.09</u>	<u>0.98</u>					
<u>NearUrbanArea</u>	<u>-0.60</u>	<u>0.23</u>	<u>-1.06</u>	<u>-0.15</u>					
Black bear					Moose				
<u>DifLateralCover50cm</u>	<u>0.39</u>	<u>0.11</u>	<u>0.17</u>	<u>0.61</u>	DifLateralCover150cm	0.18	0.17	-0.15	0.51
EdibleStems	-0.04	0.09	-0.21	0.14	EdibleStems	0.01	0.08	-0.14	0.16
EdiblePlantCover	-0.02	0.06	-0.14	0.09	EdiblePlantsCover	0.09	0.21	-0.14	0.31
Human	-0.03	0.07	-0.16	0.11	Human	-0.15	0.17	-0.47	0.18
Moose	0.02	0.05	-0.08	0.11	RegenerationStands250m	0.15	0.16	-0.16	0.45
Beaver	0.01	0.04	-0.06	0.09	DensityRoad250m	0.08	0.13	-0.18	0.35
RegenerationStands250m	0.01	0.05	-0.09	0.12	NearRoad	-0.02	0.10	-0.22	0.17
DensityRoad1000m	-0.01	0.05	-0.11	0.09					
NearRoad	0.05	0.10	-0.15	0.25					
<u>NearUrbanArea</u>	<u>-0.01</u>	<u>0.05</u>	<u>-0.11</u>	<u>0.09</u>					

*Estimate with 90% confidence interval.

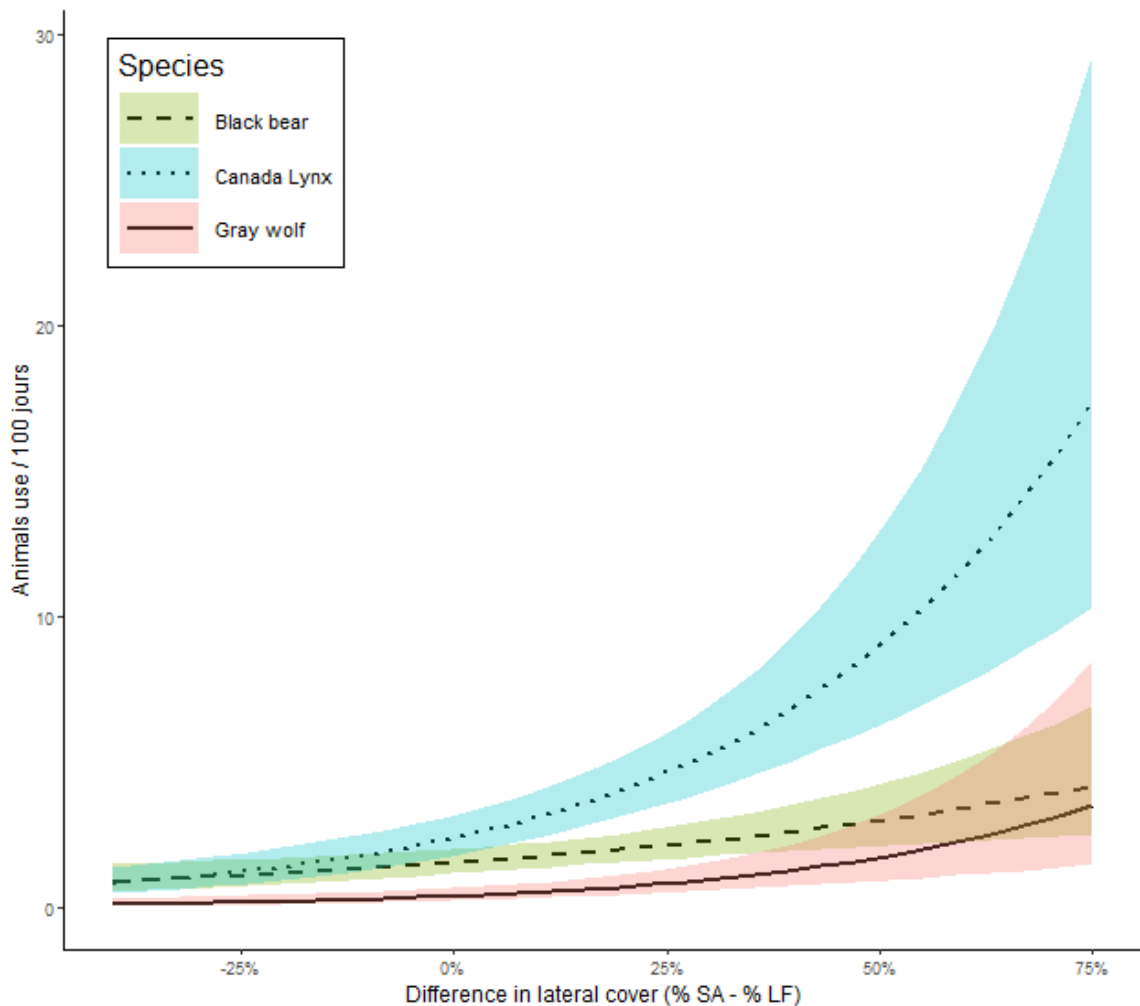


Figure 2.5 Model-averaged predicted number of uses over a period of 100 days during snow-free season of a linear feature by gray wolf, black bear, Canada lynx and moose based on the sequence of observed value of the difference in lateral cover between the surrounding area (SA) and the linear feature (LF) and the average value of all other variables. Data collected from 27-22 gravel forest roads, 24-27 winter forest roads and 16-17 riparian areas in 2020-2021 respectively, sampled in the caribou wildlife site south of Val-d'Or, western Quebec, Canada. The color shading denotes 95% prediction intervals around estimates for predators.

