EDGE EFFECTS OF ROAD MATERIAL AND COMPACTION ON THE REGENERATION OF JACK PINE IN THE ENGLISH RIVER FOREST

by

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ABSTRACT

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Keywords: compaction, edge effects, English River Forest, jack pine, modeling, roads, road material

There is potentially a considerable proportion of harvestable forest area experiencing road edge effects. It may be important to understand these effects and how trees respond to them to improve forest growth modeling systems commonly used for forest management planning. The two objectives of this study are 1) to observe if road material type and road compaction affect the height growth of jack pine trees growing on road edges and 2) to estimate the proportion of forest area experiencing edge effects within the English River Forest Management Unit of Ontario. Results from this study indicated no evidence of a relationship between road material and tree height or between road compaction and tree height. However, a larger sample size may have yielded more meaningful results. The total amount of forest area in the English River Forest experiencing edge effects was estimated to range from 1075 hectares to over 21,000 hectares. These areas represent 0.29% and 8.84% of the maximum harvestable forest area, respectively.

CONTENTS

FIGURES

TABLES

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INTRODUCTION

Jack pine (*Pinus banksiana* Lamb.) is an economically and ecologically important tree species in the boreal forests of Northern Ontario. The main silvicultural treatments for this species include clearcutting and either aerial seeding or planting to produce even-aged pure jack pine stands.

An edge is a transitional area between forested and non-forest area or between two different forest stands. The contrast between the ecological characteristics of forest versus non-forest or forest stand versus forest stand produces an edge effect (Hansen et al. 1993, Robinson et al. 2010). In the boreal forest, edges may be natural or anthropogenic. Natural edges may include transitional areas between two forest stands that are different in age, species composition, crown closure, soil type, or many other characteristics. Natural edges also include transitional areas between forest stands and areas that have experienced a natural disturbance such as wildfire. Anthropogenic edges are produced as a result of road building, forest harvesting and other human-related activities. Trees regenerated on the sides of roads often experience certain edge effects throughout their life, which can influence light availability, soil moisture, wind speed, and other attributes, therefore impacting tree growth (Bowering et al. 2006, Delgado et al. 2007, Euskirchen et al. 2000, Hansen et al. 1993, Harper et al. 2015, Robinson et al. 2010). Since edges are created through road building, a large proportion of forest areas that are regularly harvested may be experiencing edge effects, thus understanding how tree growth responds to these edge effects may be critically important for modeling future stand harvest volumes.

There are two objectives of this study. The first objective is to observe if road material type and road compaction affect the height growth of jack pine trees growing on road edges. Road material types include foreign material such as gravel or native material such as sand. The second objective is to estimate the proportion of forest area experiencing edge effects within the English River Forest Management Unit.

I propose two hypotheses as to how jack pine height growth may respond to road material type and road compaction when located on road edges. The first hypothesis is that foreign road material negatively affects jack pine height growth, and the second hypothesis is that greater road compaction negatively affects jack pine height growth.

LITERATURE REVIEW

JACK PINE ECOLOGY

Jack pine (*Pinus banksiana* Lamb.) is a hard pine characteristic of the boreal forest, and it is the most widely distributed pine in Canada (see Figure 1). This species generally occurs on poor quality sites such as those with coarse sands, shallow soils, rock outcrops, and even permafrost. Jack pine is a shade intolerant species, meaning it grows best in open conditions and will not survive long when shaded by other species. It grows in either pure stands or mixed with other shade intolerant species such as white birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), red pine (*Pinus resinosa*) and tamarack (*Larix laricina*). Jack pine thrives after forest fires, as these fires produce the open conditions required for them to grow, as well as opening their serotenous cones to release seed. In absence of fire, shade tolerant species such as black spruce (*Picea mariana*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*) will grow in the understory of jack pine and eventually succeed as the dominant species. Jack pine is closely related to lodgepole pine (*Pinus contorta* var. *latifolia*), and these species may form hybrids where their ranges overlap in Alberta (Farrar 1995).

Figure 1. Jack pine range map (Farrar 1995).

VARIABLES INVOLVED IN EDGE EFFECTS AND TREE RESPONSES

Variables

Variables involved in road edge effects may include distance from road edge, year of road establishment, road width, road type (primary, branch, operational), road use by humans, other disturbances such as partial cutting of edge trees, macroclimate, characteristics of road opening, characteristics of vegetation adjacent to road opening, site class, age class of stand, and crown closure (Bowering et al. 2006).

Variables involved in edge effects in general may include type of edge (natural or anthropogenic), forest type (coniferous or deciduous), and geographic region (Harper et al. 2015). Hansen et al. (1993) suggests that patch size and edge structure may produce different edge effects, which may be translated to road width and shape.

Tree Growth and Other Responses

The above variables may impact mean tree DBH, mean tree height, mean tree basal area, stand basal area, stand density, allocation of resources within the tree bole, crown length, tree mortality near road edges (Bowering et al. 2006). They may also affect soil and air temperature, light intensity, canopy cover, and canopy height near edges (Delgado et al. 2007).

Other responses may include changes in tree canopy, lichen, and bryophyte cover, log abundance, conifer and broadleaf regeneration, snag abundance and diversity, and shrub and herb abundance and richness (Harper et al. 2015). They may additionally include changes in microclimate, forest dynamics, disturbance rates, decomposition, nutrient cycling, and pollination (Hansen et al. 1993).

Roads may result in forest edges having greater light infiltration, changes in temperature, predation of sensitive interior species by edge-tolerant species, increase wind exposure, dust and debris from road material, and invasion of exotic species (Bocking et al. 2017).

GENERAL EDGE EFFECTS ON TREES

A significant portion of the landscape may experience edge effects due to forest harvesting, road building, and other human-related activities. However, since large-scale disturbances such as fire are common in the boreal forest, edge effects of anthropogenic disturbances may have less ecological impact than in other ecosystems without large disturbances. As forest stands are harvested and then regenerated, edge effects between stands may be reduced over time (Harper et al. 2015). However, roads generally remain intact long after stand regeneration and will continue to produce these edge effects (Robinson et al. 2010).

Harper et al. (2015) found that edges in the boreal forest had a negative influence on tree basal area, canopy cover and bryophyte cover, a positive influence on log abundance and broadleaf regeneration, and no significant influence on snag abundance and diversity, log diversity, shrub and herb abundance and richness, coniferous regeneration and lichen cover (Figure 2). Relevant to this study are the variables of basal area and coniferous regeneration. Basal area for all trees was less on edges compared to interior forest, and coniferous regeneration was not influenced by edges. It should be noted that in this study, species measured included *Populus spp.*, *Picea mariana*, *Picea abies*, and *Pinus sylvestris*, and trees were mature, ranging from 60 to 275 years in age. They also found that edge influence rarely exceeded 20 metres into the forest. Euskirchen et al. (2000) stated that other studies have shown edge effects can range from 0 to 137 metres from edge to interior.

