Decreased radial growth in sugar maple trees tapped for maple syrup

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ABSTRACT

The conversion of sap from sugar maple (*Acer saccharum*) to syrup is a multi-million dollar agroforestry industry in North America. Sugar maple trees take decades to reach a size that can be tapped; therefore, maintaining vigorous trees is crucial to the industry's sustainability. Our objectives were to identify whether syrup production altered radial growth or cambium miner activity. We extracted increment cores and measured ring widths from trees tapped for syrup production and untapped reference trees. In Pennsylvania and Ontario, radial growth in tapped trees was significantly reduced compared to reference trees. In New York, there was no significant difference in radial growth between tapped and reference trees. All sites showed a significant reduction in radial growth following commencement of tapping, compared to growth rates prior to tapping. This pattern was not identified in reference trees, which indicates that it was not an artifact of age-related growth trends. There was no significant difference between cambium miner activity in tapped and reference trees. We concluded that the reduction in sugar maple radial growth is likely due to reallocation of resources as the tree heals the damage to the stem during tapping.

Keywords: dendroecology, maple sap, maple syrup, *Phytobia setosa*, *Acer saccharum*

RÉSUMÉ

La transformation de la sève de l'érable à sucre (*Acer saccharum*) en sirop est une industrie agroforestière de plusieurs millions de dollars en Amérique du Nord. Les érables à sucre mettent plusieurs dizaines d'années à atteindre un diamètre suffisant pour être entaillés; pour cette raison, il est important de maintenir la vigueur des arbres pour assurer la durabilité de cette industrie. Nos objectifs étaient de déterminer si la production de sirop modifiait la croissance en diamètre ou le développement de l'agromyze de l'érable rouge. Nous avons prélevé des carottes et mesuré la largeur des anneaux de croissance dans le cas d'arbres entaillés pour la production de sirop et d'arbres intacts comme témoins. En Pennsylvanie et en Ontario, la croissance radiale des arbres entaillés a été significativement réduite par rapport aux arbres-témoins. Dans l'État de New York, nous n'avons pas noté de réduction significative de la croissance radiale entre les arbres entaillés et les arbres-témoins. Toutes les stations ont affiché une réduction significative de la croissance radiale après l'amorce des opérations d'entaillage par rapport aux taux de croissance antérieurs à l'entaillage. On n'a pas observé le même phénomène chez les arbres-témoins, ce qui indique qu'il ne s'agit pas d'une manifestation de la croissance en fonction de l'âge. Nous en concluons que la réduction de la croissance radiale de l'érable à sucre découle vraisemblablement d'une réallocation des ressources pour soigner les blessures occasionnées au tronc de l'arbre lors de l'entaillage.

Mots clés : dendroécologie, sirop d'érable, *Phytobia setosa*, *Acer saccharum*

Introduction

Sugar maple (*Acer saccharum* Marsh.) sap has a high concentration of sugar, which makes it ideal for sugar and syrup production (Graham *et al.* 2006). In 2011, Canada produced \$349.5 million Canadian dollars of maple products (Morin *et al.* 2011) and the United States \$106 million US dollars of maple syrup (Keough *et al.* 2012). Although the geographic range of sugar maple spans southeastern Canada and the northeastern United States, the production of maple syrup is limited to regions with specific climatic conditions (Whitney and Upmeyer 2004). Sugar maple trees only produce a heavy sap flow during spring conditions when night temperatures dip below 0°C and daytime temperatures rise to a few degrees above 0°C (Tyree 1983). How the flow of sap happens when the trees are still in

a leafless condition is still an issue of debate among tree physiologists, but a recent mathematical model proposes that it is caused by a combination of two factors: an increase in vessel sap pressure caused by the thaw of frozen sap and the release of air bubbles, and an increase in exudation pressure caused by osmotic differences in sugar concentration within the sap (Ceseri and Stockie 2013). Where these physiological responses intersect with the ideal climatic conditions, the production of syrup and maple sugar is often important to local economies, with a mature tree yielding on average 70 l of sap yr⁻¹ and during a season with ideal climatic conditions, 129 l of sap may be collected from a single tree (Marvin and Erickson 1956).

The economic value of maple syrup has led researchers to focus on applied, production-oriented questions. Researchers have discouraged producers from grazing livestock in their

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stands because it results in a decrease in production of 53 l/ha (Dambach 1944). Producers are also encouraged to use smaller-diameter spouts during sap extraction because tap holes close more rapidly and this increases the long-term productivity of trees (Staats and Kelley 1996). Although these studies have provided a valuable resource to producers, topics related to the biological impacts of the industry on the growth and susceptibility to insects of sugar maple trees remain relatively unexplored, yet these questions are equally important.