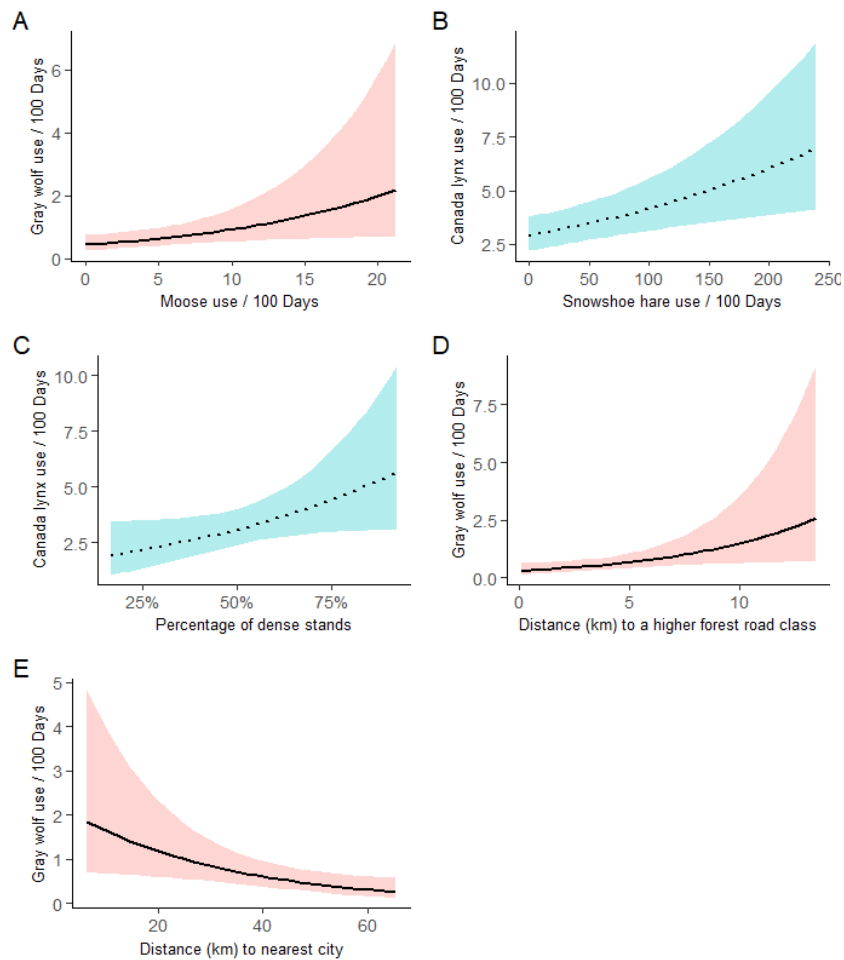


Figure 2.6 Model-averaged predicted number of uses over a period of 100 days during snow-free season by gray wolf (solid line) and Canada lynx (dotted line) based on the sequence of observed value of moose use (graph A), snowshoe hare use (graph B), percentage of dense stands (% 50 – 100%) in 1000 m radius (graph C), distance (km) to a higher forest road class (graph D) and the distance (km) to nearest urban area (graph E) and the average value of all other variables. Data collected from 27-22 gravel forest roads, 24-27 winter forest roads and 16-17 riparian areas in 2020-2021 respectively, sampled in the caribou wildlife site south of Val-d’Or, western Quebec, Canada. The shaded color denotes the 95% prediction interval around estimate for gray wolf and Canada lynx.

The results of the second group of models considering only the fixed effects of linear feature type and year and the random effect of linear feature (Table 2.3) are presented in Figure 2.7. For each species, number of uses over a period of 100 days during snow-free season is always significantly higher on gravel roads than on the two other linear features (winter roads and riparian areas). The mean prediction of the number of uses on gravel forest roads is 2 times higher for gray wolves, 3 times higher for black bears, and 4.5 times higher for Canada lynx than on the other two linear features. There was no significant difference between winter roads and riparian areas for predators, except for black bear, where a slightly higher number of uses was observed on riparian areas. For moose, the number of uses differed among types of linear features with a lower value for riparian areas than the two other types. So, there is 4.5 times more moose uses on gravel roads than on riparian areas and 2.6 times more moose uses on winter roads than on riparian areas.

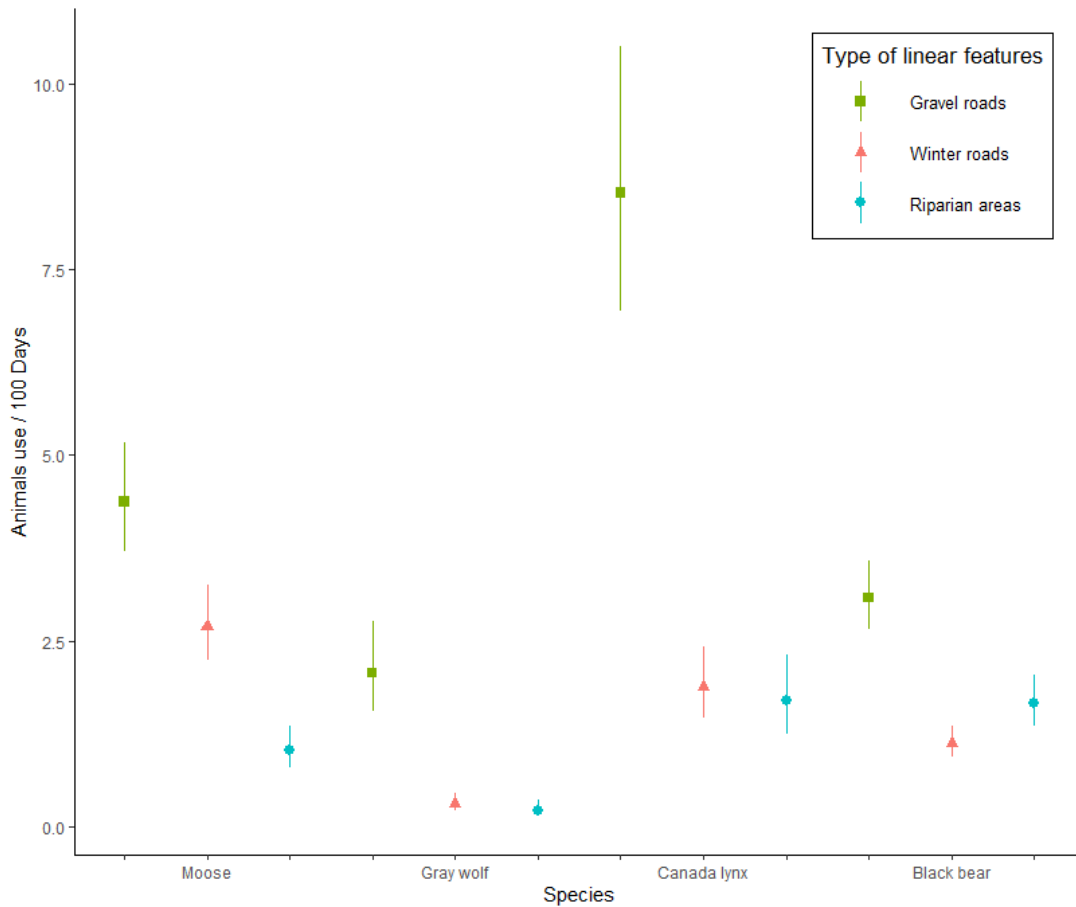


Figure 2.7 Model-averaged predicted number of uses over a period of 100 days during snow-free season by caribou predators (gray wolf, black bear and Canada lynx) and his apparent competitor (moose). Data were collected on 27-22 gravel forest roads, 24-27 winter forest roads and 16-17 riparian areas in 2020-2021 respectively, sampled in the caribou wildlife site south of Val-d'Or, western Quebec, Canada. Error bars denote 95% confidence intervals around estimates.