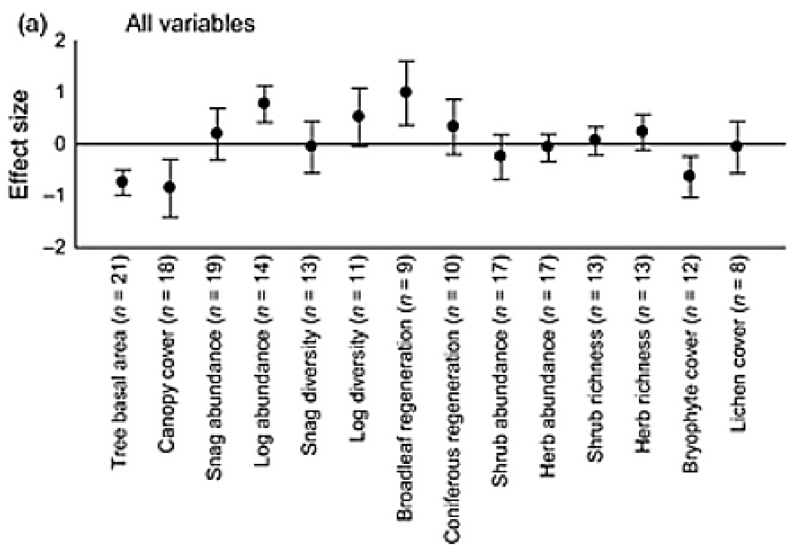

Figure 2. Edge effects of response variables (Harper et al. 2015).

Regarding roads, Harper et al. (2015) stated that although edges created by forest harvesting may not have strong effects on forest structure and vegetation in boreal ecosystems, forests fragmented by clear-cuts and roads may be detrimental to biodiversity.

EDGE EFFECTS ON SPECIFIC TREE SPECIES

<u>Lodgepole Pine</u>

The ecology of lodgepole pine is similar to that of jack pine, therefore they may respond similarly to road edge effects. A study conducted by Bowering et al. (2006) examines the effects of forest roads on the growth of adjacent lodgepole pine trees. They measured trees in plots divided into five zones beginning at the edge of the road: 0-5 m (zone 1), 5-10 m (zone 2), 10-20 m (zone 3), 20-30 m (zone 4), and 30-40 m (zone 5) from road edge. Zone 5 was used as a baseline for the interior forest. Growth attributes measured include mean diameter at breast height (cm), mean height (m), mean basal area per tree (m^2), stand basal area (m^2/ha), and stand density (stems/ha).

Their results showed that, on average, zone 1 had a 31% greater stand basal area than zone 5, which may be a result of increased stand density (stems/ha) or average tree size, or both. Individual tree size, measured as either mean DBH or mean basal area per tree, was not correlated with the distance from road edge. However, they stated that other studies have found significant differences in mean tree DBH at road edge. There was no significant difference in mean tree heights from road edge to forest interior, which was similar to the results of other studies. They also found that living trees had longer crowns and there were fewer dead trees in zone 1 (Bowering et al. 2006).

Applications of these results may include being able to estimate recovery of volume losses due to roads. The increase in stand basal area near road edges may offset the loss of not having trees grow on road space. Bowering et al. (2006) estimated that with the 31% increase in stand basal area between 0 and 5 metres from road edge, this may equate to a recovery of 3.13 m of growing space.

For this study, stands less than 10 years old were intentionally not selected for sampling because, based on previous studies, little to no growth impacts were expected (Bowering et al. 2006). My study focuses on younger jack pine trees specifically, because I wanted to observe growth impacts of roads on trees before light competition became a strong factor in their growth.

<u>Jack Pine and Red Pine</u>

Euskirchen et al. (2000) found that edges influenced up to a maximum of 30 metres into the forest interior for red and jack pine. However, this was based primarily on understory vegetation patterns and not the edge effects on red and jack pine. In this study, various diversity indices were measured along a transect run through clearcut, edge, and interior, including Shannon diversity, richness, Simpson's dominance, evenness, and total percent coverage. A significance test was done to see if there were significant differences in these diversity indices between clearcut and interior, edge and interior, edge and clearcut, and between red pine and jack pine stands (see Table 1).

Table 1. Diversity indices and estimated cover values for red and jack pine sites (Euskirchen et al. 2000)

			Significance of p-values			
	Mean	Range	Clearcut/ interior	Edge/ interior	Edge/ clearcut	Red pine/jack pine
Shannon diversity (*H′*)						
Jack Pine	0.86	0.78-0.90	No	Yes	Yes	Yes
Red Pine	0.68	0.57.0.74	No	Yes	No	
Richness (*R*)						
Jack Pine	11.2	10.2-12.2	No	No	No	Yes
Red Pine	8.1	6.1-9.1	Yes	Yes	No	
Simpson's dominance (*D*)						
Jack Pine	6.3	1.4-10.9	No	No	No	Yes
Red Pine	3.9	1.1-8.6	Yes	Yes	No	
Evenness (*E*)						
Jack Pine	0.83	0.76-0.86	No	No	No	Yes
Red Pine	0.77	0.73-0.81	No	No	No	
Total coverage (*T, %*)						
Jack Pine	110.9	63-165	No	No	No	Yes
Red Pine	79.5	16-135	Yes	Yes	Yes	

For jack pine, there was a significant difference in Shannon diversity between edge/interior and edge/clearcut, but no significant difference between clearcut and interior. There was no significant difference in species richness, Simpson's dominance, evenness, or total coverage between clearcut, edge, or interior (Euskirchen et al. 2000).

Douglas-fir

Hansen et al. (1993) examined the influence of edge effects on young Douglas-fir trees neighbouring a mature stand. They hypothesized that the young trees would experience reduced growth rates near plantation edges due to the shading from adjacent mature stands. Density, heights, and diameters at breast height were measured along transects extending 20 m from the stand edge.

They found that tree height and DBH were significantly related to distance from the edge when density was controlled for, and density was not significantly related to distance from edge. Tree heights and DBH were significantly lower at the shortest distance from the edge (Figures 3 and 4). The lack of significant changes in these growth attributes suggest that the edge effects only extended approximately 20 m into the forest interior (Hansen et al. 1993).

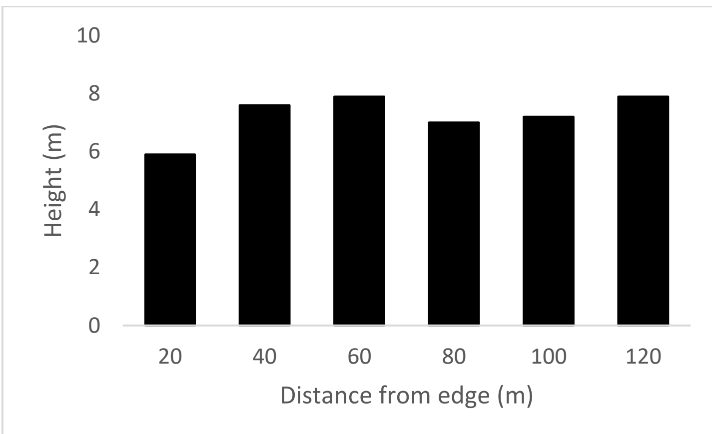

Figure 3. Douglas-fir heights along a transect from stand edge (Hansen et al. 1993).

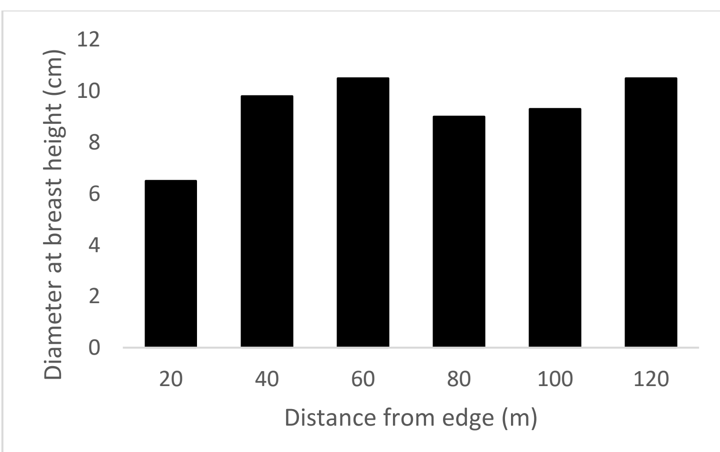

Figure 4. Douglas-fir diameters along a transect from stand edge (Hansen et al. 1993).