On average, the sap collected for syrup production is 2.45% sugar (Marvin *et al.* 1967) and extraction may consume up to 9% of a tree's stored sugar (Jones *et al.* 1903). Stored sugar is typically used by the tree to produce new foliage, with full leaf-out occurring about a month after sap collection ends (Richardson *et al.* 2006). If extraction reduces foliage production, it could subsequently result in lower photosynthetic rates and possibly a reduction in radial growth. Other disturbances (e.g., insect damage and branch breakage during ice storms) that deplete carbohydrate reserves have resulted in reduced photosynthetic rates, reduced stem radial growth and tree vigor (Kolb *et al.* 1992, Hartmann and Messier 2008, Pisaric *et al.* 2008). Thus, it is plausible that the depletion of carbohydrate storage caused by tapping may decrease growth rate and vigor and make the tree more susceptible to future disturbance events that limit growth such as drought or insect outbreaks.

Dendroecology provides a useful tool to examine the influence tapping has on growth. Previous dendroecology studies have shown that the tree-ring record in sugar maple is a particularly effective recorder of environmental conditions. Annual ring widths vary according to the temperature and precipitation of each growing season (Lane *et al.* 1993, Tardif *et al.* 2001) and when a neighbouring tree dies, sugar maple responds with increased ring widths as the reduced competition allows the tree to capture more resources such as soil nutrients, water, space, and light (Cho and Boerner 1995). Occasionally, an environmental signal will not directly alter tree-ring widths, but will leave a signal through increased sensitivity to climate. For example, the arrival of invasive earthworms in forest soils appeared in the tree-ring record of sugar maple as an increased sensitivity of tree-ring widths to drought (Larson *et al.* 2010). Given the high sensitivity of sugar maple for recording environmental conditions, dendroecology may provide the best approach for understanding the influence of tapping on growth.

Phytobia setosa (Loew), a common cambium miner, was used to evaluate the influence of tapping on insect activity. Cambium miner activity does not influence the sugar content of a tree and trees with cambium miners are still actively tapped for production (Wallner and Gregory 1979). However, the relationship between the level of cambium miner activity and whether a tree is tapped for syrup has never been examined. During the growing season, larvae tunnel through the newly differentiating xylem cells and soft tissue of the inner bark leaving hollow cavities (Gregory and Wallner 1979). The larvae activity in the cambium zone causes the xylem cells to differentiate abnormally and fill the larval cavities with thin-walled, unusually large ray parenchyma cells, resulting in the wood defect known as pith fleck (Gregory and Wallner 1979, Rioux 1994). *Phytobia setosa* has three instars, with each progressively increasing in size; therefore, the cross-sectional area of the larval cavity reflects which instar created the cavity (Wallner and Gregory 1980). *Phytobia setosa* can be present in nearly 90% of the trees within

a stand, averaging one cambium miner scar within each 5 cm² cross-sectional area, and can cause a reduction in lumber value of 35% to 40% (Hanson and Benjamin 1967, Miller *et al.* 1978). There is some evidence to suggest that younger trees and those growing near the edge of a stand experience higher levels of larvae activity, but there appears to be no relationship between infestation level and either topographic position or elevation (Hanson 1965). There is no prior examination of the effect of tapping on cambium miner activity, but the higher rates of infestation in edge trees indicates that environmental stress may influence larvae density.

Therefore, the objectives of this study were to identify differences in radial growth rate and cambium miner activity between tapped and untapped (reference) trees. Specifically, we wanted to address the following questions: (1) Does repeated tapping cause reductions in radial growth? (2) Are trees repeatedly tapped more susceptible to infestation by *Phytobia setosa* than untapped trees? We will evaluate our results within the context of providing forest landowners with recommendations for best management practices for syrup production with the assumption that tapping practices that dampen growth potential and increases susceptibility to insect damage will result in a tree with lower vigour and thus a reduced potential for future syrup production. Given that it takes decades for a sugar maple tree to grow large enough to be tapped, maintaining healthy, vigorous trees is crucial to the sustainability of this agroforestry industry.