The third group of models that compared the two best models of the first two groups of models are presented in Table 2.4. The results show that for moose, the model with the type of linear feature only in fixed effect is more parsimonious than the global model considering all local landscape variables. For black bears, the model with the difference in lateral cover in fixed effect is a little more parsimonious than the one considering the effect of type of linear feature. Finally, for both carnivores, their respective global model is much more parsimonious than the one considering only the type of linear features.

2.6 Discussion

So, regardless of the type of linear features studied, the first group of models accounting for local and landscape variables on all linear features combined was able to address the hypotheses outlined in Table 2.1. We found that the use of linear features by gray wolves, black bears and Canada lynx is explained primarily by local variables. The hypothesis of a positive effect of important local explanatory variables including the difference in lateral cover between the surrounding area and the linear feature for these predators and the presence of respective prey by gray wolf (Moose) and Canada lynx (snowshoe hare) is consistent with our results. Contrary to the hypothesis that the rate of human activity causes linear feature avoidance for all species, our results showed no effect on all species. Furthermore, we expected a favourable effect of the quantity of food found on linear features on the number of uses by black bear and moose. However, our results showed no evidence of an effect and are thus not allowing us to confirm this hypothesis.

Landscape variable appeared to have a slight detrimental effect on gray wolf and Canada lynx. The hypothesis that a high percentage of species-favorable habitat

increases the number of uses of a linear feature is only confirmed for Canada lynx on the percentage of dense cover stands in 1000 m radius. Only for wolf, the distance to the nearest higher forest road class (class 1 and 2) and the distance to a nearest urban area have a positive and negative effect respectively on their use. The density of forest roads in the landscape seems to have no effect for all species.

When the effect of the type of linear features is considered, in the second group of models, it confirms our hypothesis that gravel roads have a much higher number of uses than the other two linear features. However, it is not possible to confirm that predators have a preference for using gravel roads as a travel corridor. Indeed, there is a confounding effect between the difference in lateral cover and the type of linear features.

For black bear and especially moose, the linear feature type is sufficient to adequately predict their number of uses during the snow-free season. However, for black bear, the best fitting model is the one considering only the difference in lateral cover between the surrounding area and the linear feature measured at 50 cm above the ground. The global model for gray wolf and Canada lynx is necessary to make a prediction that reflects the observations.

2.6.1 Local and landscape explanatory variables

For the explanatory variables, starting with the one common with the three predators. The results showed, in Table 2.5 and Figure 2.5, that their number of uses during the snow-free season on linear features increase positively with the difference in the lateral cover between the surrounding area and the linear feature. Even if there is a confounding effect of the type of linear feature, the result suggests that if the values of this variable are strongly positive (e.g. 75%), these predators will use them more

frequently during the snow-free season. This response is explained by the fact that these linear features are less covered by vegetation in the forest landscape and have a lower energy cost to their use. Linear features with these conditions therefore canalize predator paths, ultimately favoring their movements in the habitat (Abrahms et al., 2016 ; Dickie et al., 2017). Despite this variable effect, there are two distinct patterns on the distributions of the number of uses by the three species (Figure 2.5). The first one concerns gray wolf and Canada lynx. This trend for both carnivores suggests that linear features with favorable lateral cover difference conditions not only contribute to movement efficiency, but also can potentially provide hunting opportunity (Latham et al., 2011b). What distinguishes the two carnivores is the range of values that this predictor variable occupies where relatively high number of uses is found. Indeed, the Canada lynx, having rather an ambush hunting behavior, seems to use linear features as soon as the difference in lateral cover is positive ($> 0\%$) (Maletzke et al., 2008). In contrast, wolves travel long distances in packs to hunt prey and maintain their territory (Mech et Boitani, 2010). So, they start to use linear features that have strongly positive values (75%) of lateral cover difference. Also noteworthy, is that the higher number of uses of Canada lynx compared to wolf is largely related to its higher population density in the study area.

The second trend observed on Figure 2.5 concerns the black bear. This opportunistic and omnivorous species (Basille et al., 2011), has too much variability in number of uses than the two carnivores in relation to the difference in lateral cover. It is assumed that this species, having a largely plant-based diet, had less pronounced selection of their environment than carnivores (Latham et al., 2011a). It may thus spend less time than carnivores on linear features suitable for travel. Despite that the detected effect is less pronounced than for carnivores, this species still responds to this variable. Thus, it is assumed that black bear use, to a lower extent, linear features with a high lateral cover difference as an efficient means of moving to their food plots rather than foraging on them. This explanation is justified by the fact that our results show no evidence of

a positive effect on its number of uses for variables quantifying the amount of food available on linear features. Another interesting fact is that predators respond better to a difference in lateral cover measured at 50 cm. Indeed, hunting predators such as wolves, bears and Canada lynx seem to choose linear features where conditions of lateral cover difference are favorable at 50 cm from ground level. The result shows that these predators choose linear features where vegetation is almost absent for increased efficiency in movement and vision for hunting.

Finally, the number of uses of the respective prey of wolf (moose) and Canada lynx (snowshoe hare) on linear features also appears consistent with our hypotheses to be a dominant factor explaining the number of uses of their predator. As shown in the results for percentage of favorable habitat, only lynx uses linear features with higher percentage of dense cover stands more frequently. This result may not be explained as a cause-and-effect relationship, but rather as a similarity of use due to the strong presence of hare in this habitat type. Also, the assumption that higher forest roads class (1 and 2) are avoided by large mammals is only valid for the wolf. This large linear feature seems to affect mostly mobile species like gray wolf. The presence of a relative high level of vehicle traffic on such large linear features are necessarily associated with a high risk of mortality. Surprisingly, the assumption that proximity to the urban area does not adversely affect large mammals is invalid. Contrary to our prediction, gray wolf use is slightly higher near the urban area. It is difficult to interpret this result with such a small effect and with no effect for the other three species. The Caribou Val-d'Or Biodiversity Reserve, which covers an area of 434.2 km², is located less than 20 km southeast of urban area of Val-d'Or, perhaps a factor that can mitigate the impact of Val-d'Or. Also, there is a landfill 5 km east of Val-d'Or which probably contribute to this result.