Pine in the Canary Islands

Delgado et al. (2007) studied the effects of roads on temperature, light, canopy cover, and canopy heights in pine forests of the Canary Islands. From road edge to forest interior, they found significant temperature changes up to 3 m into the forest for asphalt roads, light variation up to 6 m for asphalt and unpaved roads, and significant height and canopy cover changes up to 10 m for asphalt and unpaved roads. I will focus more on the results for the unpaved roads because my study primarily involves unpaved forest roads.

For the unpaved roads, light intensity was much greater near road edge compared to the forest interior (Figure 5). Canopy cover and canopy height were greater further from road edge (Figure 6). Temperature did not seem to be significantly correlated with distance from road edge (Figure 7; Delgado et al. 2007).

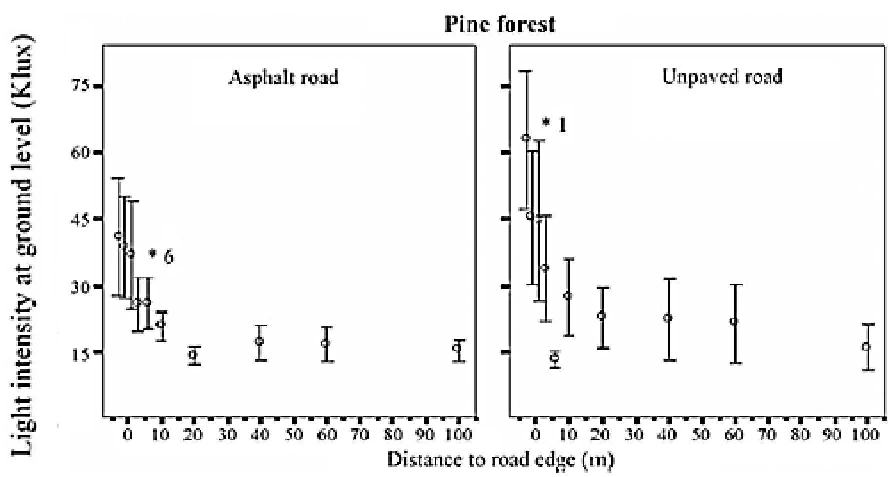

Figure 5. Light intensity in a pine forest in the Canary Islands (Delgado et al. 2007).

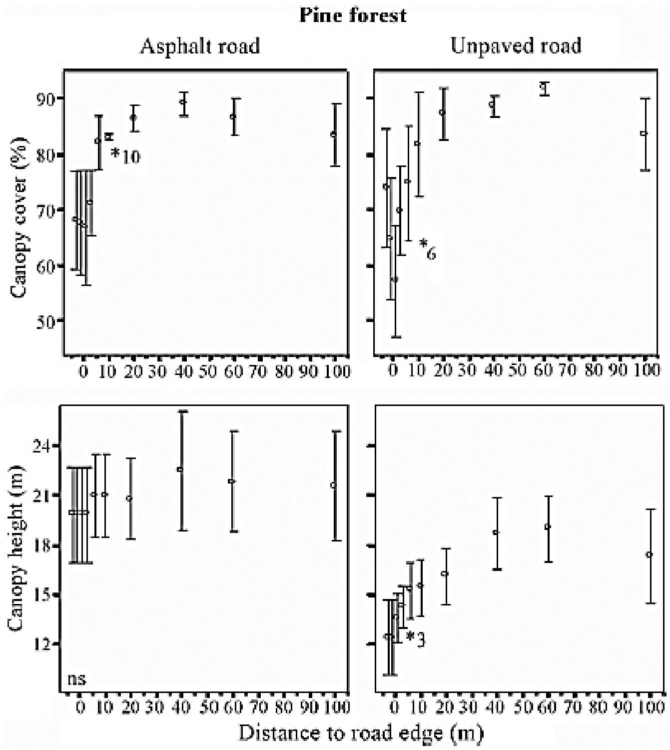

Figure 6. Canopy cover and canopy height in a pine forest in the Canary Islands (Delgado et al. 2007).

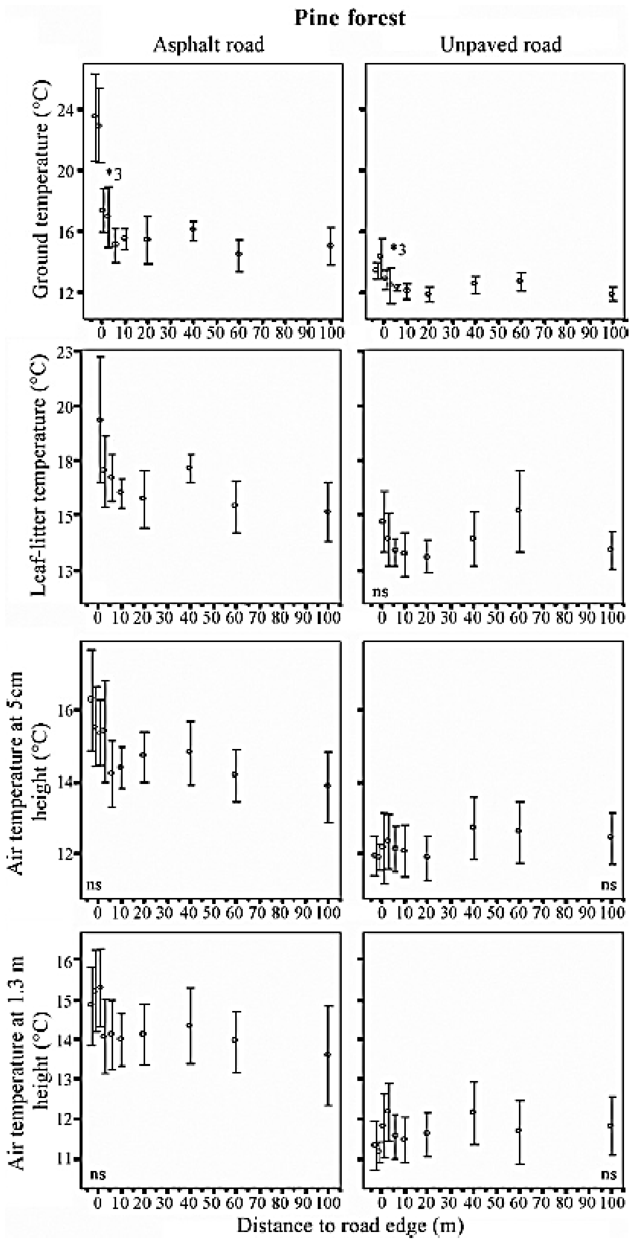

Figure 7. Temperature at four vertical layers in a pine forest in the Canary Islands (Delgado et al. 2007).

EFFECTS OF SOIL COMPACTION ON TREE GROWTH

Soil compaction is commonly known to have adverse effects on plant growth, such as poor root development, limited nutrient supply, and insufficient aeration, but these effects may vary with soil texture, structure, and climate (Fleming et al. 2006). Forest soils may take decades to fully recover from compaction (Simmons and

Anderson 2016). However, some are starting to recognize that soil compaction may not adversely affect seedlings as much as previously thought (Fleming et al. 2006).