Methods

Study areas

Study areas in Pennsylvania (40.4°N, 78.1°W), New York (42°0'N, 78°18'W), and Ontario (45.4°N, 75.7°W) were located where we had access to sugar maple trees that had been tapped for several decades and where there was an adjacent reference stand of untapped trees (Table 1). At the Pennsylvania site, the tapped and reference sites were adjacent with the centroid of each sampling area located 0.2 km apart and at the same topographic position and elevation. At the New York site, the landowner painted trees that were tapped annually and therefore reference and tapped trees came from the same stand. In Ontario, tapped and reference sites were 21 km apart; however, the area has only moderate topographic relief and therefore the sites represented similar growing conditions. At the Ontario tapped site, work horses foraged among the trees (Fig. 1), a disturbance that was not present at the reference site.

Field and laboratory methods

At each site, we used an increment borer to extract two cores from a height of 0.5 m above the root collar from 25 dominant or co-dominant trees that had minimal crown damage and few stem defects. We selected trees with minimal crown damage to avoid ice storm signals in the tree-ring record (Pisaric *et al.* 2008) that could mask the potential signal from tapping. Thus, we collected a total of 300 cores (50 cores from 25 trees) for the reference and tapped groups at each of the three study regions. The Pennsylvania site was sampled in March and the New York and Ontario sites sampled in July.

Fresh increment cores were air-dried and sanded until anatomical features of the wood were clearly visible under the microscope (Speer 2010). Each tree-ring series was cross-dated under a microscope using the list year method where narrow

Table 1. Study areas where *Acer saccharum* increment cores were collected. Sites are abbreviated as PA – Pennsylvania, NY – New York, and ON – Ontario.

Site	Landowner: extraction method	Elevation (m)	Soil	Total annual precipitation (cm)	Mean winter temperature (°C)
PA	Juniata College's Raystown Field Station: <i>metal spouts with buckets</i>	243	Berks-Weikert association	100	-2
NY	Gibbons' Sugarbush: <i>plastic tubing</i>	518	Buchanan and Gilpin Channey silt loams	95	-4
ON	Stanley's Olde Maple Lane Farm: <i>plastic tubing</i>	83	Grenville loam	90	-8

Fig. 1. Top photograph shows the metal bucket system used to tap *Acer saccharum* trees at the Pennsylvania site and the bottom photograph shows the horses that use the Ontario site for summer forage.

rings common to trees throughout the stand are used to verify dating (Yamaguchi 1991). Cross-dating in sugar maple is especially important because the species is prone to missing

and partial rings when trees grow in closed canopy stands (Lorimer *et al.* 1999). After visual cross-dating, the widths of annual rings from each core were measured to the nearest 0.002 mm with a TA Unislide Measurement System (Velmex Inc., Bloomfield, NY). The initial visual cross-dating was then confirmed with COFECHA (Table 2), a cross-dating verification software that uses segmented time series correlations to analyze tree-ring measurement data for common temporal patterns in ring widths (Grissino-Mayer 2001).

For each cross-dated and measured tree core, annual growth rings were examined under a microscope for the presence of pith fleck, the distinctive misshapen cells caused by the cambium miner. For each annual ring in which one or more pith-ray flecks were observed, the corresponding year was recorded. This created a dataset of years of cambium miner presence in each tree core. The absence of pith fleck from a specific year should not be interpreted as absence of cambium miner activity because pith fleck does not form contiguously around the circumference of the stem (Fig. 2). However, a comparison of pith fleck frequency between tapped and untapped increment cores allowed for a comparison of relative cambium miner activity.

To isolate the potential influence of tapping on growth and cambium miner activity, we truncated each tree-ring series to only include the period when the tree would have been tapped. It is common practice to begin tapping once trees reach 25 cm in diameter at breast height (DBH, 1.4 m above the root collar; Walters and Yawney 1982). To be consistent across tapped and reference sites, the portion of each tree-ring series that represented growth after trees had reached 25 cm DBH was used. This had the double advantage of eliminating a period of growth when a strong competition signal would have been recorded in the tree-ring record as the stem transitioned from understory sapling to overstory tree (Lorimer and Frelich 1989). At the Pennsylvania site, tree-ring measurements before the trees reached 25 cm DBH and prior to 1950, the date when syrup production began, were removed from further analysis. This left tree-ring measurements from 20 trees from the tapped site and 20 from the reference site. Although the number of annual ring widths varied from tree to tree, an average of 29 tree-rings per tree was used to evaluate annual growth rates. At the New York site, measurements from before the trees reached 25 cm DBH and prior to 1984, when production began, were removed from further analysis. This left tree-ring measurements from 23 tapped trees and 18 from the reference site. Although the number of annual ring widths varied from tree to tree, an average of 20 tree-rings per tree was used to evaluate annual growth rates. At the Ontario site, annual tree-ring measurements from before the trees reached 25 cm DBH and prior to 1980 when production began, were removed from further analysis. This left tree-ring measurements from 20 trees from the tapped site and 18 from the reference site. Although the number of annual ring widths

Table 2. Tree-ring characteristics from *Acer saccharum* stands. Sites that had been tapped are indicated with a "T" and reference sites with an "R."

