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A Comparison of Tree Growth in Two Sites near Schefferville, Quebec

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Abstract

Trees provide vital global ecosystem services, including carbon sequestration and biodiversity conservation, among others. Further, trees play an important role in regulating climate because of their role in complex water and carbon cycles, and other climate feedback mechanisms. Thus, understanding influences on their growth and productivity is important for gaining insight into current and future climatic conditions. Research has shown that tree height within forests is a significant indicator of the tree's health as well as overall forest productivity. This study aims to add to understanding of how stress factors might influence tree growth and how trees might adapt to stressed conditions by comparing two sites in Canada's sub-Arctic, near Schefferville, Quebec. The methodology involved collecting and analyzing tree core samples taken from trees in the two sites: one 'stressed' and a second 'ideal' or 'non-stressed.' Analysis of the tree cores found no statistically significant difference in trunk circumference (or diameter) growth between the stressed and ideal forests. This arguably indicates that trees in both plots had similar amounts of water to facilitate their annual growth. However, comparisons of annual average tree height and vertical growth found highly statistically significant differences. Trees in the stressed forest grew slower vertically (but not in thickness) than trees in the ideal forest, and they reached lower total height—by a factor of almost two. If it is assumed that the stressed forest under study constitutes a random sample of trees that comes from a population of "all stressed forests," and similarly for the "ideal forest," then we may conclude that stressed forests—ones exposed to heavy winds and facing unreliable water supply—tend to produce shorter and slower-growing trees than forests under "ideal" conditions. Equally, the non-significance of the width-growth variable can indicate that it is not necessarily true that tree-width and tree-width-growth-rate are adversely affected by a stressed environment.

Introduction

Vegetation has a significant function in influencing global climate patterns through regulation of both the water and carbon cycles, as well as earth's albedo—the level of surface reflectiveness that determines heat absorption, important in feedback cycles (Kempes et al., 2011). Thus, there is an important need to understand the dynamic interrelationships between vegetative cover and climatic factors that inform global climate models (Kempes et al., 2011). Understanding forest cover dynamics is particularly important because of the range of ecosystem services and regulation of functions trees provide, including carbon sequestration and conservation and expansion of biodiversity, among others (Barrios et al., 2018; Kempes et al., 2011 Rötzer et al., 2019). The level of service trees contribute within ecosystems is determined by such variables as characteristics of species, growth patterns, dimensions of the tree, location and type of environment, among others (Jose, 2009; Rötzer et al., 2019).

Kempes et al. (2011, p. 1) found that tree height is significant in relation to the larger forest ecosystem as an "…indicator for understanding several properties of plant communities, including total standing biomass and resource use." Thus, a key goal of forestry—and environmental—management is to understand the underlying factors that impact variation among tree height and diameter and the dynamic interconnections among the variables (Rennolls, 2009; Rypšys, 2016). Analyzing the complex interrelationships between characteristics of tree stands and understanding other factors including weather and climate patterns, and environmental and soil characteristics, is important in understanding mechanisms of climate change (Kempes et al., 2011). Moreover, measurements of tree growth and biomass density can be used to develop models for predicting earth and climate system patterns (Kempes et al., 2011).

Vegetation growth patterns can be influenced by multiple factors, including type of soil, differences in albedo, amount of moisture in the soil, intensity of sunlight due to slope aspect, and others (De Micco et al., 2019; Kempes et al., 2011; Peng et al., 2019; Rupšys, 2016; Zhao et al., 2018). Thus, two geographically close areas may develop quite different vegetation (Peng et al., 2019; Zhao et al., 2020). Similarly, the growth of a particular type of vegetation, while inhabiting two plots, may favor one site over another (Juutinen et al., 2017; Ni et al., 2017). For example, trees may display particular patterns of growth under "ideal" conditions, while in a plot that is geographically very close but with "less-than-ideal" conditions, rates of growth may be quite different (Rupšys, 2016). Studies have found that tree height is a better indicator of forest productivity and growth demographics than trunk diameter (Kempes et al., 2011; Rupšys, 2016). This present study seeks to evaluate this finding.