Fleming et al. (2006) conducted a study which included observing the effects of soil compaction on various tree species seedlings across North America. They found that soil compaction actually improved conifer (including jack pine in Ontario) survival and growth, regardless of climate or species. They expected that species on coarse-textured soils would benefit more from compaction than those on fine-textured soils. This is because with fine textured soils, compaction may reduce water-holding capacity, restrict roots, and limit gas exchange, whereas compaction on coarse-textured soils may increase water-holding capacity without significantly affecting soil aeration. In their study, they also found that increased compaction reduced the amount of competing vegetation, which aided in seedling survival and growth.

Froehlich (1979) studied the effects of soil compaction on young ponderosa pine. They found that growth of the young pine trees was negatively affected by soil compaction from logging equipment on skid trails. 75 trees across a wide range of soil disturbances were measured, and soil densities around each tree were measured. Each tree was put into a compaction class: light, moderate, or heavy.

Over a 16-year period, moderately impacted trees showed a 6 percent reduction in growth rate and heavily impacted trees showed a 12 percent reduction in growth rate, which was measured as average basal area added per year.

MATERIALS AND METHODS

STUDY AREA

The study area is located in the southeast corner of the English River Forest Management Unit, just north of Upsala, Ontario. (See Appendix I for a detailed map of the study area). The area can be accessed from Highway 17 by driving north on Graham Road to kilometer 23, turning onto Petri Road to kilometer 23, north onto Petri Crossover to kilometer 36, left onto Aribi Road to kilometer 38, then north on Baltic Lake Road for 13 kilometers to get to the south access point, for a total of 74 kilometers from Highway 17. The licence for the English River Forest Management unit is held by Resolute Forest Products. The privately-owned Wagner forest is located to the south edge of the study area. Much of the study area has been regenerated with jack pine and black spruce through natural seeding and planting as part of Resolute's Forest Management Plan for the English River Forest. This study area is also being used for other research projects conducted by Lakehead University.

Two sites regenerated with jack pine relatively recently (i.e. within the past twenty years) within the study area were chosen based on road material: one with foreign material used for road building (gravel) and one with native material used (sand). The following site information was obtained from the Forest Resources Inventory geodatabase for the English River Forest, which was last updated in 2010.

Site 1 has the gravel roads. This site is a pure, even-aged jack pine stand that originated from artificial seeding in 2009 and was therefore 8 years old at the time of sampling. The ecosite classification for this site is B034TID n, meaning that it is a boreal, low treed (tree species <10 m tall), deep soiled (> 120 cm soil depth over bedrock), non-calcareous, dry, and sandy ecosite (Ministry of Natural Resources 2009).

Site 2 has the sand roads. This site is a pure, even-aged jack pine stand that originated from planting in 2000 and was therefore 17 years old at the time of sampling. The ecosite classification for this site is B034TID n, the same as site 1.

FIELD SAMPLING

Four circular 25 m^2 plots were placed on each site, two on road edge and two approximately 20 metres from road edge, for a total of 8 plots across the two sites. The centre of edge plots was placed directly where road material ends and where forest soil begins (see Figure 8). Plots were made using a plastic stake hammered into the ground at the centre of the plot with a 2.82 metre string attached so that it may move freely around the stake (see Figure 9). The heights of young jack pine trees within the plots were measured using a tree height pole with the assistance of a second observer. Trees that were affected by white pine weevil (*Pissodes strobi*) were intentionally not measured because this insect causes the tops of jack pine trees to die, thus reducing their height (Natural Resources Canada 2015). Four road compaction samples were randomly taken in each road edge plot using a soil penetrometer to obtain a mean soil compaction for the plot.

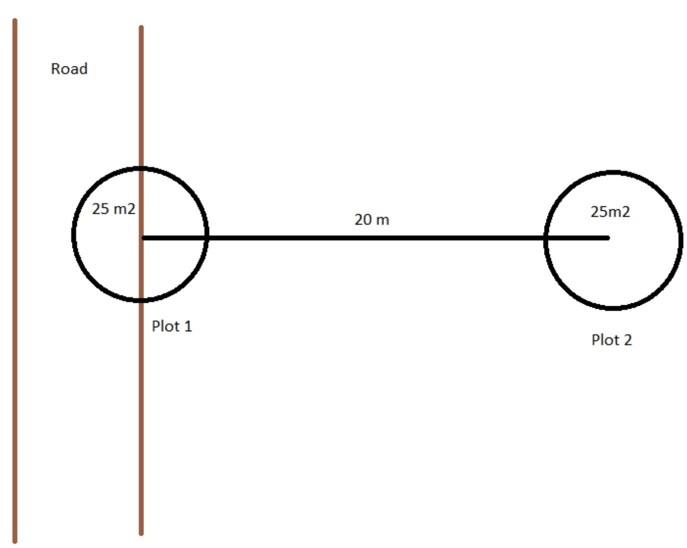

Figure 8. Example of plot placement relative to road edges.

Figure 9. Circular 25m^2 plot materials.

ANALYSIS OF DATA

The mean height of jack pine in road edge plots was compared with those in the forest interior plots on the same site to observe if there was a noticeable difference in tree height from edge to interior that could be attributed to road material. The mean road compaction for road edge plots on the same site was compared using correlation analysis to observe if differences in height on the same site could be attributed to soil compaction.

CALCULATING POTENTIAL ROAD EDGE EFFECT AREA IN THE ENGLISH RIVER FOREST

Using ESRI ArcGIS software, linear road features within the English River Forest Management Unit were buffered 20 metres for primary roads, 15 metres for branch roads, and 10 metres for operational roads to represent approximate real road width. These road widths were acquired from measuring forest resource inventory road polygons, which were digitized using aerial imagery of the management unit. The reason the linear road features were used instead of the FRI road polygons is because the linear features were updated much more recently than the FRI. The resulting three polygons were merged and dissolved to create a single road polygon. This road polygon was then buffered at 1, 5, 10, 15, and 20 metres to create polygons that simulate possible road edge effect areas from road edge to the forest interior. The road polygon was also buffered at 300, 450, and 600 metres to create polygons to simulate maximum straight-line, off-road wood transport distances from roadside. The initial road polygon was subtracted from the buffer polygons so that road area did not count toward edge effect area and harvestable forest area. Maximum straight-line, off-road wood transport distance is 300 metres for cable and grapple skidders, and 600 metres for clam-bunk skidders, the primary machines used to transport wood to roadside in Ontario (Pulkki n.d). The 450-metre buffer represents the mean transport distance of these machines. From the forest resources inventory data, all "productive forest" polygon types were selected and then clipped to these buffers to represent forest area experiencing road edge effects and maximum harvestable forest area. See Figure 10 for an example of these areas.