2.6.2 Type of linear feature

Comparing the number of uses on the three types of linear features in relation to local and landscape variables is highly relevant from a forest management perspective. With the result shown in Figure. 2.7, we accept the hypothesis that there is no significant distinction in number of predators uses between winter roads and riparian areas, and that the number of uses on gravel roads for all species are significantly higher from these other two linear features. Thus, it appears that wolves, bears, lynx and moose differentiate gravel roads from the other two linear features but it is due to the confounding effect between the difference in lateral cover and the type of linear features. These values tend to be more frequently higher on gravel forest roads than on the two others linear features. Thus, it is not possible to distinguish the type of linear feature from the difference in lateral cover. In other words, the number of uses is higher on gravel roads, but this is possibly due to the lower lateral cover on gravel forest roads than around these roads. So, we cannot really confirm that gravel roads are preferred over the two other linear features. However, it is interesting to make links between the level of use of the different types of linear features and their specific characteristics.

The analysis that predict the number of uses according to the local and landscape variables (Table 2.5) shows that the number of uses depends mainly on a favorable difference in lateral cover for predators and on the presence of prey (moose for wolf and snowshoes hare for Canada lynx). Incidentally, this type of characteristics is found on the gravel roads with significantly higher difference values than on the other two linear features (Figure 2.3). These largely explain the strong difference in the level of number of uses of the three predators (especially Canada lynx) on the gravel roads compared to the two other linear features. Being a persistent disturbance in the landscape, gravel roads have an almost complete absence of vegetation on the roadway. This vegetation has difficulty colonizing and persisting in this type of compacted soil

(St-Pierre et al., 2021). Therefore, there are less barriers to movement on gravel roads than on the other two linear features. Gravel roads represent an efficient and sustainable movement corridor in space and time for large mammals. In addition, gravel roads are often associated with an abundance of prey (moose and snowshoe hare), thus the number of uses increases significantly on gravel roads for predators.

Winter roads, on the other hand, have very similar values of difference in lateral cover to the riparian areas. That is, close to 0, signifying no difference between the surrounding area and the linear feature (Figure. 2.3). Indeed, this value is consistent with the comparison results of the number of uses between linear feature types as winter roads show low number of uses compared to the gravel roads but similar to riparian areas. This result is explained by the fact that winter roads are generally already heavily revegetated. Indeed, the lack of land shaping on these anthropogenic linear features allows the vegetation to quickly recolonize the winter road after its construction (Girardin et al., 2022 ; Braham et al., 2023). After a few years, the lateral cover on winter roads is strongly similar to the surrounding forest making it less efficient to movement in the landscape. Noteworthy, the selection of winter roads revealed that they were rarely connected to a lower class (3 and 4) logging road than higher forest roads class (1 and 2) in our study area (Figure. 2.4I). For this reason, it possible that wolf uses less winter roads.

Surprisingly, the riparian areas have a similar number of uses to winter roads for predators, but a lower number of uses for moose. In fact, these natural linear features have smallest values of differences in lateral cover between the surrounding area, apparently explaining the low number of uses by carnivores. Several studies show that riparian environment is a linear feature frequently used by predators in the summer season (Latham, 2009 ; Mech et Boitani, 2010 ; Latham et al., 2011b ; Kittle et al., 2017). Nevertheless, our study is in line with that of Newton et al. (2017) showing that gray wolf selection of forest roads is compensatory to natural linear features. Dickie et

al. (2020) for wolves and bears as well as Terwilliger et Moen (2012) for lynx observed as well that these three predators respond less to natural linear features in the presence of anthropogenic linear features in the landscape. In our study, we observe similar results since we find better conditions of difference in lateral cover on gravel roads than on the other two linear features. The habitat use of these species seems to be relocated, in the forest, on this type of linear features rather than on natural linear features as riparian environments of large water bodies in the free-snow season.

To facilitate management without compromising restoration or conservation objectives, predicting the number of uses for each species with only the type of linear features is extremely relevant. However, comparison of the best model (biology vs. type of linear feature) shows that only for moose the type of linear features is sufficient to identify priorities of forest road restoration. For the black bear it could also be valid. However, for gray wolf, black bear and lynx, the best biological models (local and landscape variable) are more representative of their use during the snow-free season and can eventually identify more precisely the roads that promote the functional response of these three boreal caribou predators.

The limit of our study is that we predict the number of uses, all other things being equal, among the type of linear feature. We have therefore chosen common variables within the linear structures studied. So, some explanatory variables that concern only the anthropogenic linear features were not included in our model because of our interest to studying the riparian areas. It could be relevant for a study that is only interested in the anthropogenic linear feature to analyze the variables evoked in (Braham et al., 2023) such as the width and the years-post construction.

2.7 Conclusion

The difference in lateral cover between the surrounding area on the linear feature seems to be the main factor explaining the number of uses by large wildlife predators in the white birch-balsam fir domain. In the absence of a difference in lateral cover, the number of uses by caribou predators decreases drastically to almost zero. This result is of paramount importance in a context where the cause of the decline of boreal caribou is linked to an increase in predation by wolves and bears with the contribution of the presence of the anthropogenic linear features. Reducing the number of linear features with low lateral cover relative to the surrounding area could reduce the ability of predators to locate and move through caribou habitat. This reduction thus can potentially reduce the likelihood of co-occurrence, which should help reduce the risk of predation on caribou.

Although gray wolf and Canada lynx is also influenced by the presence of their prey and are slightly affected by landscape variables, the difference in lateral cover is an extremely informative variable in the context of forest management. Especially since this data predicts the number of predators uses better than only with the type of linear features as information. The difference in lateral cover allows for the concrete identification of all forest roads that improve the functional response of predators. By acting directly on those forest roads, through restauration action, the number of predator and prey uses should decrease on linear features and the habitat would be less functional for travel to them.

Our results show that gravel roads have a significantly higher level of use than winter roads and riparian areas but it is possibly due to the higher value of difference in lateral cover on these linear features. Nevertheless, in general these roads seem to promote the functional response of predators in their habitat. With these confounding effects, we strongly recommend that financial resources available for forest road restoration should

be targeted specifically on gravel roads and winter roads that have positive value of difference in lateral cover between the surrounding area and the linear feature. Closing or re-vegetating these roads with an effective short-term treatment (Lacerte et al., 2021) can potentially control gray wolf, black bear, Canada lynx and moose use on this type of anthropogenic linear features. However, long-term research of restoration activities (closures, barriers, and revegetation) on gravel and winter roads is needed to estimate the time and the effectiveness of these treatment on the same mammal community and to see if there is a change in the functional response of predators in this habitat. We recommend to forest managers as a mitigation measure for future forest harvesting in boreal caribou habitat, rethink the design of forest road network by minimizing their proportion, especially those that are gravelled.

