Edge effects on shrub height

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Abstract

Forest edges are transitional zones between two ecosystems which mark the boundary where forests meet their adjacent environments. Their influence can vary depending on edge type, age, and other factors. Understanding the dynamics of shrub height along forest edges is important to expand our knowledge on ecological processes governing these transitional zones. This thesis investigates the influence of forest edges on shrub heights in boreal forests of Alberta and Quebec, Canada. I examined the influence of edge type, age, species-specific responses and region on shrub height patterns through systematic transect sampling of forest edges in boreal forest ecosystems from previous research. The results revealed that forest edges generally did not significantly impact shrub height across species and edge types with a few exceptions highlighting regional variations and the importance of considering species-specific responses. Overall, this study contributes to our understanding of how forest edges influence shrub height dynamics alongside emphasizing the need for further research to unravel the impacts of environmental variables on these ecosystems.

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1. Introduction

The boreal forest, Earth's largest terrestrial biome covering 30% of the world's forest land, is dominated by coniferous trees, complemented by deciduous trees (Kellomäki, 2022). The mosaic-like structure features a blend of coniferous and deciduous species, creates unique ecological niches and provides essential support for various successional and subclimax plant communities (Taggart, 2009). Natural processes, including cold north winds and summer wildfires, contribute to its complexity. The ecological significance of boreal forests lies in their role as a vast and dynamic biome that influences global biodiversity and climate processes (Miller-Schroeder, 2011). These extensive forests contribute significantly to the Earth's carbon balance and serve as critical habitats for diverse plant and animal species (Taggart, 2009). Furthermore, the boreal forest's susceptibility to disturbances such as fire, wind, and snow provides insights into ecological resilience and adaptation. This susceptibility offers valuable insights into the mechanisms of ecological resilience and adaptation within this biome (Gauthier, 2015). How these ecosystems respond to various stressors is important to understanding their long-term sustainability and for informing effective conservation and management strategies (Gauthier, 2015).

Forest edges represent the transitional zones between two ecosystems, marking the boundary where forests meet their adjacent environments (British Columbia Ministry of Forests Research Program 1998). These edges are a crucial aspect of landscape ecology and can introduce unique dynamics that differ from the interior of the forest. These transitional zones often experience altered environmental conditions such as increased light penetration, wind exposure, and temperature fluctuations due to exposure (Franklin, 2021). Additionally, edges may differ from the forest interior in species distribution, plant community structure, and ecological processes, which contribute to the overall complexity of the forest landscape (Franklin, 2021). Understanding these dynamics is pivotal for explaining the ecological dynamics at forest edges and devising effective conservation and management strategies. Harper and Macdonald (2011) used the term "edge influence" or "edge effects" to describe the alterations in forest structure and the composition experienced at these boundaries.

Forest edges can be categorized into two main types: anthropogenic edges, which are human-created, and naturally created edges, formed by natural ecological processes (Franklin, 2021). Anthropogenic edges arise from activities like clear-cutting, fires ignited by human actions, or pollution-induced tree destruction (Harper, 2002). They often suffer intensified tree damage from wind exposure, leading to increased coarse woody debris (Franklin, 2021). Light exposure in adjacent forests promotes shrub growth, herbaceous understory development, invasion of non-native plants, and tree regeneration (Harper, 2002). In contrast to anthropogenic edges, naturally created edges, formed by ecological processes such as fires or insect outbreaks, exhibit more varied and nuanced patterns influenced by the disturbance events, displaying irregular and fragmented exposure (Franklin, 2015). This irregularity affects intact forests at varying distances from the edge, as scattered disturbance effects extend into the surrounding landscape (Harper, 2005). Understanding the ecological significance and dynamics of these edge types contributes to broader insights into forest ecosystems and the impacts of human and natural interventions on their structure and composition. Furthermore, the time dimension adds another layer of complexity. Anthropogenic edges may exhibit more immediate and observable changes while naturally created edges may undergo a longer process of recovery and adaptation (Harper, 2013). Exploring the intricacies of forest edges is essential for unraveling their ecological significance and devising effective conservation and management strategies.

I selected shrubs for investigating the impact of different forest edge types on plants due to their critical ecological role and sensitivity to edge dynamics. Their moderate height and multi-stemmed structure shape understory composition and overall biodiversity (Kellomäki, 2022). Shrubs, responsive to environmental changes, serve as valuable indicators of ecological dynamics (Kellomäki, 2022), influenced by both anthropogenic activities and natural disturbances at forest edges (Harper, 2016). Monitoring shrub responses at these transition zones provides insights into the ecological consequences of edge influence on the broader plant community. Additionally, the adaptability and resilience of shrubs make them reliable indicators of environmental changes (Kellomäki, 2022), which offers valuable information for conservation and forest management efforts. I chose shrub height as the response variable due to its role as a successional factor. Due to the altered environmental conditions such as increased light penetration, wind exposure, and water availability (Franklin, 2021), height patterns of shrubs may differ among various edge types. They can also be influenced by various factors such as geographical location and forest type (Harper, 2005). Variations in edge characteristics, including age, creation method, and environmental conditions, contribute to the diverse patterns observed in shrub dynamics (Harper, 2001). In diverse ecological settings, varying patterns of shrub composition and diversity at forest edges have been observed (Harper, 2013).

I focused on investigating shrub height at forest edges created by clear-cutting and fire, and along lakeshores due to the distinct ecological implications posed by these edge types. By examining shrub height across these varied edge types, my research aimed to understand the influences of edge types on shrub in different environments. Additionally, I explored differences in findings among shrub species and geographic locations and ages to understand varying patterns on shrub height. This is crucial for understanding the broader ecological implications of forest edge dynamics. While forest edges have been studied in ecological research, there's a significant gap in understanding shrub dynamics across these zones, particularly in terms of height variation. Recognizing this gap, my research aimed to investigate how shrub height responds to edge influence, filling an important knowledge gap in this area.

2. Materials and Methods

2.1 Study Sites

I used data collected from systematic transect sampling of forest edges in boreal forest ecosystems in Quebec and Alberta from previous research (Harper and MacDonald, 2001; Harper et al., 2002; Harper et al., 2013; Harper et al., 2015; Harper, 2016) that studied fire, clear-cut and lakeshore edge forests. I chose the sites for their representativeness of boreal forest ecosystems and the distinct edge conditions as well as the presence of similar species of shrubs, ensuring a comparable basis for analysis.

In northwestern Québec, the fire edge and clear-cut studies were situated within the black spruce boreal forest in the Abitibi region, across coordinates from 49°620 to 49°870N and 79°000 to 79°500W (Harper, 2013, 2015). The area is part of the northern Clay Belt with a flat elevation of 300 m above sea level (Harper et al., 2013). The annual temperature and precipitation in this area are 0.8 °C and 856 mm (Harper et al., 2013). With predominately organic soil and black spruce dominated forests, the region of Quebec experiences large crown fires that wipe out the majority of aboveground vegetation (Harper et al., 2013).