Dendrochronology, according to Biondi (2020, p. 1), may be defined as "…the study and reconstruction of past changes that impacted tree growth," where these "changes may be caused by processes that are internal as well as external to a tree" --both tree biology and climatic and environmental forces. One dendrochronological method involves counting concentric tree rings and measuring their band width to determine the growth trees experience annually (Agrawal, 1995; Biondi, 2020). The basic technique is to extract a wood core from a tree's trunk or branch using an increment borer (Baltrenaite et al., 2010). The extracted core consists of concentric circles, added each year, which demonstrate annual growth and provide information about the climatic conditions or environmental factors that influence the tree's periods of growth throughout its history (Altman, 2020; Baltrenaite, et al., 2010; Worbes, 1999). For example, a drought year or other environmental stresses will result in a narrower band than a wetter year (De Micco et al., 2019).

A tree's wood structure is composed of dead cells called xylem, hollow tubes that transport water from the roots to the leaves. New xylem is produced annually under a protective layer of bark, with the xylem layer lighter-colored and thicker during periods of plentiful water, while darker and thinner bands indicate less water availability (Crous et al., 2012; Rossi et al., 2006). These light and dark concentric ring-layers of xylem form a record of the tree's full annual growth periods (De Micco et al., 2019; Rossi et al., 2006). Counting and measuring the rings—dendrochronology—provides the water history of a tree, and when multiple trees of a forest are studied, may tell us something about the experiences of the forest as a whole (Altman, 2020). For example, a tree with adequate water will generally produce wider bands, evidence of a faster growth rate.

Dendrochronology can help reconstruct the climate history of a forested area when there is no access to other data or can be used to confirm data from other sources (Altman, 2020; DeRose et al., 2017). These methods can help in understanding the growth history of a forest, when average individual tree data is compiled. For example, we can gain information about the relative growth rates of forests by looking at the ratio of the age of a tree, as determined by dendrochronological methods, to the radius of that tree, in addition to information related to climate because of inter-year variations in tree rings (Frank & Esper, 2005; Fritts et al., 1989; Housset et al., 2018).

In order to determine the role of particular phenomena, such as impacts of pollution or drought, it is necessary to define a control site to draw a comparison between the trees that are impacted by the factor under examination and those that are not impacted by the same factor (Lageard & Drew, 2008; Pelfini et al., 2007). The first area where core samples for this study were collected is the Ephemeral Lake area, on the border of Labrador and Quebec (near Schefferville, see Figure 1.). The elevation, from a nearby benchmark, is 745 meters, and the site is considered a 'stressed condition' as it is in an area unprotected from wind stress. It is also located about four minutes further north, and closer to the tree line, than the second site. As there is less vegetation due to the wind stress, there is a smaller amount of organic matter decomposition on the soil layer. Thus, the soil is more vulnerable to evaporation and erosion. Furthermore, the trees are much sparser, and there is much less vegetation providing ground cover. These conditions lead to stress on the trees as the wind causes the trees to grow closer to the ground, and in most cases, their main trunks are buried underground with only large branches protruding from the surface. In the stressed forest, the trees grow in clusters spread a few tens of meters apart. The soil is rough and thin, with bedrock outcropping. When examining the site, only spruce trees, *Picea mariana*, are found, and the ground cover includes mostly *Cladina stellaris*, as well as some *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Empetrum nigrum*, and *Betula glandulosa*.