APPENDICE

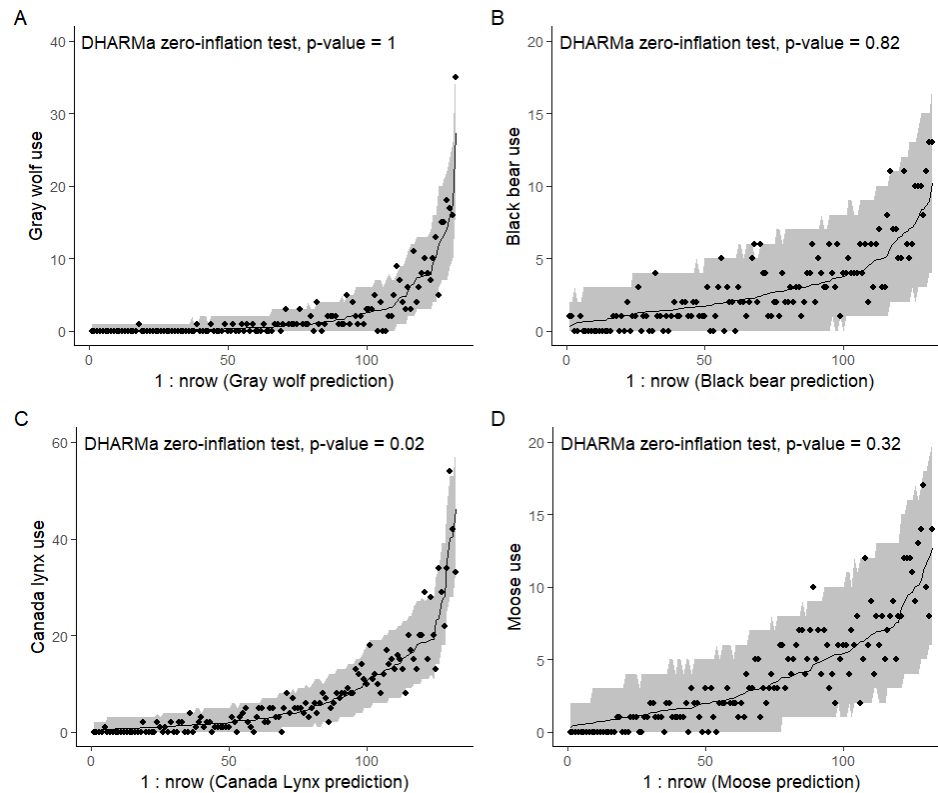


Figure A2.1 Simulation (1000) of global models for gray wolf, black bear, Canada lynx and moose using a generalized linear mixed effect model with Poisson distribution. Data were ordered according to their predicted values and were collected from 27-22 gravel forest roads, 24-27 winter forest roads and 16-17 riparian areas in 2020-2021 respectively, sampled in the caribou wildlife site south of Val-d'Or, western Quebec, Canada. The color shading denotes 95% prediction intervals for each observation in the dataset. The DHARMA zero-inflation test is comparing the observed number of zeros with the zeros expected from simulations (a value < 1 means that the observed data has less zeros than expected).

Table A2.1 Mammal detections observed during the snow free season in 2020-2021 on 27-22 camera traps on gravel forest roads, 24-27 on winter forest roads and 16-17 on riparian areas respectively sampled in the caribou wildlife site south of Val-d'Or, western Québec, Canada. Mammals in bold represent those used for the statistical analyses.

Species	2020			2021		
	Gravel roads	Winter roads	Riparian areas	Gravel roads	Winter roads	Riparian areas
Snowshoe hare (<i>Lepus americanus</i>)	901	727	313	777	765	419
Red fox (<i>Vulpes vulpes</i>)	1056	6	2	287	9	7
Human (<i>Homo sapiens</i>)	570	112	4	470	109	19
Canada Lynx (<i>Lynx canadensis</i>)	292	69	60	324	143	56
American red squirrel (<i>Tamiasciurus hudsonicus</i>)	145	31	59	59	222	291
Moose (<i>Alces americanus</i>)	136	57	21	129	123	35
Beaver (<i>Castor canadensis</i>)	3	22	33	21	220	113
Black bear (<i>Ursus americanus</i>)	83	23	30	127	72	58
Gray wolf (<i>Canis lupus</i>)	102	12	18	129	46	10
Eastern chipmunk (<i>Tamias striatus</i>)	107	2	20	19	0	22
Porcupine (<i>Erethizon dorsatum</i>)	27	0	0	22	4	0
Northern flying squirrel (<i>Glaucomys sabrinus</i>)	0	0	12	0	2	38
Striped skunk (<i>Mephitis mephitis</i>)	2	5	1	21	16	5
American marten (<i>Martes americana</i>)	3	0	2	1	1	5
Coyote (<i>Canis latrans</i>)	4	0	0	2	2	0
Fisher (<i>Martes pennanti</i>)	3	3	2	0	0	0
North American river otter (<i>Lontra canadensis</i>)	0	0	0	0	6	0
Muskrat (<i>Ondatra zibethicus</i>)	0	0	0	1	4	0
Groundhog (<i>Marmota monax</i>)	2	0	0	2	0	0
Long-tailed weasel (<i>Mustela frenata</i>)	1	0	2	0	0	1
Raccoon (<i>Procyon lotor</i>)	1	0	0	0	1	0

Table A2.2 List of summer edibles plants (< 1 m) for Moose and black bear that were found on linear features. Data was collected on 33 gravel forest roads, 29 winters forest roads and 18 riparian areas in the caribou wildlife site south of Val-d'Or, western Quebec, Canada in 2021. For each mammal species, the sum of plants cover with value of 1 in each linear feature represented edible plants cover (EPR) variables.