In Alberta, the fire edge sites formed part of a broader synthesis study conducted across various locations in Canada, including Alberta, Ontario, and Quebec, as well as Sweden and Finland (Harper et al., 2015). In Canada, *Populus*-dominated forests at the elevation of 610-670 m were studied. However, only data from Alberta were utilized for this research. The Alberta clear-cut and lakeshore edge studies were situated in the *Populus*-dominated Mid Boreal Mixed-wood Ecoregion in central Alberta, featuring a boreal climate and Gray Luvisolic soils on upland mesic sites (Harper, 2002, 2016) and near Lac La Biche (558N, 1128W, 610 m above sea level), and near Calling Lake (558N, 1148W, 640 m above sea level). This region of Alberta experiences summer temperatures of 13.5°C and mean winter temperatures of -13.2°C with an annual precipitation of 397 mm mostly during the summer months (Harper and Macdonald, 2001).

2.2 Data collection

The Quebec fire edge study comprised four transects (Table 1) each across the edges of single fires aged 13, 25, and 39 years for a total of twelve transects, with sampling conducted between June and August 2001 (Harper, 2002). The Quebec clear-cut study established ten transects on 16–17-year-old edges within the same region, with measurements taken from outside the forest edge up to 50 m into the clear-cut to facilitate vegetation assessment (Harper, 2016).

The fire edge study in Alberta was a 1-year-old fire edge within broadleaf and coniferous forests, where successional dynamics of forest edges between different locations were being examined on 8 transects (Franklin et al., 2021; Harper, 2015). The clear-cut and lakeshore studies in Alberta focused on forest edges adjacent to clear-cuts of various ages with 10, 10, 10 and 8 transects at 1-, 2-, 5- and 16-year-old clear-cut edges, respectively, and 12 transects at lakeshore edges (Harper, 2002, 2016).

Across all studies, transects were established perpendicular to edges at least 100 m from other transects, major forest openings, and salvage-cut burned areas. Rectangular 20 × 5 m plots were positioned along each transect, at distances ranging from the forest edge (0 m) to 200 m into the forest. The measurements at 100, 150, and 200 m served as reference points for comparison with data collected at distances closer to the edge. Two shrub subplots (2 m x 2 m) were established along the major axis of each plot. Data collected included variables such as height, density, cover, species composition of trees, shrubs, seedlings, snags etc. Data used in this study included shrub height and species. In each study, shrub height was measured by recording the height of the tallest shrub of each species in a plot.

Table 1. The number of transects edge type and age and the location of different study sites that were used in this paper. At the Alberta cut edge, only the 5- and 16-year-old edges were used for this study.

Study Sites	# of Transects	Age of Edge (years)	Location
Alberta Fire	8	1	56°N 113°W
Alberta Cut	38	1, 2, 5, 16	55°N,112-114°W
Alberta Lakeshore	12	NA	55°N, 112°W
Quebec Cut	10	16–17	49°40′24″N,79°18′54″W
Quebec Fire	12	13, 25, and 39	49°62′,49°87′N, 79°00′, 79°50′W

Figure 1. Map showing the study areas. Map created on R using the package maps

2.2 Species Selection

I chose four shrub species to examine how different forest edge types impact their height: *Acer spicatum, Alnus inca ssp. rugosa, Viburnum edule,* and *Rosa acicularis*. These species were chosen based on their abundance in the studies. *Acer spicatum* and *Alnus inca ssp. rugosa* were the two most abundant species in the Quebec studies; however, their numbers weren't as high in the Alberta studies (Table 2). Similarly, *Rosa acicularis* and *Viburnum edule* were the most abundant species in Alberta with lower numbers in Quebec (Table 2). Due to lack of data, instead of comparing the same shrub species in different locations, two species were compared within each location. In Quebec *Acer spicatum* and *Alnus inca ssp. rugosa* were compared to each other and in Alberta *Viburnum edule* and *Rosa acicularis* were compared to each other to observe the edge influence on different shrub species. This approach allows for a nuanced understanding of how forest edges affect different shrub species within their respective ecological contexts.

Table 2. The number of plots with individual shrub species within each study.

Study sites	*Alnus inca ssp. rugosa*	*Acer spicatum*	*Rosa acicularis*	*Viburnum edule*
Quebec fire	41	5	2	1
Quebec cut	11	84	27	42
Alberta cut	28	0	306	287
Alberta fire	0	0	98	78
Alberta lake	1	0	168	134

2.3 Data Analysis

I focused on understanding shrub height patterns from the forest edge to interior forest, with a specific emphasis on the top two most frequently occurring shrub species in each location. For this edge influence was estimated across all studies. Edge influence (EI) is observed when there is a noticeable distinction in a particular response variable between the forest edge and the nearby forest interior (Franklin et al., 2021); in this case the variable is shrub height. The EI varies depending on factors such as the type of edge, the type of forest, and the specific response variable being measured (Franklin et al., 2021). Calculating the distance of edge influence (DEI), which is defined as the distance from the edge towards the interior forest over which a given variable is found to be significantly different from the interior forest, is a way to quantify EI (Harper et al., 2011).

The data were graphically presented using R version 2023.06.2+561 using the packages tidyr (Wickham, 2023) and ggplot2 (Wickham, 2016). Graphs of *Rosa acicularis* and *Viburnum edule* were compared to each other for the Alberta edge types. *Acer spicatum* and *Alnus inca ssp. rugosa* were compared to each other for the Quebec edge types.

The randomization test of edge influence (RTEI) is a method to estimate DEI. The RTEI method assesses the significance of EI across various distances from the edge. This method utilizes randomization tests conducted on the data observed at a specified distance from the edge as well as in the reference areas (Harper et al., 2011). The RTEI analysis was done separately for each species, edge type and region. The results of the RTEI analysis are p-values that are used to determine whether EI is significant or not. If the p-values were lower or higher than the significance levels (I used $\alpha = 0.05$ for a two-tailed test and therefore compared the p-values to 0.025 and 0.0975), then the null hypothesis was rejected, and the average height of a shrub at a specific distance was determined to be significantly different the average shrub height at the reference ecosystem or interior forest.

3. Results

3.1 Alberta forest edges

Rosa acicularis and *Viburnum edule* demonstrated similar trends at lake and fire edges (Figures 2, 3) with an increase in height from the edge to 50 m into the forest followed by a decrease at 100 m. At the fire edges, *Viburnum edule* was shorter compared to interior forest. There were taller *Rosa acicularis* shrubs between 30 and 60 m at the forest edge compared to the interior forest. However, from the forest edge to 30 m, *Rosa acicularis* shrubs were shorter than in interior forest. The fire edge had the tallest *Viburnum edule* shrubs around 150 m from the edge and the tallest *Rosa acicularis* shrubs around the 50 m distance. Both species were shortest at the forest edge at 0 m (Figure 3). At the lakeshore edge, *Viburnum edule* was taller than in the interior forest except at 5 m and 10 m where height was similar to interior forest. *Rosa acicularis* increased in height from the forest edge to interior forest and reached the highest values at 60 m. However, for both species the RTEI results show that the difference in heights between the forest edges and interior forest were not significant (Table 3).