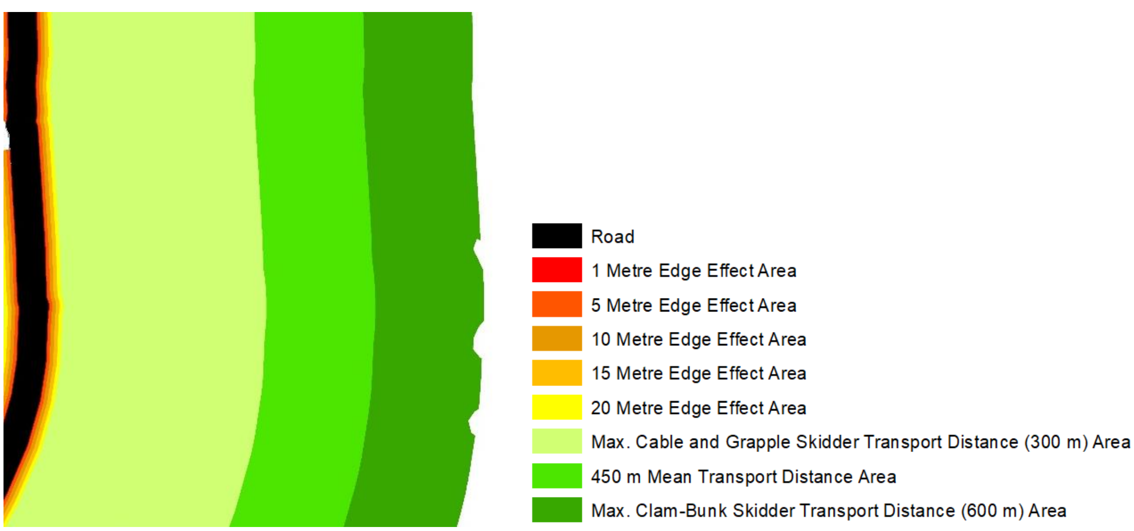

Figure 10. Example of road edge effect areas and maximum harvestable areas using buffers from road edge.

RESULTS

TREE HEIGHTS AND ROAD MATERIAL

For site 1 that had gravel roads, it was expected that trees located on road edge would have a mean height less than those located in the forest interior due to the foreign road material affecting height growth. However, tree heights collected from the four plots on this site indicated the opposite. The mean height of trees on road edge was 316.05 centimetres, while the mean height of forest interior trees was 302.75 centimetres, a difference of 13.3 centimetres (see Figure 11a).

For site 2 that had sand roads, it was expected that there would be no significant difference between tree heights on road edge versus those in the forest interior because they were on the same growing medium. Tree heights collected from the four plots on this site indicated that mean tree height was much greater in the forest interior. Mean tree height was 656.19 centimetres for road edge trees and 687.64 centimetres for forest interior trees, a difference of 31.45 centimetres (see Figure 11b).

Table 2 below contains the data used for the creation of these graphs, which is the site 1 and 2 plots combined into one set of data for each site. The full set of original tree height data collected in all edge and interior plots on both sites can be found in Appendix II.

Based on the tree height data collected, there is not enough evidence to suggest that gravel roads negatively affect jack pine height growth on road. I therefore reject my first hypothesis that foreign road materials negatively affect jack pine height growth.

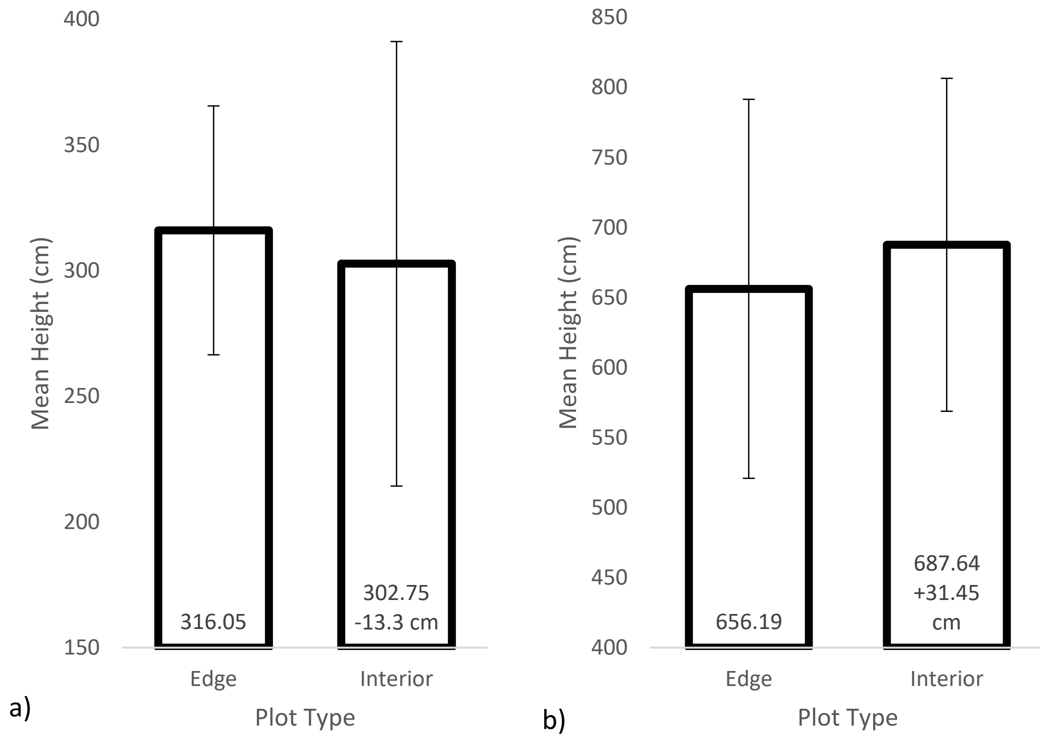

Figure 11. Mean tree heights and one standard deviation of trees in road edge and forest interior plots at a) Site 1 (gravel roads) and b) Site 2 (sand roads).

Table 2. Plot data for site 1 combined and plot data for site 2 combined.

	Site 1 Plots Combined		Site 2 Plots Combined	
Tree #	Edge	Interior	Edge	Interior
1	223	142	314	461
2	261	164	441	479
3	268	166	449	491
4	275	194	505	509
5	280	201	519	531
6	281	210	520	578
7	284	226	559	580
8	291	276	560	636
9	308	282	569	670
10	308	293	593	687
11	310	295	609	703
12	331	299	619	704
13	337	311	635	721
14	340	322	640	731
15	342	328	641	759
16	358	352	644	760
17	387	374	651	770
18	409	375	673	770
19	412	377	688	771
20		386	697	772
21		396	730	781
22		412	732	787
23		439	763	828
24		446	765	852
25			773	860
26			775	
27			827	
28			845	
29			860	
30			860	
31			886	
Mean	316.05	302.75	656.19	687.64
Variance	2451.63	7822.44	18304.99	14122.63
Standard Deviation	49.51	88.44	135.30	118.84

TREE HEIGHTS AND ROAD COMPACTION

For both sites it was expected that greater road compaction would negatively affect jack pine height growth. Site 1 edge plot mean tree heights were almost identical at 315.89 centimetres for the first edge plot and 316.20 centimetres for the second edge plot, while road compaction was noticeably different at 1.88 and 2.88 pounds per square inch for the respective plots. Figure 12a illustrates the pattern of mean road compaction compared to the pattern of mean tree height for site 1.

Site 2 edge plot mean tree heights were noticeably different at 621.83 and 677.89 centimetres, while mean compaction for each plot was identical at 0.94 pounds per square inch. Figure 12b illustrates the pattern of mean road compaction compared to the pattern of mean tree height for site 2.

Table 3 contains the data used for these graphs, which is the mean tree heights, mean road compaction, and one standard deviation for both values for edge plots. The full set of original road compaction data collected in all edge plots on both sites can be found in Appendix III.

There is no similar pattern among the two sites between compaction and jack pine height growth. Based on the data collected, there is not enough evidence to suggest that greater road compaction negatively affects jack pine height growth. I therefore reject my second hypothesis that greater compaction negatively affects jack pine height growth. However, it is important to note that the gravel roads were noticeably more compact than the sand roads, which may be relevant to future research questions.