Figure 1. Ephemeral Lake" site, near the Quebec-Labrador Border on August 27, 2012, Juliana Rosario Yeung

The second area, the sheltered spruce-lichen Airport Woodland (see Figure 2) is considered an ideal forest. It is much more densely forested, and thus, is protected from wind stress. The ground is also much more densely vegetated, and due to the decomposing organic matter covering the soil, there is less soil moisture loss, much less soil erosion (because less wind), and more ground insulation and protection from snow and ice, as well as from excessive erosion caused by precipitation runoff. Airport Woodland's elevation is lower than the Ephemera Lake at 521 meters. The soil appears to be thin and rough and like the other site has bedrock outcropping. The trees are predominantly spruce, with a few birch and hemlock as well as *Sphagnum sp, Cladina stellaris, Polytrichum, Lycopodium annotium, Vaccinium uliginosum, and Vaccinium angustifolium, as well as Empetrum.* This site also has clusters of trees, but they are much more densely packed than those of the Ephemeral Lake site, and grow upright, and are therefore, on average, taller.

Figure 2. "Airport Woodland" in Schefferville, Quebec, August 28, 2012, Juliana Rosario Yeung

Conditions in the subarctic in general lead to slower growth rates for a variety of reasons that both sites share, such as low soil temperatures except in the top few centimeters of soil, and a short growing season. Tree ring sizes are generally thinner in the subarctic high latitude regions than in lower latitudes (Crous et al., 2012; Fillion et al., 1986; Rossi et al., 2006)). There are also likely other factors including poor soil aeration that affect tree growth in these regions.

Despite sharing certain factors common to subarctic areas, the two study sites also have some differences that may lead to varying levels of stress in the vegetation they support. Ephemeral Lake is considered a stressed site as it experiences high winds, with no protection. Further, it is located close to the tree line, on the side of a mountain. Airport Woodland is defined as ideal as it is protected from winds and weather events and is well-watered, with the soil retaining moisture.

Methodology

A 10 x 10-meter study plot was selected in the Airport Woodland, along with a 100 x 100- meter study plot in the Ephemeral Lake site. All trees in both study sites were numbered, and latitude and longitude data recorded. A total of 20 trees were identified for analysis at Ephemeral Lake and 30 at Airport Woodland. Trees were then examined visually, and a brief description developed to give information on whether the tree's trunk or branch was used for measurement, and the position of the trunk or branch, i.e., upright or horizontal. All trees were measured, including circumference in centimeters, and height (estimated) using a meter stick.

Core samples were extracted from all trees within the selected plots at both sites, using an increment borer inserted into the trunk of each tree (or branch when the trunk was determined to be underground). Cores were then placed in plastic straws and taped shut and labeled. The cores were later sanded to facilitate ease of measurement and placed in a rack. Rings were counted for each tree to determine the tree's age and recorded on a spreadsheet, which also was used to record other data collected at the site.

Aims of the study

The aim of this study is to determine if there are differences in tree growth rates between two sites near Schefferville, Quebec (54°48′N, 66°50′W): The Ephemeral Lake and Airport Woodland site. Tree core samples were collected in order to determine if the "stressed" condition might make a difference in the growth of the trees within the site, and to evaluate how trees might adapt to particular conditions. Cores were collected from 20 trees located in the stressed site, Ephemeral Lake, and core samples were taken from 30 trees located in the ideal site, Airport Woodland.

Comparison and analysis of the two sites

A visual inspection of the two sites showed some differences. In the stressed site, trees appeared to be growing nearly parallel to the ground, with trunks or branches running close to the ground for some distance before turning upward and growing in a more vertical direction. The site was located on the side of a mountain and the soil appeared fairly dry on an inspection of its surface. On the other hand, the ideal site had the appearance of a forest with healthy, strong trees mostly growing vertically. The ground also seemed moist, and supported groundcover, including thriving blueberry plants.

The stressed site only had a population of 20 trees, in a much larger area, while the ideal site contained 30 trees in a much smaller area, meaning the stressed site was much more sparsely forested. Of the 20 stressed site trees, 10 (one half) had a vertically standing trunk, while the rest had trunks that were slanted or had main trunks underground. In the latter case, data were collected on the thickest branch above ground. One dead tree in this group was excluded from the study. On the other hand, only one of the trees in the ideal group was slanted or not standing upright. For the stressed group, the height was measured from the trunk's base. This technique was used even when the trunk ran parallel to the ground for some distance before turning upward. In many cases, the trunks appeared to be below ground and longer than the measured height.