Opposite to the lake and fire forest edges, both species at the clear-cut edge became taller from the edge to the interior forest (Figure 4). The analysis of different age groups shows similar trends in Alberta for both species studied. Both *Rosa acicularis* and *Viburnum edule* showed similar height trends at 16-year-old and 5-year-old clear-cut forest edges (Figure 7, 8). *Viburnum edule* exhibited similar patterns for both the 5 and 16-year-old edges. At both ages of edge *Viburnum edule* shrubs were shorter at 5 m and 10 m compared to the rest of the distances including interior forest (Table 3). The RTEI results showed that *Viburnum edule* height was significantly lower only at 5 m than the interior forest at the 5-year-old edges. *Rosa acicularis* showed variations in height between the 5-year-old and the 16-year-old cut edges. *Rosa acicularis* shrubs were shorter than in the interior at the 5-year-old cut edge while showing a trend of increasing height from the edge (0 m) to 60 m from the edge. At the 16-year-old edge shrub heights were similar to interior forest; however, shrubs were shorter between 5 and 10 m (Table 3).

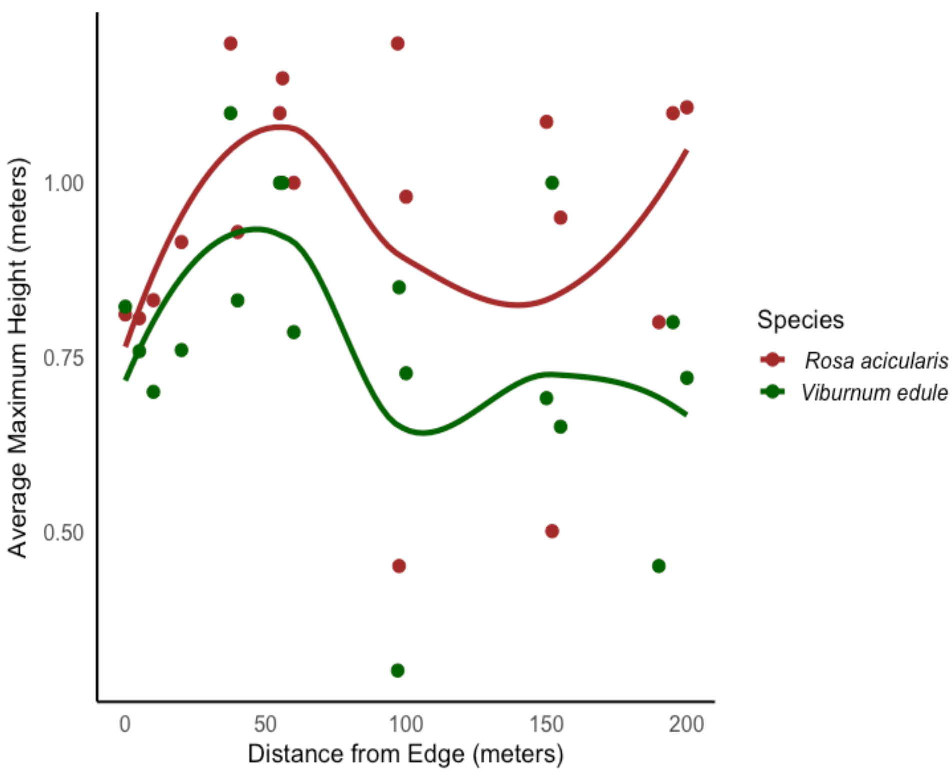

Figure 2. Scatter plot illustrating the average maximum height of *Rosa acicularis* (brown) and *Viburnum edule* (dark green) at varying distances from the Alberta lake forest edge. Each point represents the average height, with a trend line fitted using the locally weighted scatterplot smoothing (LOESS) method to show the overall trend of the data.

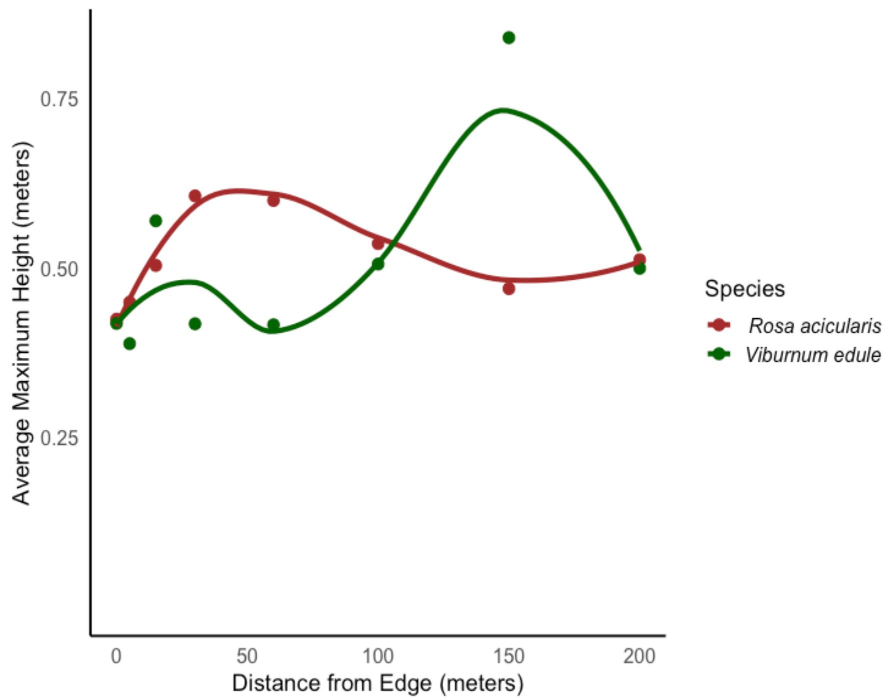

Figure 3. Scatter plot illustrating the average height of *Rosa acicularis* (brown) and *Viburnum edule* (dark green) at various distances from the 1-yr old Alberta fire forest edges. See Figure 2 for details.