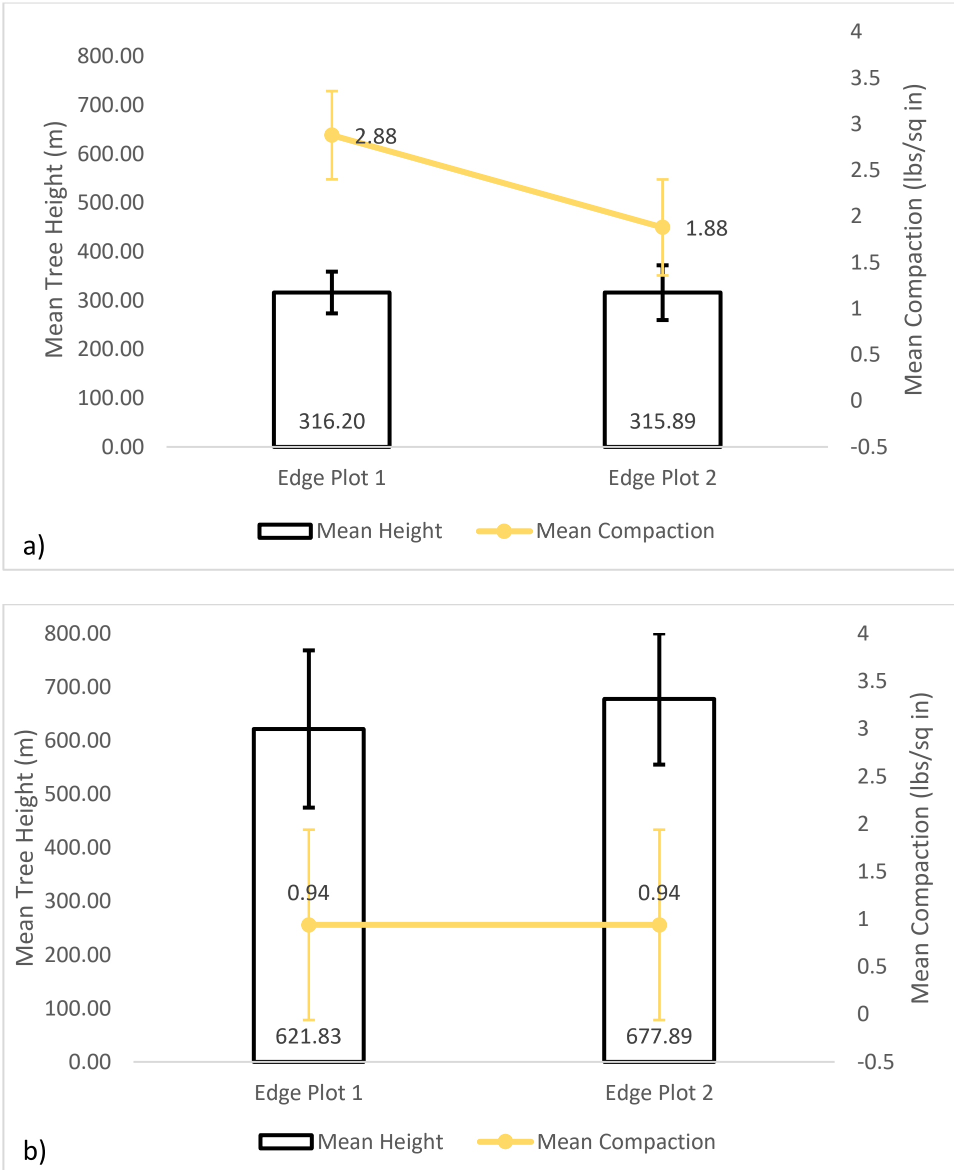

Figure 12. The pattern of mean road compaction compared to the pattern of mean tree height for a) site 1 and b) site 2, showing one standard deviation for each mean height or compaction value.

Table 3. Mean tree heights, mean road compaction, and standard deviations for edge plots on sites 1 and 2.

	Site 1		Site 2	
	Edge Plot 1	Edge Plot 2	Edge Plot 1	Edge Plot 2
Mean Height	316.20	315.89	621.83	677.89
Mean Compaction	2.88	1.88	0.94	0.94
Height Standard Deviation	42.74	56.09	146.89	122.57
Compaction Standard Deviation	0.48	0.52	0.31	0.38

POTENTIAL ROAD EDGE EFFECT AREA IN THE ENGLISH RIVER FOREST

The maximum harvestable forest areas for different off-road wood transport distances (300, 450, and 600 metre buffers from roads) are shown in Table 4. The potential edge effect areas (1, 5, 10, 15, and 20 metre buffers from roads) are shown in hectares and as a percentage of the maximum harvestable areas in Table 5. This was done to estimate a range of the possible amount of forest area experiencing edge effects in the English River Forest.

Table 4. Maximum harvestable forest area based on maximum straight-line off-road wood transport distances.

Maximum Straight-Line Off-Road Transport Distances (m)	Total area (ha)	Maximum Harvestable Productive Forest Area (ha)
300	274572.57	242997.94
450	370154.61	315839.08
600	449915.78	373151.65

Table 5. Potential edge effect areas in hectares and as percentages of maximum harvestable forest areas.

Edge Effect Distance (m)	Total Area (ha)	Productive Forest Area Experiencing Edge Effects (ha)	% of Max. Clam-Bunk Skidder Distance (600 m)	% of Mean Transport Distance (450 m)	% of Max. Cable and Grapple Skidder Distance (300 m)
1	1137.20	1075.06	0.29	0.34	0.44
5	5674.05	5385.29	1.44	1.71	2.22
10	11318.54	10771.69	2.89	3.41	4.43
15	16930.26	16136.92	4.32	5.11	6.64
20	22512.51	21473.13	5.75	6.80	8.84

The area of productive forest experiencing edge effects in the English River Forest is estimated to range from approximately 1075 hectares to over 21,000 hectares. With the smallest edge effect distance (1 metre) and the longest wood transport distance (600 metres), the minimum amount of forest area experiencing edge effects is estimated to be 0.29% of the harvestable forest area. With the largest edge effect distance (20 metres) and the shortest wood transport distance (300 metres), the maximum amount of forest area experiencing edge effects is estimated to be 8.84% of the harvestable forest area. Figure 13 below displays the full range of possible percentages of harvestable forest experiencing edge effects depending on maximum wood transport distances and potential edge effect distances.

Additionally, there are 5,782.66 kilometres of roads located on the English River Forest, which accounts for an estimated 15,508.81 hectares of lost growing space

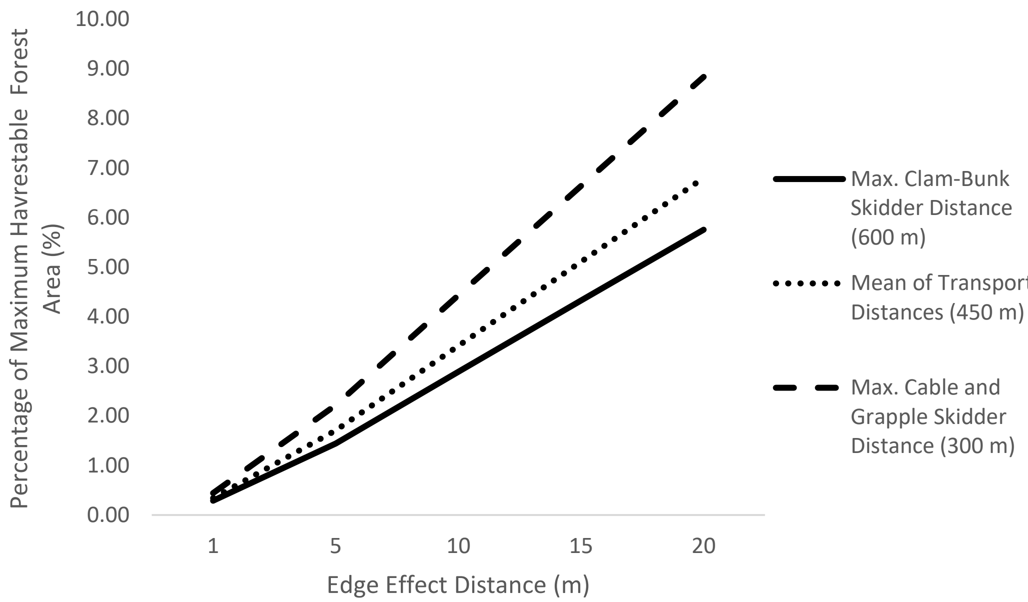

Figure 13. The possible range of percentages of harvestable forest area experiencing edge effects in the English River Forest.