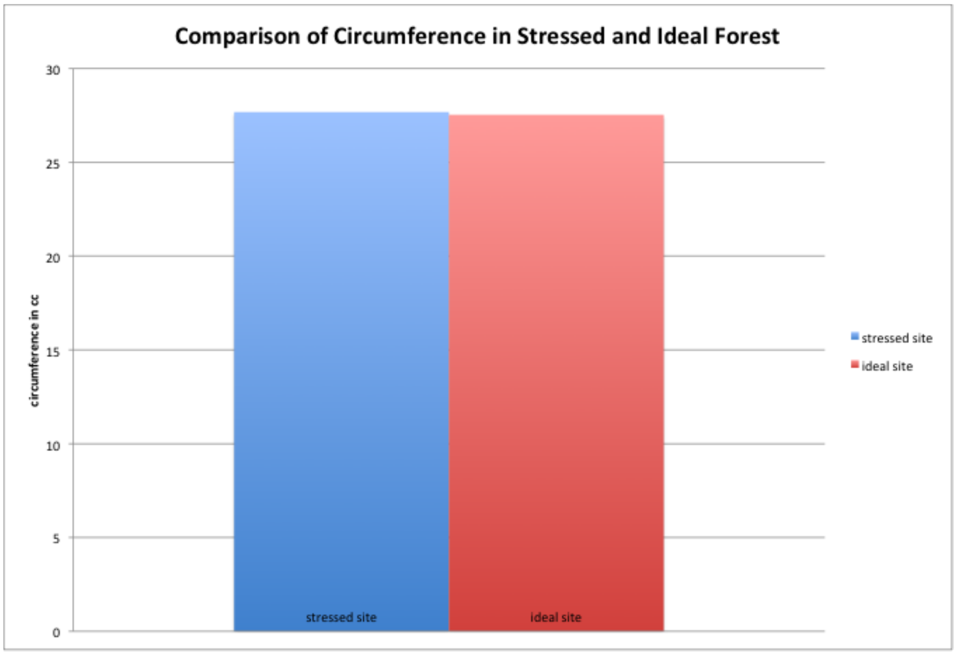
First, the ages of trees in the two sites were determined by dendrochronology: counting the concentric tree rings in each of the cores extracted from the individual trees, and the average age for each of the two forest groups calculated. Trees in the stressed group ranged in age from 15 to 73 years, while those in the ideal group ranged from 17 to 96 years. The average age of a tree in the stressed forest was 35.47 years, while the average age of a tree in the ideal forest was 37.57. Thus, the trees at both sites were found to be of very similar average ages. We would assume that if conditions were the same at both sites on average growth of trees in the two groups should also be similar.

The study, therefore, looked at data on growth, including circumference and height, as well as rate of growth for trees in these two groups. The first variable considered was the circumference of the trees, using measurements taken for each tree. In the stressed group, the narrowest tree circumference was 12.0 cm (although this measurement was for the thickest branch, with the trunk itself likely underground). The thickest trunk was 55.0 cm. For the ideal group, the circumferences ranged from 12.5 cm to 49.0 cm. The difference in average circumference between the stressed forest and ideal or unstressed forest was then computed. The average circumference in the stressed forest was 27.675 cm while in the ideal forest surprisingly it was slightly less, 27.53 cm.

A two-sample z test was carried out for each comparison of characteristics in the two groups: circumference, height, growth rate of circumference, and growth rate of height. Since the combined sample size is 50, the normal curve works well, and there is no need to use t; this test assumes different population standard deviations.