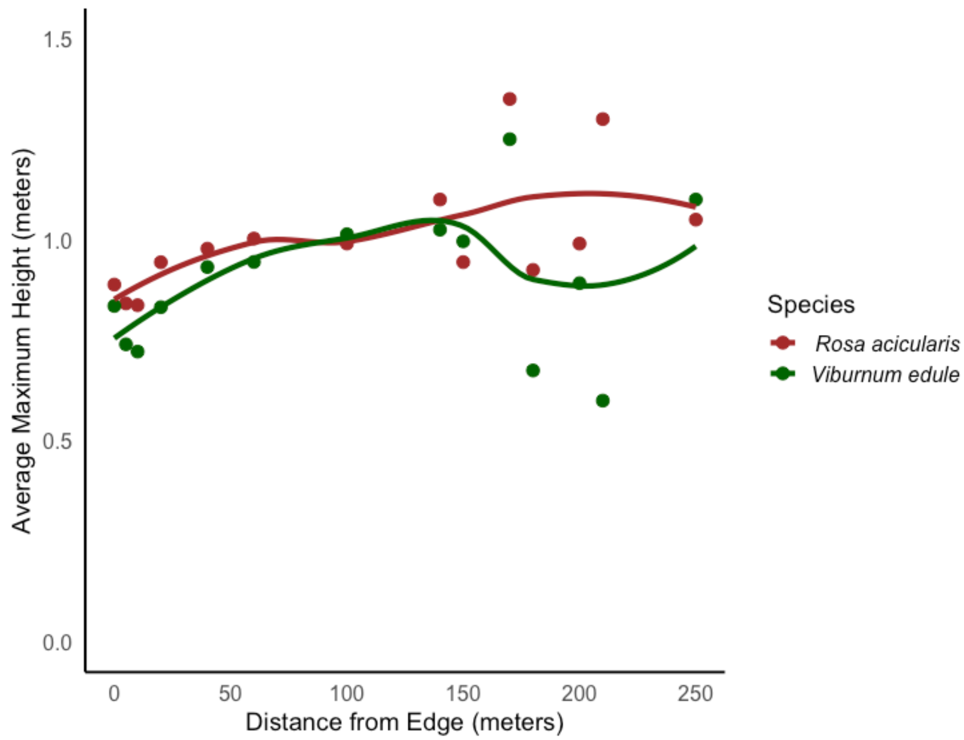

Figure 4. Scatter plot illustrating the average height of *Rosa acicularis* (brown) and *Viburnum edule* (dark green) at various distances from the Alberta clear cut forest edges. See Figure 2 for details.

Table 3. Mean shrub heights at various distances at different forest edges in Alberta. The reference values are mean shrub heights in the interior forest.

	Response Variables	Distance from the edge (m)								Reference
		0	5	10	15	20	30	40	60	
5-Year-old cut edge	*Viburnum edule*	0.73	0.61*	0.62	-	0.75	-	0.80	0.90	0.86
	Rosa acicularis	0.76	0.75	0.82	-	0.88	-	0.96	0.85	0.91
16-Year-old cut edge	*Viburnum edule*	0.95	0.86	0.83	-	0.92	-	1.10	0.99	1.08
	Rosa acicularis	1.03	0.95	0.85	-	1.02	-	1.00	1.16	0.91
Lakeshore edge	*Viburnum edule*	0.82	0.75	0.70	-	0.76	-	0.86	0.81	0.71
	Rosa acicularis	0.81	0.80	0.83	-	0.91	-	0.95	1.03	1.00
Fire edge	*Viburnum edule*	0.41	0.38	-	0.57	-	0.41	-	0.41	0.62
	Rosa acicularis	0.42	0.45	-	0.50	-	0.61	-	0.60	0.50

* Average values that were significantly from the interior forest.

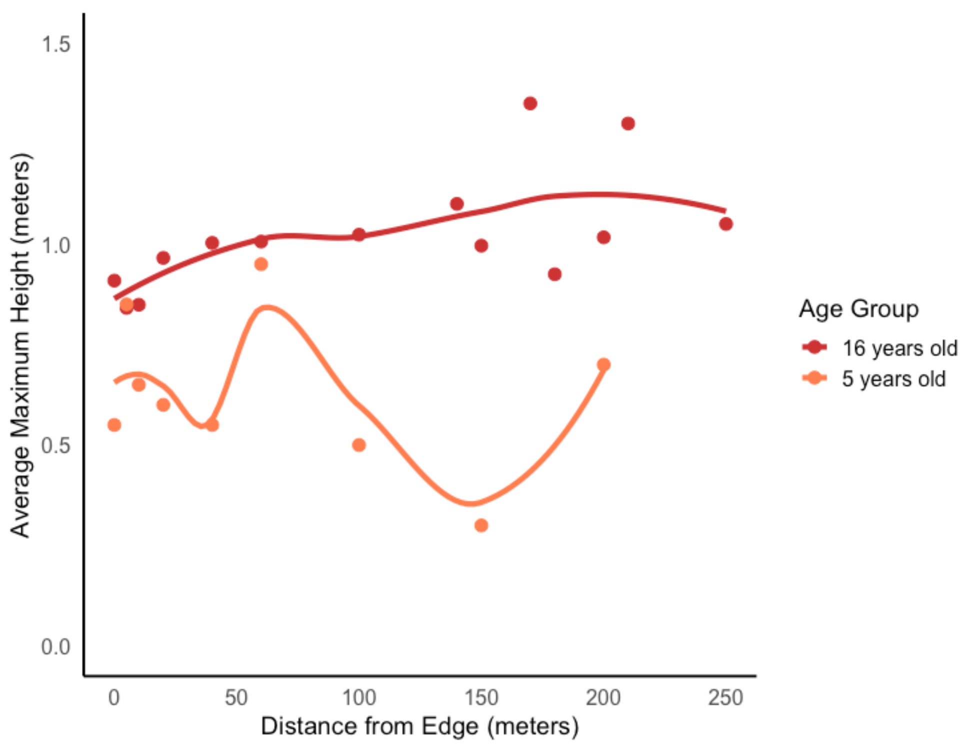

Figure 5. Scatter plot illustrating the average height of *Rosa acicularis* at Alberta clear-cut forest edges comparing two distinct edge ages (5 years old and 16 years old). See Figure 2 for details.

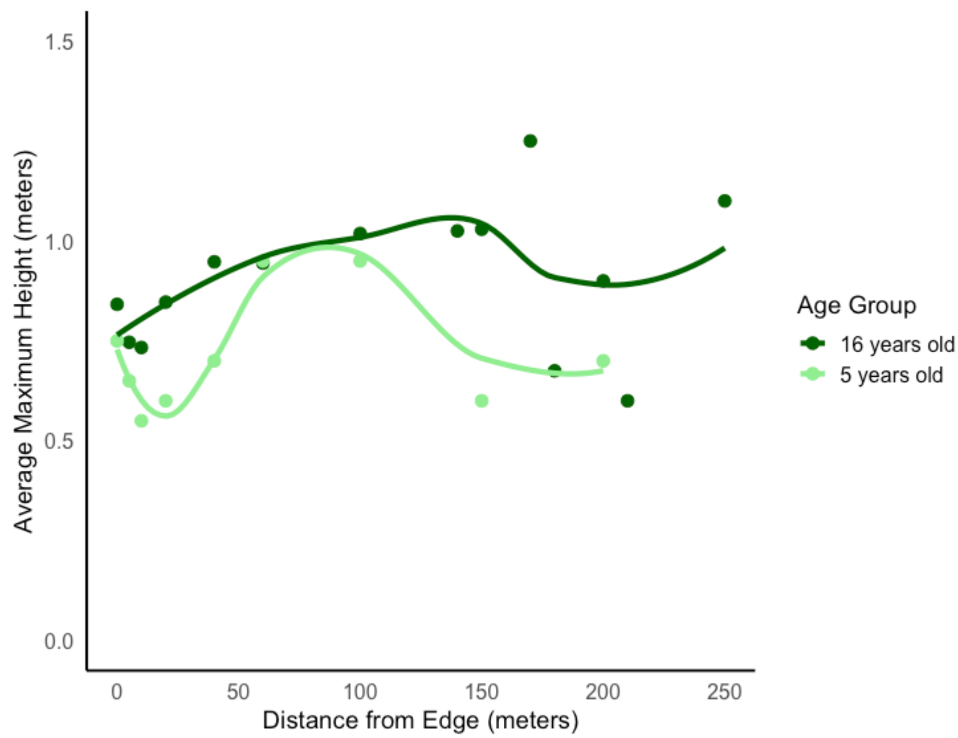

Figure 6. Scatter plot illustrating the average height of *Viburnum edule* Alberta clear-cut forest edges. The graph compares two distinct edge ages (5 years old and 16 years old). See Figure 2 for details.