DISCUSSION

ROAD MATERIAL, COMPACTION AND TREE HEIGHT

My initial hypotheses regarding the effects of road material and compaction on tree height were that foreign road material (gravel) would negatively affect jack pine height growth and greater road compaction would also negatively affect jack pine height growth. I hypothesized the relationship between road material and height growth because it is well-known that jack pine trees grow best on sandy soils, therefore I predicted that jack pine growing on the edges of sand roads would experience more height growth than those on the edges of gravel roads. I hypothesized the relationship between compaction and height growth because several authors have found that soil compaction can reduce the growth rate of trees. However, based on my data analysis, I could not find a relationship between either road material or compaction and jack pine height growth and therefore rejected both hypotheses.

Conversely, the site with gravel roads had a greater mean edge tree height than mean forest interior tree height, while the site with sand roads had greater mean interior tree height. These results were the exact opposite of what I predicted. While I believe that this is likely due to the small sample size of tree heights, there may be another reason why this pattern emerged. One possibility is that tree height growth was instead positively influemced by increased road compaction and was independent of road material entirely. The gravel roads had a noticeably greater amount of compaction than the sand roads, and it was stated earlier that Fleming et al. (2006) found soil compaction to actually improve jack pine growth due to increased water holding capacity and a reduced amount of competing vegetation for coarse-textured sandy soils.

ROAD EDGE AREA IN THE ENGLISH RIVER FOREST

Several authors that studied edge effects found various distances that edge effects extend into a forest interior. Delgado et al. (2007) studied the effects of roads on temperature, light, canopy cover, and canopy heights in pine forests of the Canary Islands. From road edge to forest interior, they found that edges affected tree height and canopy cover up to 10 metres into the forest. In a study of edge effects in the boreal forest conducted by Harper et al. (2015), they found that edge influence on forest structure and composition extended approximately 20 metres into the forest interior. Similarly, Hansen et al. (1993) observed edge effects such as differences in stem density, tree heights, and diameters extending 20 metres into the forest interior of young douglas-fir stands neighbouring mature stands. Euskirchen et al. (2000) found that edges influenced understory vegetation patterns up to 30 metres into the forest interior of red and jack pine stands. Bowering et al. (2006) observed edge effects of forest roads on adjacent lodgepole pine trees by measuring trees in plots divided into five zones beginning at the edge of the road: 0-5 m (zone 1), 5-10 m (zone 2), 10-20 m (zone 3), 20-30 m (zone 4), and 30-40 m (zone 5) from road edge, where zone 5 was used as a baseline for the interior forest. Euskirchen et al. (2000) also stated that other studies have shown edge effects extending up to 137 metres into the forest interior.

The findings of Delgado et al. (2007), Harper et al. (2015), and Hansen et al. (1993) are most relevant to this study, and therefore 20 metres was chosen as a maximum edge effect distance to estimate a total road edge effect area for the English River Forest. Furthermore, machines such as cable and grapple skidders can transport wood from the forest to roadside up to a straight-line distance of approximately 300 metres to remain economical, while clam-bunk skidders can transport wood up to 600 metres (Pulkki n.d). These distances and the mean of the two were chosen to estimate a total harvestable forest area for the forest.

There were two assumptions made when estimating the percentage of harvestable forest area that is experiencing road edge effects for the English River Forest. The first assumption is that edge effects only extend up to 20 metres into the forest from road edge. There is a possibility that edges can affect tree and stand characteristics as well as many other things like understory vegetation patterns and wildlife behaviour much further into the forest. Secondly, the percentage of harvestable forest area experiencing edge effects is based on the estimated “maximum” harvestable productive forest area derived from maximum straight-line off-road wood transport distances. It is extremely unlikely that this amount of area would actually be harvested over the course of the average rotation age in the boreal forest. This is because a large portion of forest area is left unharvested for reasons such as natural disturbance pattern emulation, wildlife cores and corridors, recreational area buffers, lake and stream buffers, or simply inaccessibility. Therefore, the percentage of harvestable forest area experiencing edge effects may be underestimated.

Additionally, the most commonly used off-road wood transport machine in Ontario is the grapple skidder (Pulkki n.d.), with a maximum transport distance of 300 metres, indicating that the actual proportion of forest area experiencing edge effects is likely closer to the higher end of the estimated range.

IMPLICATIONS

Trees located near road edges are more economical to harvest than ones located far from roads. This is due to the fact that road building and wood transport are two of the highest costs in forest harvesting. There is also a possibility that a considerable proportion of harvestable forest area experiences edge effects. Therefore, it may be critically important to understand the edge effects of roads on tree growth to model future stand harvest volumes based on the amount of road edge in a forest. If trees growing near road edges experience significant increases or reductions in height, diameter, basal area, volume, stem density or mortality, then forest modelling systems commonly used for forest management may over or underestimate future harvest volumes. Overestimating future harvest volumes may negatively affect the ability of forest industries to remain economical. For example, if the volume of timber that can be harvested is overestimated and only a smaller amount may be harvested, there may be significant economic losses for the industry. Underestimating future harvest volumes may also cause forest management planning difficulties, for example a company may choose to not harvest an area because it is deemed not economical to do so based on the underestimation of volume.

Additionally, the implication of the lost growing space due to roads must be acknowledged. As stated previously, the roads located on the English River forest account for over an estimated 15,000 hectares of space that could potentially be used for growing trees. Reforesting some of these areas should be considered in forest management planning so that future yields may be increased. For example, roads that are built using native soil materials could likely be reforested more easily than roads that have foreign materials like gravel. Furthermore, Bowering et al. (2006) suggested that increased tree growth near road edges may equate to a recovery of lost growing space, which must also be considered in future edge effects research and in forest modelling.

FUTURE WORK

There is much more research that could be done regarding edge effects in the boreal forest. For the topic of road material and compaction specifically, I suggest several improvements to the methodology described in this study to provide more meaningful results for future research. First, I suggest an increase in the total number of tree height measurement plots on a single site, in addition to placing plots at several intervals from road edge to forest interior, similar to the methodology of Bowering et al. (2006). This would allow the distance of different edge of effects to be measured, as well as provide more statistically testable results. Second, I suggest including more road material types, more site types, more tree species at a variety of ages in future research so that the full effects (if any) of road material on tree height growth can be determined. Third, future research questions could include the edge effects on other tree and stand characteristics such as diameter, individual tree and stand level basal area, individual tree and stand level volume, wood quality, tree form, stem mortality, stem density, canopy closure, and interception and throughfall of precipitation and soil moisture, some of which are included in the research questions of Bowering et al. 2006, Delgado et al. 2007, Froehlich (1979), Hansen et al. (1993) and Harper et al. (2015). Fourth, future research could include testing for different edge effect variables such as distance from road edge, road width, year of road establishment, road type (primary, branch, or operational), road use by humans, site class, age class, insects and disease, wildlife browsing, and wind speed, which are possible variables suggested by Bowering et al. (2006). Finally, in addition to measuring the edge effects of roads, future research could include measuring edge effects between stands and other natural edges.