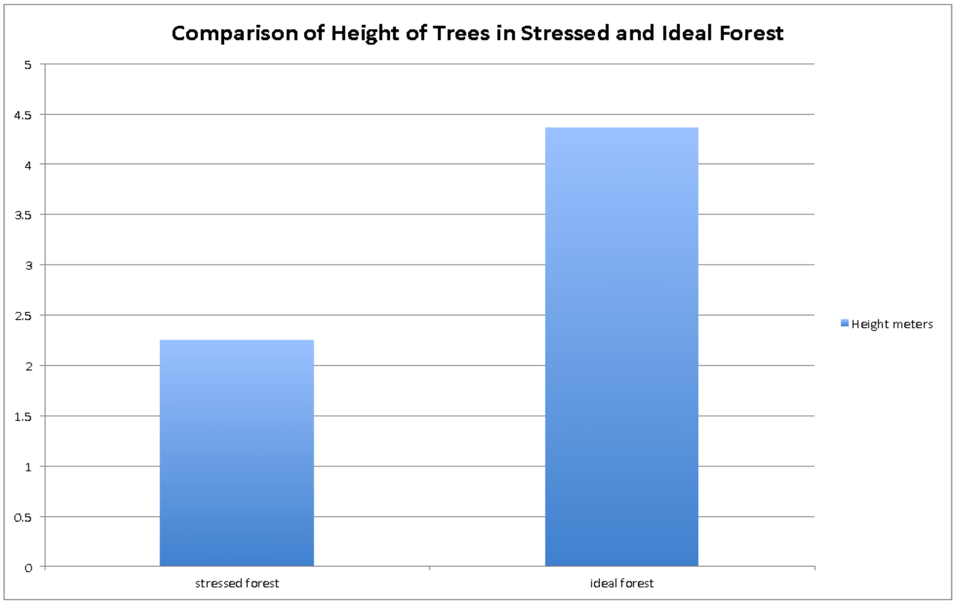
The difference in average circumference of trees in the two groups proved not to be statistically significant. The z-statistic value was 0.047. The two standard deviations were 10.79 for the stressed and 9.6 for the unstressed forests. Figure 3 (below) compares the measured circumferences of trees in the stressed and ideal forest sites.

Figure 3. Comparison of circumference in stressed and ideal forest, author's chart.



With respect to height, the findings proved to be very different. The height was the key variable here that seems to distinguish the stressed forest from the ideal forest. In the stressed forest, the average height of a tree is 2.2535 meters, and the standard deviation is 0.6773 meters. In the ideal forest, on the other hand, the average height of a tree was almost twice the average height of a tree in the stressed forest at 4.36 meters, with a standard deviation of 1.274 meters. The test statistic value here was 7.6. The p-value, therefore, is less than 0.000000001 (from the normal table), an extremely highly statistically significant result. Figure 4 compares height (or length of trunk for heaviest above-ground branch) for the two sites.

Figure 4. Comparison of tree height in stressed and idea forest, author's chart.



Next, the average trunk growth in thickness of trees for the two groups was examined. Thickness growth was calculated as the radius of the tree divided by the number of rings counted in that tree's core sample. The average growth in thickness per year for the stressed forest was 0.1415 cm with a standard deviation of 0.066. In the ideal forest, it was only 0.128 cm per year with a standard deviation of 0.051. The z-statistic value was -1.46, a result that is not statistically significant. The p-value is 0.1442, or about 14%. Figure 5 (below) compares growth in trunk thickness for the two groups.

Lastly, growth in height for the two groups was compared by taking the height of each tree and dividing by the number of rings, with an average computed for the two groups. In the stressed forest, the average vertical growth was 0.07894 meters per year, with a standard deviation of 0.0385. In the ideal forest the average vertical growth per year was 0.128 meters per year, with a standard deviation of 0.0477. Using the same two-sample z-test for equality of population means, the z-value is equal to 5.64. The two-sided p-value is less than 0.0000006, meaning that the difference between the vertical growth rates in the stressed and the ideal forests is highly statistically significant. While nothing else seemed to discriminate between the stressed and ideal forests in terms of statistically significant factors, average tree height and average vertical growth per year were indeed highly statistically significant, hence are key factors. Trees in the stressed forest grow upwards more slowly (but not in thickness) than trees in the ideal forest, and they reach lower total height—by a factor of almost two—than trees in the ideal forest. Figure 6 compares growth in height (or length, for trunks) of trees in the two sites.