3.2 Quebec forest edges

The Quebec plant species displayed diverse patterns in response to different edge types (Figure 7, 8). *Acer spicatum* was shorter in the interior forest compared to the fire edge, whereas at clear-cut edges its height was taller in the interior forest compared to the forest edge. *Alnus inca ssp. rugosa* had similar trends at both Quebec clear-cut and fire edges where there was an increase in the average maximum height from the forest edge to 50 m into the forest. The height of *Alnus inca ssp. rugosa* ranged from 0.55 m to 3.75 m in the clear-cut edge (Figure 8) and from 0.85 m to 2.26 m at the fire edge (Figure 7). The height of *Acer spicatum* ranged from 0.15 m to 7 m from the edge to interior forest.

At the 39-year-old fire edge, *Alnus inca ssp. rugosa* shrubs were taller than interior forest shrubs. The greatest mean height (1.8 m) was at 60 m. Like the shrub species in Alberta, *Alnus inca ssp. rugosa* shrubs were shorter at 5 m as well as at 25 m and 40 m (Table 4) meaning the shrubs at distances 0 m and 60 m were taller. At the 13- and 25-year-old fire edges, *Alnus inca ssp. rugosa* numbers were low in the interior forest so RTEI could not be done (Figure 12).

At the 2-year-old cut edges, *Acer spicatum* height fluctuated throughout the edge transects and the shrubs were taller than the shrubs in interior forest except at the edge at 0 m. The mean height of *Acer spicatum* reached a maximum at 60 m from the edge at 4.56 m (Table 4).

Due to the absence of *Alnus inca ssp. rugosa* at Quebec clear-cut forest edges after 60 m (Figure 7), further examination of the trends of the shrub heights couldn't be done. Due to the lack of data comparisons between *Acer spicatum* and *Alnus inca spp. rugosa* at the 25- and 39-years old fire edge and the 5-year-old cut edge could not be made.

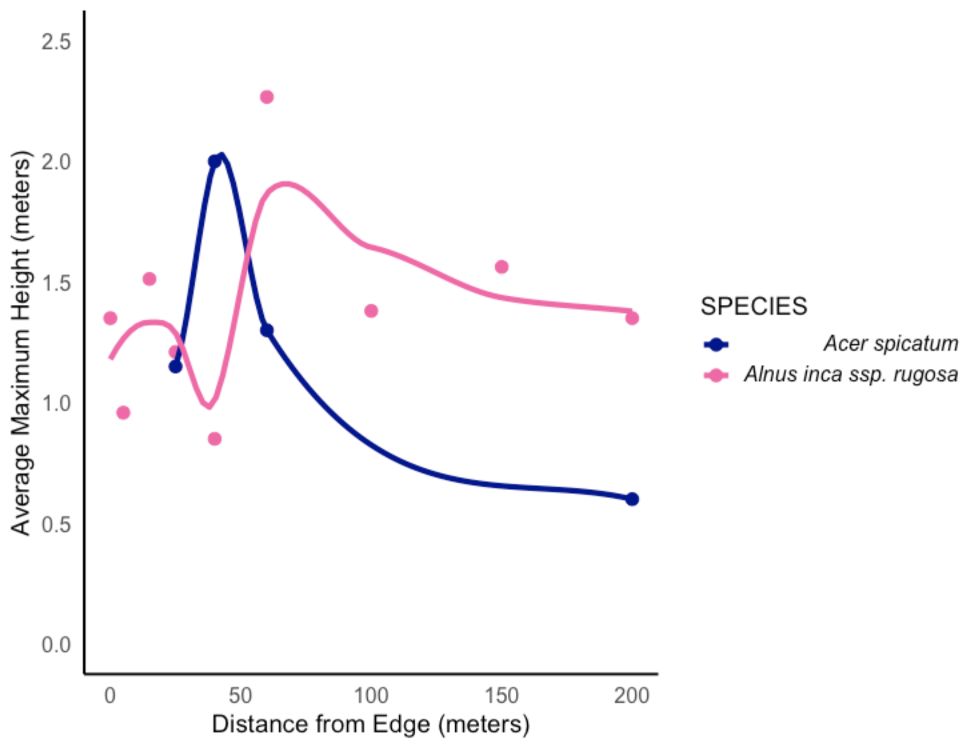

Figure 7. Scatter plot visualizing the average height of *Acer spicatum* (dark blue) and *Alnus inca ssp. rugosa* (pink) at various distances from the Quebec fire forest edge. See Figure 2 for details.

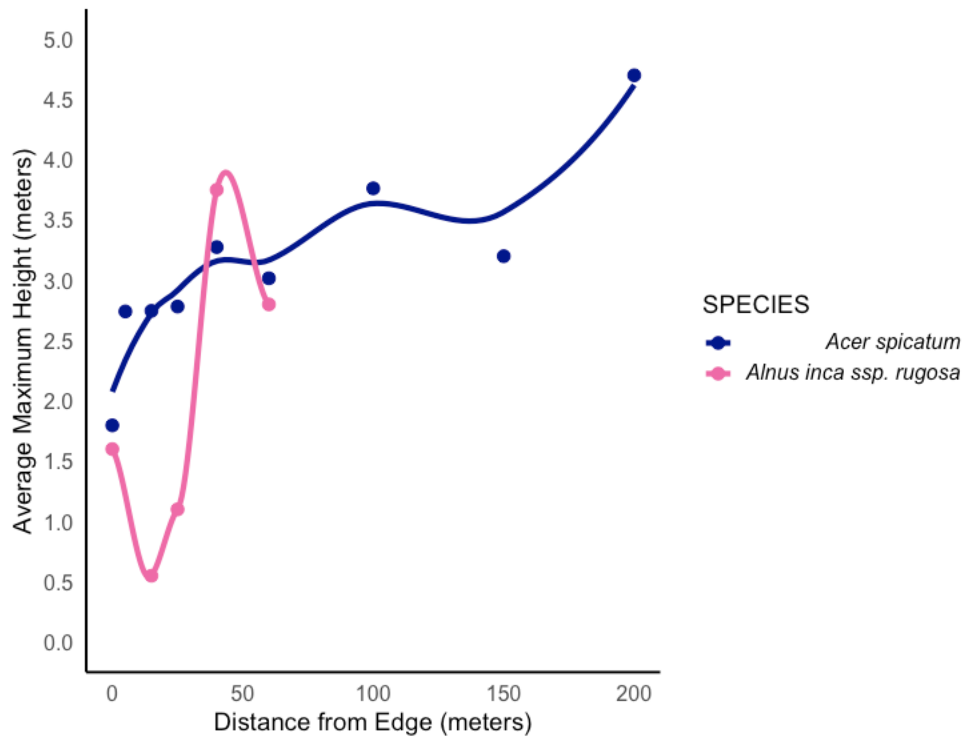

Figure 8. Scatter plot visualizing the average height of *Acer spicatum* (dark blue) and *Alnus inca ssp. rugosa* (pink) at various distances from the Quebec clear-cut forest edge. See Figure 2 for details.