CONCLUSION

Jack pine is a highly important species in the boreal forest of northern Ontario, both ecologically and economically. It is therefore important to understand how the growth of this species responds to edge effects. Edges are transitional areas between forest and non-forest or between one forest stand and another, and can be natural or anthropogenic. Road building is one anthropogenic reason that edges and edge effects are produced. Variables involved in road edge effects may include road material type, road compaction, road width, road type (primary, branch, or operational), year of road establishment, distance from road, site class, and age class of stand. These variables can affect tree and stand characteristics such as tree diameter, tree height, individual tree and stand basal area, stem density, crown length, and tree mortality, all of which are important in estimating stand and forest timber volume.

Based on jack pine tree height and road compaction data collected from the study area in the English River Forest, no relationship could be found between road material type and tree height or road compaction and tree height. However, a larger sample size may have yielded more meaningful results.

Using GIS analysis, it was estimated that the minimum proportion of the harvestable forest area in the English River Forest experiencing edge effects is 0.29%, this is with an edge effect distance of 1 metre and a maximum straight-line, off-road wood transport distance of 600 metres. It was estimated that the maximum proportion of harvestable forest area experiencing edge effects is 8.84%, and this is with an edge effect distance of 20 metres and a maximum straight-line, off-road wood transport distance of 300 metres. The absolute values for the forest area experiencing edge effects is estimated to range from approximately 1075 hectares to over 21,000 hectares. The two assumptions made in these calculations may have resulted in an underestimate of this range.

Understanding exactly how much forest area is experiencing road edge effects, in addition to how these edges affect tree growth, may be critically important for modeling future stand harvest volumes. Further research should be done on road edge effects to gain a better understanding of them and improve forest growth modeling systems commonly used for forest management planning.

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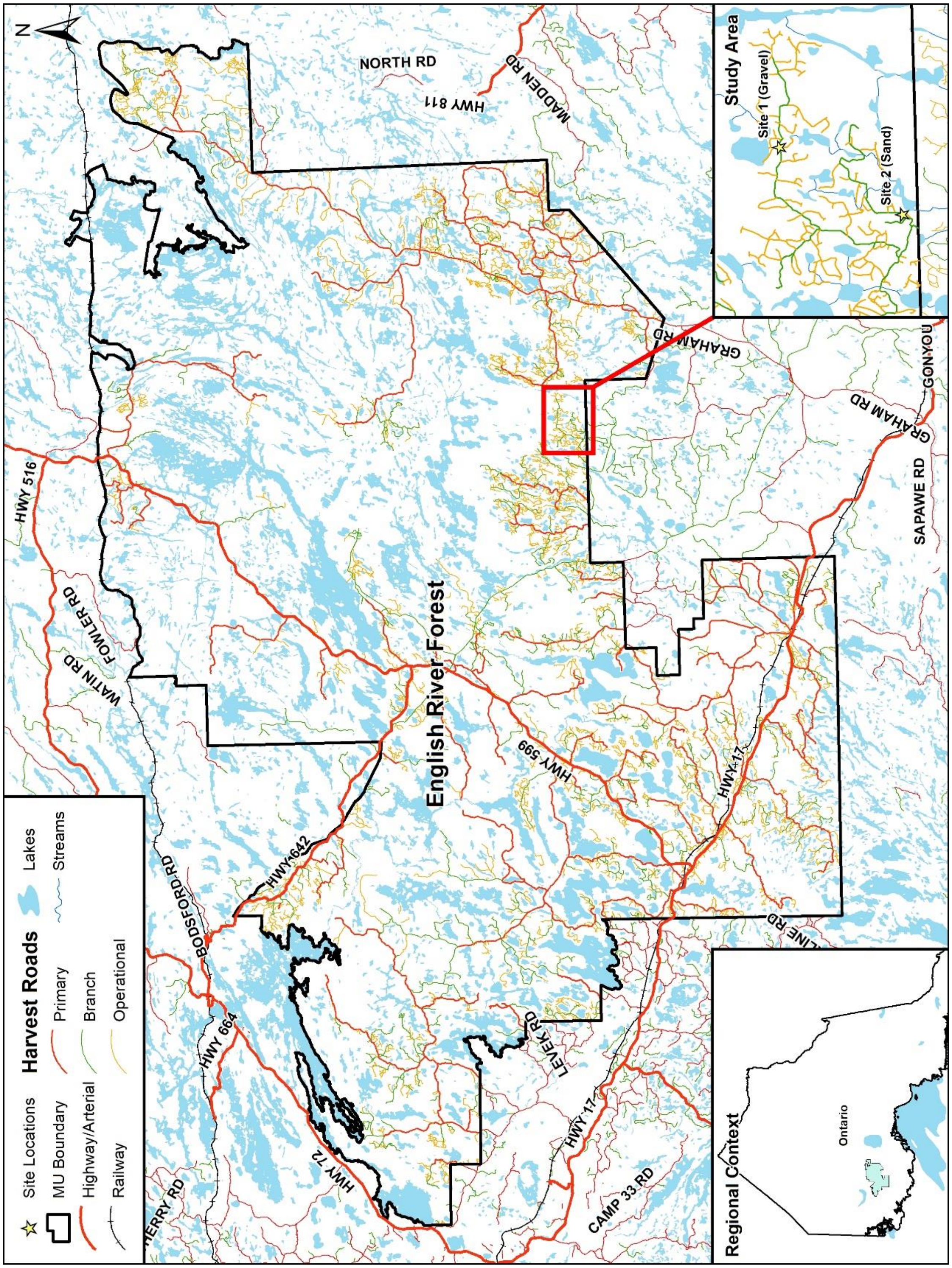
APPENDICES

APPENDIX I – MAP OF STUDY AREA



APPENDIX II – TREE HEIGHTS RECORDED IN CENTIMETRES

	Site 1				Site 2			
	Gravel		Gravel		Sand		Sand	
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
Tree #	Edge	Interior	Edge	Interior	Edge	Interior	Edge	Interior
1	261	142	223	201	314	461	449	479
2	268	164	280	276	441	491	519	580
3	275	166	281	282	505	509	520	636
4	291	194	284	293	560	531	559	687
5	308	210	308	295	593	578	569	703
6	331	226	310	328	640	670	609	731
7	337	299	358	374	641	704	619	759
8	340	311	387	375	688	721	635	771
9	342	322	412	377	697	760	644	772
10	409	352		396	732	770	651	828
11		386		412	765	770	673	860
12		446		439	886	781	730	
13						787	763	
14						852	773	
15							775	
16							827	
17							845	
18							860	
19							860	
MEAN	316.20	268.17	315.89	337.33	621.83	670.36	677.89	709.64

APPENDIX III – EDGE PLOT COMPACTION TESTS

Plot #	Road Material	Compaction Tests (lbs/sq in)				MEAN
1	Gravel	3.5	2.5	3	2.5	2.88
3	Gravel	1.75	2	2.5	1.25	1.88
5	Sand	1	0.5	1.25	1	0.94
7	Sand	0.5	1.25	0.75	1.25	0.94