Plants species	Edibles by	
	Moose	Black bear
Red Maple (<i>Acer rubrum</i>)	1	0
Mountain Maple (<i>Acer spicatum</i>)	1	0
American green alder (<i>Alnus alnobetula</i>)	1	0
Wild Sarsaparilla (<i>Aralia nudicaulis</i>)	0	1
Paper Birch (<i>Betula papyrifera</i>)	1	0
Leatherleaf (<i>Chamaedaphne calyculata</i>)	1	0
Yellow clintonia (<i>Clintonia borealis</i>)	0	1
Bunchberry (<i>Cornus canadensis</i>)	1	1
Red-osier Dogwood (<i>Cornus sericea</i>)	0	1
Woody debris	0	1
Horsetail (<i>Equisetum sp.</i>)	1	1
Wild strawberry (<i>Fragaria virginiana</i>)	0	1
Mountain Holly (<i>Ilex mucronata</i>)	0	1
Twinflower (<i>Linnaea borealis</i>)	1	0
Lycopod (<i>Lycopodium sp.</i>)	1	0
Grass (<i>Poaceae sp.</i>)	1	1
Trembling aspen (<i>Populus tremuloides</i>)	1	1
Pin cherry (<i>Prunus pensylvanica</i>)	1	1
Skunk Currant (<i>Ribes glandulosum</i>)	1	1
Rose (<i>Rosa sp.</i>)	1	0
Red raspberry (<i>Rubus idaeus</i>)	1	1
Dwarf raspberry (<i>Rubus pubescens</i>)	1	1
Willow (<i>Salix sp.</i>)	1	0
Canada Goldenrod (<i>Solidago canadensis</i>)	1	0
American Mountain-ash (<i>Sorbus americana</i>)	1	1
Rose twisted stalk (<i>Streptopus lanceolatus</i>)	1	0
Early lowbush blueberry (<i>Vaccinium angustifolium</i>)	0	1
Small Cranberry (<i>Vaccinium oxycoccos</i>)	0	1
Wild raisin (<i>Viburnum nudum</i>)	0	1

Table A2.3 List of summer edibles plants ($\geq 1\text{m}$) for Moose and Black bear found on linear feature. Data was *collected* on 33 gravel forest roads, 29 winters forest roads and 18 riparian areas in the caribou wildlife site south of Val-d'Or, western Quebec, Canada in 2021. For each mammal species, the sum of plants counts with value of 1 in each linear feature represented count of edible stems (ES) variables.

Plants species	Edible by	
	Moose	Black bear
Red Maple (<i>Acer rubrum</i>)	1	0
Mountain Maple (<i>Acer spicatum</i>)	1	0
American green alder (<i>Alnus alnobetula</i>)	1	0
Serviceberry (<i>Amelanchier sp.</i>)	1	1
Paper Birch (<i>Betula papyrifera</i>)	1	0
Red-osier Dogwood (<i>Cornus sericea</i>)	0	1
Beaked Hazelnut (<i>Corylus cornuta</i>)	1	1
Mountain Holly (<i>Ilex mucronata</i>)	0	1
Trembling aspen (<i>Populus tremuloides</i>)	1	1
Balsam Poplar (<i>Populus trichocarpa</i>)	1	1
Pin cherry (<i>Prunus pensylvanica</i>)	1	1
Willow (<i>Salix sp.</i>)	1	0
American Mountain-ash (<i>Sorbus americana</i>)	1	1
Wild raisin (<i>Viburnum nudum</i>)	0	1

Table A2.4 Distribution of local variables depending on the type of the linear feature. Camera traps are located on 33 gravel forest roads, 29 winters forest roads and 18 riparian areas in the caribou wildlife site south of Val-d'Or, western Quebec, Canada. The comparisons were conducted with the Anova one-way for all the variables, except for the difference in lateral cover between the surrounding area and the linear feature, which was analyse with Anova two-way. The result of Tukey test is presented with a letter.

Type of linear feature	DLC ¹ at			ES ² for		EPR ³ for	
	50 cm	100 cm	150 cm	Black bear	Moose	Black bear	Moose
Gravel road ^a	36 ± 25 ^a	22 ± 21 ^{ab}	16 ± 16 ^{bc}	2 ± 4 ^a	12 ± 21 ^a	11 ± 12 ^b	14 ± 12 ^a
Winter road ^b	-2 ± 22 ^d	4 ± 23 ^{cd}	8 ± 15 ^{bcd}	10 ± 16 ^a	9 ± 10 ^a	28 ± 16 ^a	13 ± 15 ^a
Riparian area ^b	1 ± 28 ^{cd}	4 ± 28 ^{bcd}	5 ± 23 ^{bcd}	11 ± 15 ^a	4 ± 6 ^a	29 ± 14 ^a	6 ± 9 ^b

¹ Difference in lateral cover between the surrounding area and the linear feature (%)

² Count of edible stem (≥ 1 m)

³ Edible plants (< 1 m) recovery (%)

Table A2.5 Distribution of landscape parameters depending on the type of the linear feature on different radii around camera traps location. Camera traps are located on 33 gravel roads, 29 winter roads and 18 riparian areas in the caribou wildlife site south of Val-d'Or area, western Quebec, Canada. The comparisons were conducted with a two-way Anova for all the variables, except for the distance to higher forest road class and the distance to nearest urban area, which was analysed with a one-way Anova. The result of Tukey test is presented with a letter.

Landscape variables	Type of linear feature	Radius			
		250 m	500 m	750 m	1000 m
Proportion of regenerating stands (10 years)	Gravel road ^a	39 ± 26 ^a	29 ± 18 ^{ab}	26 ± 14 ^{ab}	25 ± 12 ^{ab}
	Winter Road ^c	15 ± 23 ^c	14 ± 16 ^c	13 ± 12 ^c	12 ± 11 ^c
	Riparian area ^b	16 ± 15 ^{bc}	21 ± 12 ^{abc}	21 ± 12 ^{abc}	22 ± 12 ^{abc}
Proportion of dense cover stands (50%-100% cover)	Gravel road ^b	48 ± 27 ^a	49 ± 22 ^a	49 ± 19 ^a	48 ± 17 ^a
	Winter Road ^a	64 ± 30 ^a	60 ± 21 ^a	61 ± 18 ^a	61 ± 16 ^a
	Riparian area ^b	44 ± 12 ^a	44 ± 14 ^a	46 ± 16 ^a	47 ± 15 ^a
Density of forest roads (km /km ²)	Gravel road ^b	3.21 ± 1.25 ^{ab}	2.06 ± 0.77 ^{cde}	1.67 ± 0.52 ^{def}	1.55 ± 0.36 ^{def}
	Winter Road ^a	3.96 ± 1.86 ^a	2.71 ± 1.18 ^{bc}	2.31 ± 0.77 ^{bcd}	2.07 ± 0.63 ^{cde}
	Riparian area ^c	0.85 ± 1.11 ^g	1.26 ± 0.76 ^f	1.34 ± 0.72 ^{ef}	1.35 ± 0.59 ^{ef}
Distance (km) to higher forest road class	Gravel road		4.93 ± 3.16 ^a		
	Winter Road		1.75 ± 1.53 ^b		
	Riparian area		6.38 ± 3.89 ^a		
Distance (km) to nearest urban area	Gravel road		46.8 ± 12.7 ^a		
	Winter Road		41.2 ± 17.6 ^a		
	Riparian area		39.0 ± 22.1 ^a		

Table A2.6 Model selection based on the Akaike Information Criterion corrected for small samples and overdispersion (AICc) explaining the number of uses of linear features (gravel forest roads, winter forest roads and riparian areas) according to linear feature characteristics (first group model) by gray wolf, black bear, Canada lynx and moose in the caribou wildlife site south of Val-d'Or, western Québec, Canada, in 2020 and 2021. The models for each species were compared to a null model. All models of each species are represented with respective Akaike weights (ω_i), log likelihood (LL), the number of estimated parameters (K), the marginal (R^2M) and conditional R-square.