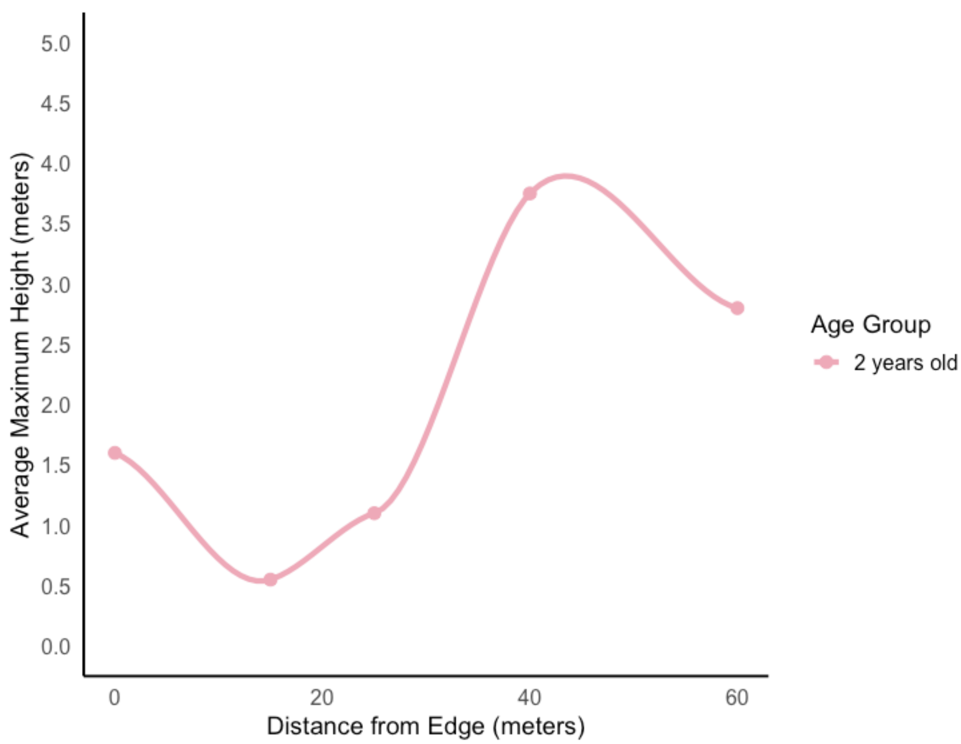

Figure 9. Scatter plot illustrating the average height of *Alnus inca ssp. rugosa* in Quebec clear-cut forest edges. The graph compares two distinct edge ages (2-year-old and 5-year-old). Data for the 5-year-old forest edge is not available due to lack of date, hence not depicted on the graph edge.

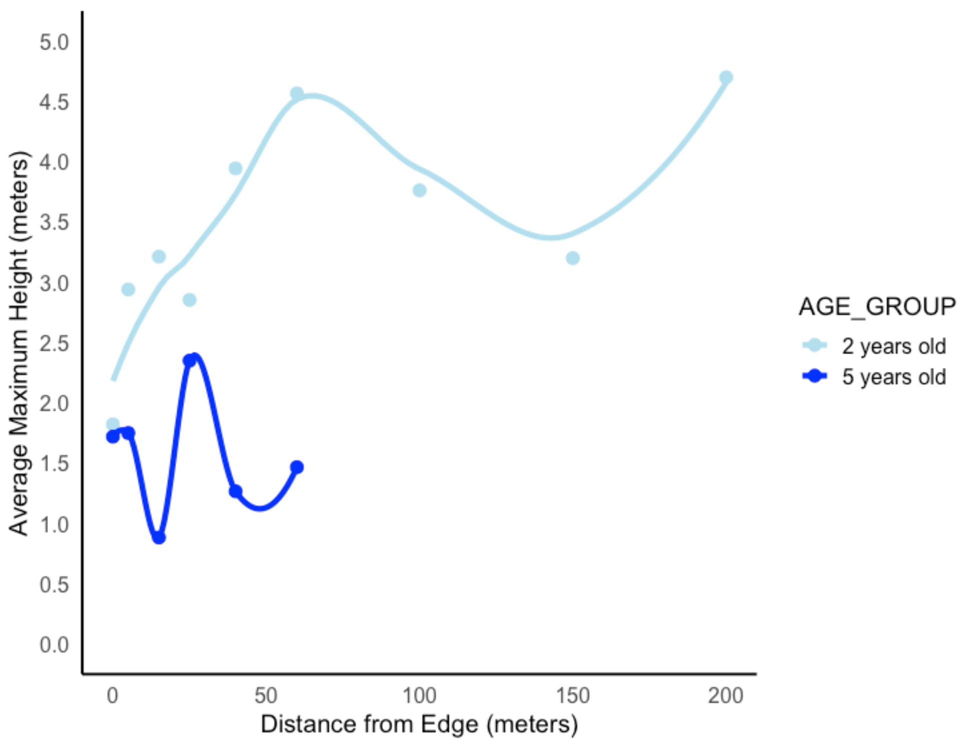

Figure 10. Scatter plot illustrating the average maximum height of *Acer spicatum* in Quebec clear-cut forest edges. The graph compares two distinct edge ages (2 years old and 5 years old). See figure 2 for details.