Figure 5. Comparison of trunk growth in stressed and ideal forest, author’s chart.

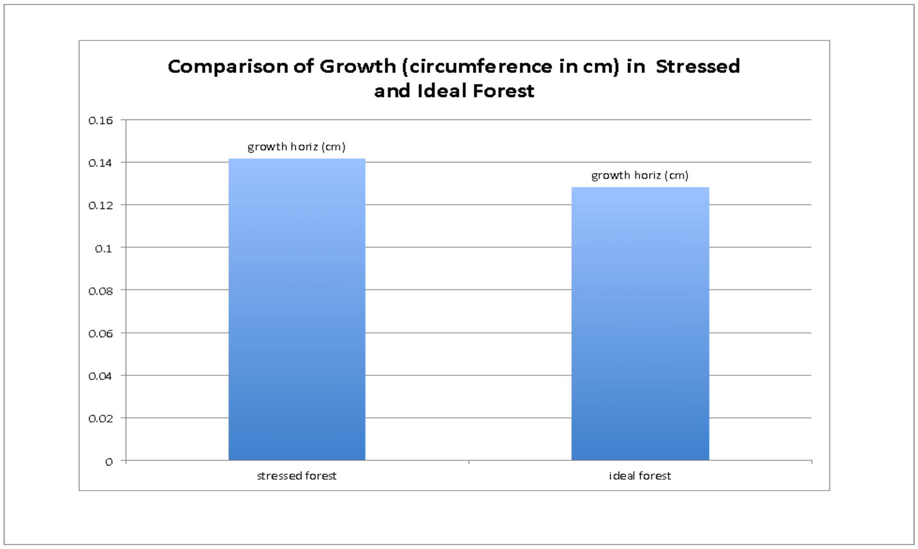


Figure 6. Comparison of growth in height in stressed and ideal forest, author’s chart.

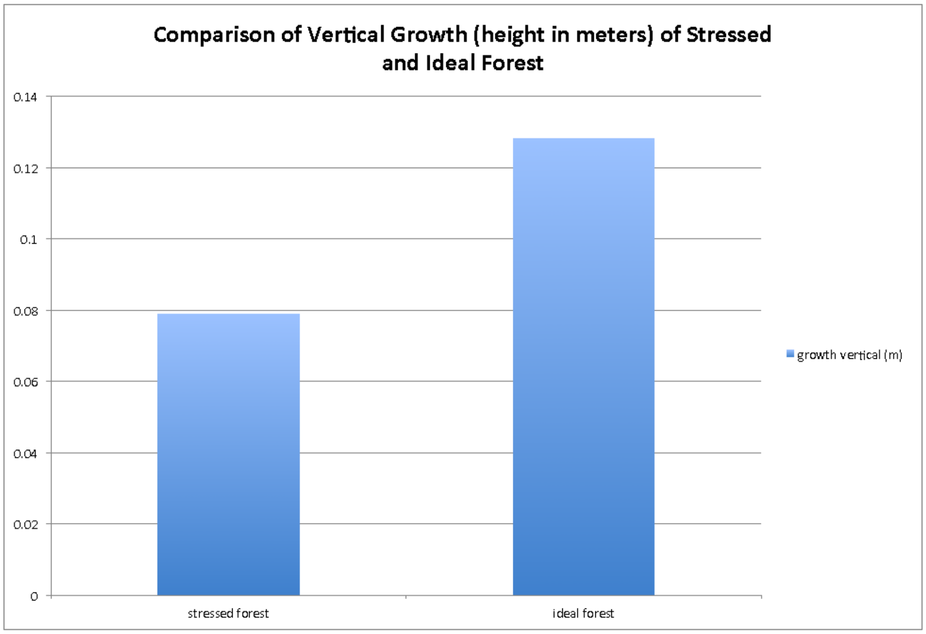


Table 1 summarizes comparison of average circumference, tree height, horizontal growth, and age for the two study sites: Ephemeral Lake and Airport Woodland.