Models	LL	K	AIC _c	Δ AIC _c	ω_i
Gray wolf ~					
DiFLateralCover50cm + Human + Moose + Beaver + RegenerationStands250m + DensityRoad1000m + NearRoad+ NearUrbanArea + Year + (1 LinearFeatureID)	-224.70	10	473.59	0.00	0.97
DiFLateralCover50cm + Year + (1 LinearFeatureID)	-236.19	4	480.69	7.09	0.03
Moose + Year + (1 LinearFeatureID)	-242.79	4	493.89	20.30	0.00
RegenerationStands250m + Year + (1 LinearFeatureID)	-244.59	4	497.49	23.90	0.00
NearRoad + Year + (1 LinearFeatureID)	-245.76	4	499.84	26.24	0.00
DensityRoad1000m + Year + (1 LinearFeatureID)	-247.57	4	503.46	29.86	0.00
Null + Year + (1 LinearFeatureID)	-249.14	3	504.47	30.87	0.00
Beaver + Year + (1 LinearFeatureID)	-248.54	4	505.39	31.80	0.00
NearUrbanArea + Year + (1 LinearFeatureID)	-248.69	4	505.69	32.09	0.00
Human + Year + (1 LinearFeatureID)	-249.05	4	506.41	32.82	0.00
Black bear ~					
DiFLateralCover50cm + Year + (1 LinearFeatureID)	-275.60	4	559.51	0.00	0.77
DiFLateralCover50cm + EdibleStems + EdiblePlantsCover + Human + Moose + Beaver + RegenerationStandS250m + DensityRoad1000m + NearRoad + NearUrbanArea + Year + (1 LinearFeatureID)	-266.48	13	562.04	2.53	0.22
NearRoad + Year + (1 LinearFeatureID)	-280.26	4	568.84	9.34	0.01
EdibleStems + Year + (1 LinearFeatureID)	-281.15	4	570.62	11.12	0.00
RegenerationStand250m + Year + (1 LinearFeatureID)	-281.94	4	572.19	12.68	0.00
DensityRoad1000m + Year + (1 LinearFeatureID)	-282.43	4	573.17	13.66	0.00
EdiblePlantsCover + Year + (1 LinearFeatureID)	-282.48	4	573.27	13.76	0.00
Moose + Year + (1 LinearFeatureID)	-283.49	4	575.29	15.78	0.00
Null + Year + (1 LinearFeatureID)	-285.61	3	577.41	17.90	0.00
NearUrbanArea + Year + (1 LinearFeatureID)	-285.21	4	578.74	19.23	0.00
Human + Year + (1 LinearFeatureID)	-285.58	4	579.47	19.96	0.00
Beaver + Year + (1 LinearFeatureID)	-285.59	4	579.49	19.99	0.00
Canada lynx ~					
DiFLateralCover50cm + Human + SnowshoeHare + DenseCoverStands1000m + DensityRoad1000m + NearUrbanArea + Year + (1 LinearFeatureID)	-355.65	9	730.78	0.00	0.99
DiFLateralCover50cm + Year + (1 LinearFeatureID)	-365.86	4	740.04	9.26	0.01
SnowshoeHare + Year + (1 LinearFeatureID)	-378.59	4	765.50	34.72	0.00
DensityRoad1000m + Year + (1 LinearFeatureID)	-380.82	4	769.96	39.19	0.00
DenseCoverStands1000m + Year + (1 LinearFeatureID)	-381.81	4	771.94	41.16	0.00
Null + Year + (1 LinearFeatureID)	-383.33	3	772.85	42.08	0.00
NearUrbanArea + Year + (1 LinearFeatureID)	-382.92	4	774.16	43.38	0.00
Human + Year + (1 LinearFeatureID)	-383.00	4	774.32	43.54	0.00
Moose ~					
DiFLateralCover150cm + EdibleStems + EdiblePlantsCover + Human + RegenerationStands250m + DensityRoads250m + NearRoad + Year + (1 LinearFeatureID)	-303.12	10	628.06	0.00	0.47
DiFLateralCover150cm + Year + (1 LinearFeatureID)	-310.76	4	629.84	1.77	0.19
RegenerationStad250m + Year + (1 LinearFeatureID)	-311.10	4	630.52	2.46	0.14
DensityRoads250m + Year + (1 LinearFeatureID)	-311.62	4	631.55	3.49	0.08
EdiblePlantsCover + Year + (1 LinearFeatureID)	-312.06	4	632.44	4.38	0.05
Human + Year + (1 LinearFeatureID)	-312.27	4	632.86	4.80	0.04
Null + Year + (1 LinearFeatureID)	-314.23	3	634.65	6.59	0.02
EdibleStems + Year + (1 LinearFeatureID)	-314.15	4	636.61	8.54	0.01
NearRoad + Year + (1 LinearFeatureID)	-314.19	4	636.69	8.62	0.01

CHAPITRE III

CONCLUSION GÉNÉRALE

L'objectif général de ce projet de maîtrise était de quantifier l'utilisation de structures linéaires naturelles et anthropiques par les prédateurs du caribou boréal (loup gris, lynx du Canada et ours noir) ainsi que son compétiteur apparent, l'orignal. Pour ce faire, les objectifs spécifiques étaient 1) d'expliquer par des facteurs locaux et de paysages communs aux structures linéaires étudiées comment le nombre d'utilisations de ces espèces varie, 2) de comparer le nombre d'utilisations de ces espèces sur les chemins forestiers gravelés et d'hiver ainsi que du milieu riverain pour ainsi définir si les espèces ont une préférence pour un type en particulier et 3) identifier, entre le modèle biologique (variables locales et de paysage) et celui considérant seulement le type de structures linéaires, celui le mieux ajusté pour prédire le nombre d'utilisations des quatre grands mammifères durant la période sans neige.