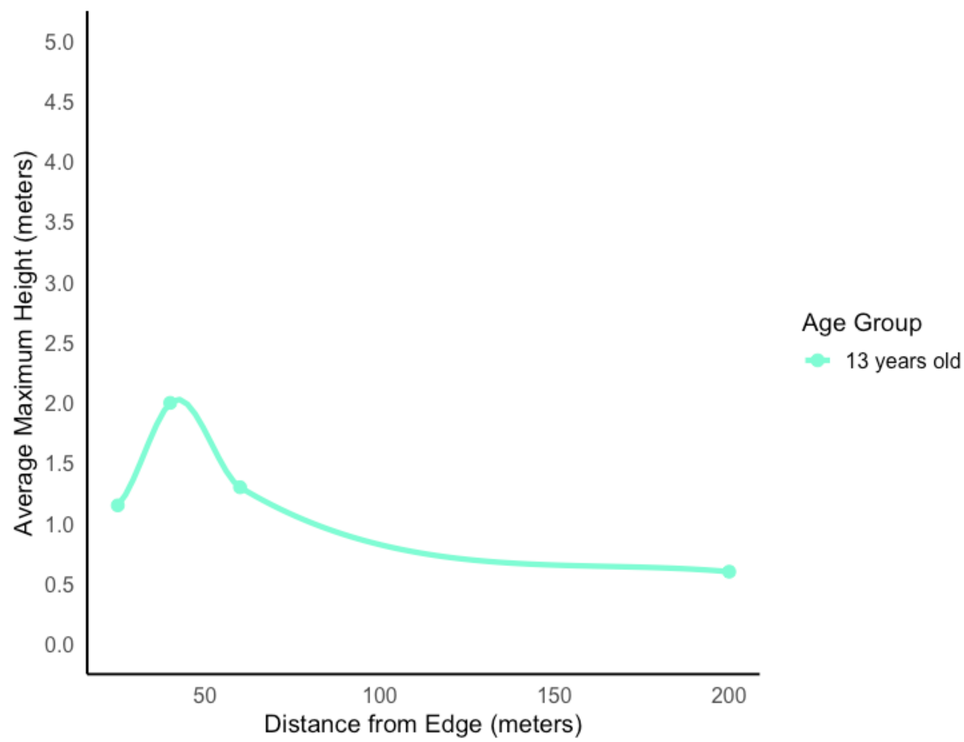

Figure 11. Scatter plot illustrating the average height of *Alnus inca ssp. rugosa* at varying distances from the Quebec fire forest edge. Data for the 25-year-old and 39-year-old forest edges are not available, hence not depicted on the graph.

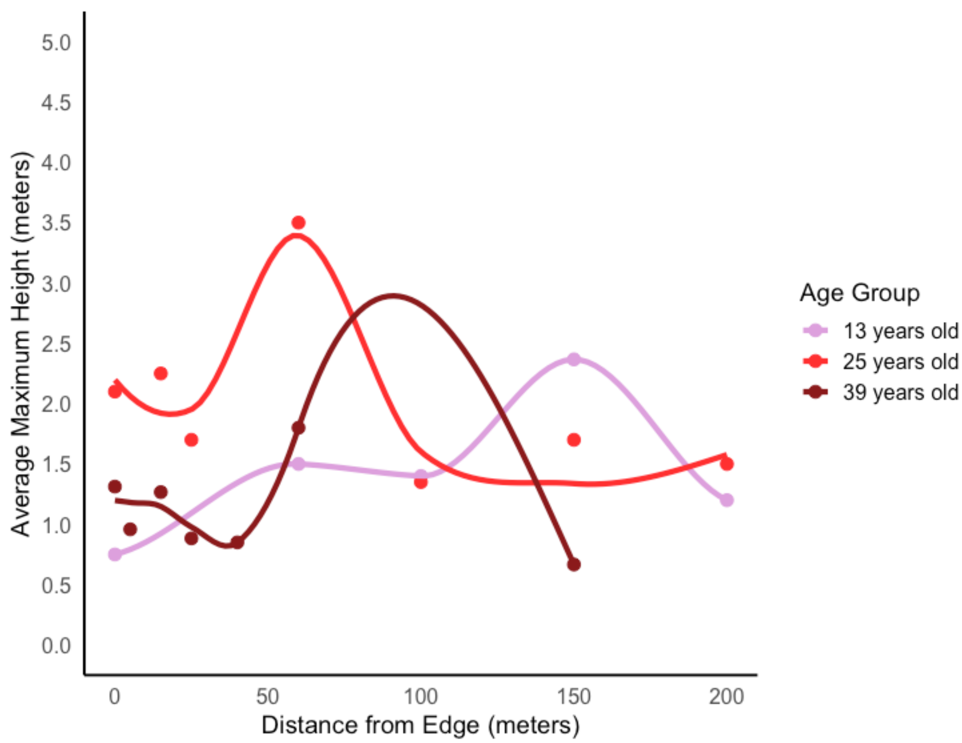

Figure 12. Scatter plot illustrating the average maximum height of *Alnus inca ssp. rugosa* in Quebec fire forest edges. The graph compares three distinct edge ages (13 years old, 25 years old and 39 years old).

Table 4. Table showing the mean shrub heights at various distances at different forest edges in Quebec. The reference values are mean shrub heights at the interior forest. Superscript symbol * designates values that were significantly from the forest edge to interior forest.

	Response Variables	Distance from the edge (m) 0	5	15	25	40	60	Reference
39-Year-old Fire edge	*Acer spicatum*	-	-	-	-	-	-	-
	Alnus inca ssp. rugosa	1.31	0.95	1.26	0.88	0.85	1.80	0.66
2-Year-old Cut edge	*Acer spicatum*	1.82	2.94	3.21	2.85	3.94	4.56	3.66
	Alnus inca ssp. rugosa	-	-	-	-	-	-	-

* Average values that were significantly from the interior forest.

4. Discussion

In general, the influence of forest edges on shrub height did not exhibit significant impacts, except for *Viburnum edule* at the Alberta clear-cut forest edge located 5 meters from the edge. Despite this, trends from edge to interior forest were similar with some exceptions. Shrub heights were taller at forest interior compared to the edge in most locations and edge types with the only exception of *Acer spicatum* at the Quebec fire edge. Additionally, there was a notable trend of lower mean height values within 5 to 10 meters of the edge across species and edge types, indicating a potential influence on shrub height at different edge types.

Although different species exhibited similar responses at the same edge type, this response differed among edge types. At the lake edge, *Rosa acicularis* and *Viburnum edule* had similar height patterns at the edge but throughout the forest they averaged different heights which could mean that water availability can impact different species the same way at the edge but as they get father from the edge the influence reduces. More species height data need to be examined to justify this statement. At clear-cut edges both species average similar heights at the edge and through the interior forest. Edge influence from clear-cut edges could be impacting the shrubs similarly across the forest and has a longer range of influence compared to the lake edge. Similarly, at the fire edge both species average the same heights at the edge and in the interior forest. However, their height patterns differed throughout the forest. This could be due to external factors like competition and more detailed research into species-specific responses must be examined.

The variability in height patterns among shrub species in Quebec further emphasizes the importance of considering species-specific responses to edge influence. Like Alberta shrub species, *Alnus inca ssp. rugosa* exhibited similar height patterns across different edge types and ages. *Acer spicatum* not only had different patterns at different edge types but also at different aged edges. This could mean that *Alnus inca ssp. rugosa* is more resilient to ecological differences across different edge types and the age of the edge might have less of an impact compared to *Acer spicatum*. At the fire edges, there were no *Acer spicatum* shrubs until 40 m (Figure 7) although *Acer* species are known to be more fire resistant compared to other *Populus* species (Gretel, 1994). However, the bark thickness is a factor that increases the fire resistance of *Acer* species and *Acer spicatum* might not be as resistant as other species due such factors (Gretel, 1994). The absence of the species can simply be due to eradication of the species after a fire as well. *Alnus inca ssp. rugosa* exhibits taller shrubs than *Acer spicatum* at the fire edge and the opposite is the case for the clear-cut edge. *Alnus inca ssp. rugosa* can be a better competitor compared to *Acer spicatum* at the fire edge than the clear-cut edge. This claim can be supported with the fact that *Alnus inca ssp. rugosa* shrubs were not present at the clear-cut edge past 60 m (Figure 8).