Table 1

Averages for Forests in Study

	Height (m)	Circum. (cc)	Growth Horiz.	Growth Verti.	Age in Years
Ephemeral Lake Forest	2.2535	27.675	0.1415	0.07894	35.47
Airport Woodland	4.36	27.53	0.128	0.128	37.57

Conclusion and areas for additional study

Assuming that the stressed forest under study constitutes a random sample of trees that comes from a population of "all stressed forests," and similarly for the "ideal forest," we may conclude that stressed forests—ones exposed to heavy winds and with unreliable water supply—tend to produce shorter and slower-growing trees than forests under "ideal" conditions. Equally, the non-significance of the width-growth variable can indicate that it is not necessarily true that tree-width and tree-width-growth-rate are adversely affected by a stressed environment.

On the other hand, there were differences in the heights—or lengths of trunks—of trees in the two groups. First, trees in the stressed group were less likely to grow vertically. About half of the trees in the stressed group were tilted or growing with their main trunk underground. The trees in the ideal group, on the other hand, were nearly all growing vertically, with only a single tree identified as "slanted" rather than "straight." Also, the trees in the stressed group grew upward at a slower rate than those in the ideal group and displayed lower overall heights.

Interestingly, there was no statistically significant difference in rate of trunk circumference growth. Both the stressed and ideal forests displayed nearly identical growth rates. This seems to indicate that trees in both plots had similar amounts of water to facilitate their annual growth rate.

It would appear that the heavier wind conditions, and the more exposed aspect, of the stressed site affected the vertical growth of the trees. The trees do not seem to lack water for annual growth, as circumference growth does not seem to be adversely affected. The stressed trees were able to survive in the harsher conditions of the stressed environment of the Ephemeral Lake, by growing shorter, and keeping branches and trunk more parallel to the ground, thus reducing exposure to wind.

The stress of trees in the Ephemeral Lake site seem to come from more than one source. The most important stress, though, seems to be due to wind exposure. The wind causes dry soil conditions, because the wind transports evaporated water molecules, thus enabling more water molecules to evaporate.

A further study of the microclimates of the two sites would yield more information on what conditions might have contributed to the differences in rate and type of tree growth. Also, another area for further study would be to use a finer-gauged device to measure widths of specific bands and correlate that information with the climate data. This might help us understand differences in how trees at the two sites have responded to specific events. For example, in periods of drought or near-drought, does the growth of the "stressed-area" reduce even more than we would expect when compared with a tree in an "ideal" site?

As discussed previously, understanding tree growth dynamics is crucial to inform research in a wide range of fields, and dendrochronology is used as a technique to inform ecosystem health, and species interactions and resilience in response to a changing climate (Altman, 2020; del Rio et al., 2017; Levesque et al., 2019). This study sought to demonstrate how collection of tree height and age data sheds light on resilience to environmental stress factors. Further research, particularly combining multiple objectives and perspectives, is valuable for potential contributions to a wide range of applications and research objectives.

Moving beyond this, one of the key limitations of dendrochronology is the arguable focus on certain species and ecosystems, and there is an important need for future research involving a wider range of forest ecosystems (Altman, 2020; Babst et al., 2017). Moreover, combining a wider diversity of research methodologies, and incorporation of a multidisciplinary focus, including ecology, climate change modelling, and earth systems dynamics, among others is important in developing a more holistic and comprehensive understanding of the complex interrelationship between vegetation and other climatic and anthropogenic forcings (Altman, 2020; Babst et al., 2017; De Micco et al., 2019; Kempes et al., 2011).

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