Notre étude révèle que ce sont surtout les facteurs locaux au sein de la structure linéaire qui expliquent le nombre d'utilisations des 3 prédateurs du caribou. Comme spécifié dans l'étude (Abrahms et al., 2016), nous avons trouvé pour le loup, l'ours et le lynx que la différence du couvert latéral entre le milieu environnant et la structure linéaire reflète leur nombre d'utilisations durant la période estivale. De plus, nos résultats concordent avec ceux de Fuller et al. (2003) et Keim et al. (2011) où une utilisation fréquente des proies incite plus fortement le loup et le lynx à utiliser une structure linéaire que l'habitat de leur proie (orignal et lièvre d'Amérique). En effet, nous interprétons le résultat d'un nombre d'utilisations plus élevé par le lynx du Canada là où le pourcentage de couvert de peuplement dense est élevé, par une coïncidence avec

la présence importante de lièvre dans ce genre d'habitat. Certains facteurs anthropiques ont un léger effet sur le loup. Perçue comme un risque, cette espèce mobile semble éviter légèrement l'espace autour des chemins forestiers de classe supérieure (1 et 2), des résultats similaires à Lesmerises et al. (2013). Enfin, contrairement à nos prédictions, la proximité de la ville de Val-d'Or semble avoir peu d'effet négatif sur l'utilisation de l'habitat par ces quatre grands mammifères.

Le nombre d'utilisations est presque identique entre les chemins forestiers d'hiver et les milieux riverains pour les prédateurs, alors que celui des chemins gravelés est nettement plus important pour toutes les espèces. Cependant, il n'est pas possible d'affirmer que les prédateurs ont une préférence d'utilisation pour les chemins gravelés comme corridors de déplacement. En effet, la présence d'un effet confondant entre le couvert latéral et le type de structure linéaire ne permet pas de distinguer ces deux variables. C'est-à-dire que le nombre d'utilisations est plus élevé sur les chemins gravelés, mais cela est probablement dû au couvert latéral moins important sur les chemins forestiers gravelés qu'autour de ceux-ci. Nous pouvons quand même faire un lien avec l'étude de Newton et al. (2017) qui a déterminé que la sélection des structures linéaires anthropiques est compensatoire. C'est-à-dire que les prédateurs ne se déplacent plus sur les structures linéaires naturelles, mais sélectionnent maintenant les structures linéaires anthropiques pour leurs déplacements puisque ces dernières ont de meilleures conditions de différence de couvert latéral.

Les modèles biologiques (variables locales et de paysage) des quatre espèces prédisent mieux le nombre d'utilisations durant la période sans neige avec la variable de la différence du couvert latéral. De par ce constat, il serait donc judicieux de ne pas seulement cibler les priorités de restauration des chemins forestiers uniquement en fonction des chemins gravelés, mais plutôt selon la différence du couvert latéral entre le milieu environnant et la structure linéaire. De cette manière, l'identification des

chemins forestiers favorisant la réponse fonctionnelle des prédateurs serait plus représentative de la réalité.

La limite de notre étude est de prédire le nombre d'utilisations, toutes choses égales par ailleurs, en fonction du type de structure linéaire. Nous avons donc choisi intentionnellement des variables communes aux structures linéaires étudiées. Ainsi, certaines variables explicatives qui ne concernent que les structures linéaires anthropiques (chemins forestiers gravelés et d'hiver) n'ont pas été incluses dans nos modèles en raison de notre intérêt pour l'étude des milieux riverains. Il pourrait être pertinent pour une étude qui ne s'intéresse qu'aux structures linéaires anthropiques d'analyser les variables évoquées dans Braham et al. (2023) telles que la largeur et le temps écoulé depuis le dernier entretien des chemins forestiers.

Devant le constat de cette étude et dans un contexte de restauration de l'habitat du caribou forestier, nous émettons donc les recommandations suivantes :

- Les ressources financières disponibles à la restauration des chemins forestiers doivent viser particulièrement les actions de restaurations des chemins gravelés et d'hiver propices aux déplacements. C'est-à-dire ceux avec des conditions positives de différence de couvert latéral entre le milieu environnant et la structure linéaire.
- La fermeture par la mise en place d'obstacles sur les chemins d'hiver et le démantèlement par revégétalisation des chemins forestiers gravelés propices aux déplacements devrait faire l'objet de recherches afin de valider si c'est un bon moyen à court terme pour diminuer la réponse fonctionnelle des espèces dans l'habitat du caribou boréal.
- Réaliser une recherche à long terme de la fermeture des chemins forestiers gravelés et d'hiver est toutefois nécessaire pour estimer l'efficacité du traitement sur la même communauté de mammifères.

- Comme mesure d'atténuation des futures récoltes forestières dans l'habitat du caribou, nous recommandons aux aménagistes forestiers de repenser la manière de construire le réseau de chemins forestiers. Ces mesures devraient porter sur 1) la diminution de la proportion de chemins forestiers, plus particulièrement ceux gravelés afin de diminuer les coûts de restauration, le cas échéant et 2) la prévisibilité d'activités de restauration (fermeture des chemins, implantation d'obstacles et revégétalisation) en amont de l'accès au territoire.
- La présence de chasseurs peut compromettre les efforts de restauration, car ceux-ci, par la circulation motorisée relativement fréquente, maintiennent une différence du couvert latéral propice à son utilisation dans le temps. Le gouvernement du Québec devrait, en contexte d'habitat de caribou boréal, prévoir des mesures afin de limiter l'utilisation de chemins forestiers prioritaires par les mesures de restauration.

Ces recommandations sont nécessaires pour une restauration efficace et moins coûteuse des chemins forestiers nuisant au succès de rétablissement du caribou boréal. Malgré des solutions axées sur une voirie forestière qui diminue la réponse fonctionnelle des prédateurs ainsi que son compétiteur apparent dans l'habitat du caribou, il faut impérativement agir sur d'autres composantes de son habitat. Le fait est que si nous omettons d'agir simultanément sur la réponse numérique des prédateurs et de l'orignal, tous ces efforts et ces investissements sur les stratégies de restauration de chemins forestiers seraient futiles. Offrir un habitat de qualité à l'espèce est donc l'objectif à atteindre. Elle peut se faire par l'établissement d'aires protégées dans le cœur de son habitat. Ensuite, en périphérie de ces aires, les zones où l'on doit concilier les besoins du caribou et l'aménagement forestier pourraient appliquer une récolte forestière sur de plus longues périodes de révolution afin d'atténuer l'impact de la foresterie sur les populations de caribou boréal. Ces deux éléments sont probablement des incontournables pour diminuer le pourcentage de perturbations anthropiques et

maintenir des attributs de vieilles forêts dans son habitat, des indicateurs contributifs de l'état de santé des différentes populations de caribou boréal au Québec.

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