When compared, boreal forests in Alberta and Quebec exhibited differences in the responses of shrub height to edge dynamics. In comparison to Alberta, the Quebec clear-cut, and fire edges displayed taller shrubs. This difference suggests potential regional variations in the intensity of edge effects and highlights the influence of local environmental conditions and disturbance histories on shrub growth dynamics. Factors such as soil characteristics and temperature or latitude may contribute to plant succession (Kellomäki, 2022) leading to these regional differences in shrub height patterns along forest edges. In addition to the differences in average heights, the variability in heights between the regions differed noticeably. Alberta exhibited a greater variability in average shrub heights across different edge types and ages compared to Quebec. This variability suggests that Alberta's forest edges may be subject to a wider range of ecological factors influencing shrub growth, such as microclimate variation, soil nutrient availability. Conversely, Quebec's forest edges may experience more uniform environmental conditions or have different underlying ecological processes driving shrub height dynamics. Further studies across different boreal forest regions can provide valuable insights into the underlying mechanisms driving these differences and enhance our understanding of forest edge dynamics on a broader scale.

Most some species showed consistent height patterns across different edge ages, indicating that the age of the edge may not always be a significant factor in influencing shrub height. For example, Rosa acicularis and Viburnum edule exhibiting similar height patterns at the 5-year-old and 16-year-old edges, meaning the age of the edge might not have so much of an impact when it comes to shrub heights. As well as *Alnus inca ssp. rugosa* and *Acer spicatum* at the 2-year-old clear-cut edges where both species exhibit similar trends with the only difference being the average height at the edge and throughout the forest. The only exception of different height trends in different aged edges is the 13-year-old Quebec cut edge where *Alnus inca ssp. rugosa* and *Acer spicatum* exhibited different height patterns. *Acer spicatum* averaged taller shrubs at the edge compared to interior forest while *Alnus inca ssp. rugosa* averaged taller shrubs in the interior forest. The reasoning between the difference between 13-year-old Quebec fire edge and the rest of the studies could be that the 13-year-old Quebec fire edge may represent a critical stage in the successional process since structure of forest ecosystems can change overtime effecting succession (Kellomäki, 2022). Further investigation into the specific ecological processes operating at this edge age and their interactions with species-specific traits and environmental conditions can reveal the mechanisms driving this difference.

In addition to the factors discussed above, a myriad of environmental variables, including water availability (Moles, 2009), competition (Doust, 1988), light availability (Pronk, 2007), and forest edge age (Harper, 2002), can exert significant influences on plant height dynamics. One explanation for the observed variations in shrub heights could be attributed to competition dynamics, particularly in the context of regenerating aspen trees. As aspen trees rapidly establish themselves in open spaces, they intensify competition for light within the understory, potentially impeding the vertical development and growth of shrubs (Ripple, 2001). Further investigations are warranted to unravel the nuanced impacts of aspen regeneration on the intricate dynamics of understory plant development.

While forest edges generally didn't significantly impact shrub height across species and edge types, exceptions were noted. This can be seen in *Viburnum edule* at the Alberta clear-cut edge. Trends from edge to interior were mostly consistent, with shrubs typically taller at the edge. Quebec's clear-cut and fire edges had taller shrubs compared to Alberta which indicates potential regional variations. Most species showed consistent height patterns across edge ages, except at the

13-year-old Quebec cut edge. Environmental variables such as water and competition also influenced shrub heights, which emphasises the need for further research into their nuanced impacts on forest edge dynamics. Despite the lack of statistical significance in certain trends, the observed patterns hint at trends for further exploration into the mechanisms of environmental factors and shrub dynamics along forest edges. Further research could shed light on these underlying mechanisms driving these patterns, and ultimately enhancing our understanding of forest edge dynamics and ecosystem resilience.

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Appendix

Table 5. Table showing the average shrub heights and p-values at various distances at different forest edges at Alberta fire edge. The reference values are mean shrub heights at the interior forest.

	Average height values at Alberta Fire edge (m)					Reference
Distance (m)	0	5	15	30	60	
Viburnum edule	0.41	0.38	0.57	0.41	0.41	0.62
p-value	16.12	11	42.8	12.88	11.3	
Rosa acicularis	0.425	0.45	0.5	0.61	0.6	0.50
p-value	26.64	32.82	50.32	79.18	75.46	

Table 6. Table showing the average shrub heights and p-values at various distances at different forest edges at Quebec fire edge. The reference values are mean shrub heights at the interior forest.

	Average values in Quebec Fire (m)						
Distance (m)	0	5	15	25	40	60	Reference
Alnus inca ssp. rugosa 39YO	1.31	0.95	1.26	0.88	0.85	1.8	0.66
p-value	82	70.28	82.8	65.28	63.52	90.4	

Table 6. Table showing the average shrub heights and p-values at various distances at different forest edges at Quebec clear-cut edge. The reference values are mean shrub heights at the interior forest.

	Average values in Quebec Clear-cut (m)						
Distance (m)	0	5	15	25	40	60	Reference
Acer spicatum 2YO	1.82	2.94	32.125	2.8	3.94	4.56	3.66
p-value	9.6	32.26	37.76	29.18	58.7	74.5	

Table 7. Table showing the average shrub heights and p-values at various distances at different forest edges at Alberta lake edge. The reference values are mean shrub heights at the interior forest.

	Average values at Alberta lake edge (m)						
Distance	0	5	10	20	40	60	Reference
Viburnum edule	0.82	0.75	0.7	0.76	0.86	0.81	0.71
p-value	76.3	60.88	48.22	65.74	87.54	78.28	
Rosa acicularis	0.81	0.8	0.83	0.91	0.95	10.25	1
p-value	10.28	9.95	12.96	26.18	38.6	55.34	

Table 7. Table showing the average shrub heights and p-values at various distances at different forest edges at Alberta lake edge. The reference values are mean shrub heights at the interior forest.

	Average values at Alberta cut edge 16YO (m)						
Distance (m)	0	5	10	20	40	60	Reference
Viburnum edule 16YO	0.95	0.86	0.83	0.92	1.1	0.99	1.08
p-value	19.82	7.02	4.48	13.32	53.94	25.14	
Rosa acicularis 16YO	1.03	0.95	0.85	1.02	1	1.16	1.11
p-value	32.58	15	4.88	26.74	24.76	61.24	

Table 8. Table showing the average shrub heights and p-values at various distances at different forest edges at Alberta clear-cut edge. The reference values are mean shrub heights at the interior forest.

	Average values at Alberta clear-cut edge 5YO (m)						
Distance (m)	0	5	10	20	40	60	Reference
Viburnum edule	0.73	0.61	0.62	0.75	0.8	0.9	0.86
p-value	14.92	1.5	2.94	17.6	30.8	59.58	
Rosa acicularis	0.76	0.75	0.82	0.88	0.96	0.85	0.91
p-value	7.72	5.44	21.08	39.18	66.88	29.22	

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