Site	Years	Maximum tree age (years)	No. series	No. trees	Series intercorrelation
PA – T	1901–2006	105	40	21	0.610
PA – R	1893–2006	113	38	22	0.581
NY – T	1914–2011	97	40	24	0.589
NY – R	1921–2011	91	40	21	0.684
ON – T	1916–2011	95	40	22	0.615
ON – R	1906–2011	105	33	21	0.532

Fig. 2. Pith fleck caused by *Phytobia setosa* larvae in *Acer saccharum*.

varied from tree to tree, an average of 20 tree-rings per tree was used to evaluate annual growth rates.

Data analysis

To identify if sap extraction altered growth rates, a two-tailed *t*-test was used to compare mean growth rates of tapped vs. reference trees at all study sites. To eliminate any potential growth differences between tapped and reference sites, a second approach for identifying the potential impact of tapping on radial growth was employed using a paired *t*-test to compare average tree-ring widths from the 10 years prior to tapping with average tree-ring widths 10 years after tapping. This approach allowed us to examine the influence of tapping within the context of each individual's growth potential, but by using the short 10-year windows for comparison, age-related trends in radial growth should not unduly impact the comparison. To ensure that no age-related trends would influence this test, a *t*-test was used on paired 10-year growth windows in the reference trees that compared average growth prior to the tree reaching 25 cm (the diameter limit used to identify a tree as sufficiently large

to tap) with growth after the tree exceeded 25 cm DBH. If no significant difference between these two 10-year periods were found, it would indicate that the comparison in the tapped trees could be used to identify a potential influence of tapping on radial growth and that the comparison would not be influenced by age-related growth trends.

To contrast the intensity of cambium miner activity between tapped and reference trees, we calculated the mean percent of tree rings with pith fleck for each tree during the period of potential tapping and compared these with a two-tailed *t*-test. An alpha-level of 0.05 was used to identify significant responses. It should be noted that the increment borer used to extract tree cores was of fixed diameter and as such we sampled a greater

portion of each annual ring during the years when trees had smaller diameters than when trees had larger diameters.

Results

Radial growth

The radial growth rate in tapped trees was significantly less (Table 3) compared to growth rates in untapped trees at both the Pennsylvania ($t = -3.465$, $P = 0.001$) and the Ontario site ($t = 2.163$, $P = 0.037$). At the Pennsylvania site, the average radial growth was almost half that of the reference trees; tapped trees averaged 1.6 mm yr^{-1} and reference trees 2.4 mm yr^{-1} . At the New York site ($t = 0.992$, $P = 0.327$), there was no significant difference in radial growth between tapped and untapped trees (Table 3).

In the reference trees at all three sites, within-tree comparisons of growth found no significant differences in the mean growth over a 10-year period, from prior to the tree reaching the minimum tapping diameter (25 cm) compared to the subsequent 10 years (Table 4). This indicates that for comparisons of these 10-year growth windows, age-related growth trends do not significantly influence annual ring width. In the tapped trees in Pennsylvania ($t = 1.931$, $P = 0.031$), New York ($t = 3.240$, $P = 0.001$), and Ontario ($t = 2.930$, $P = 0.003$), radial growth 10 years after tapping began was significantly less than growth in the 10 years before tapping occurred (Table 4).

Pith fleck

There were no significant differences between the percent of pith fleck in tapped trees compared to reference trees (Table 5). Comparison between tapped and reference trees only spanned the period when the trees were larger than 25 cm DBH and after the period when tapping had begun at each site. Our dataset of presence and absence of pith fleck spanned the full life of the trees and not just the period when the trees were tapped. Both reference and tapped trees experienced higher rates of cambium miner activity when they were too small to be tapped. In Pennsylvania, sugar maple less than 25 cm DBH had pith fleck in 13% of the annual rings but only 2% of the rings had pith fleck after the trees were large enough to be tapped. Similarly, in New York trees less than 25 cm DBH had pith fleck in 21% of the annual rings, but after these trees were large enough to be tapped, cambium miner activity occurred in only 7% of the annual rings. Ontario trees less than 25 cm in diameter had pith fleck in 5% of the annual rings, but after these trees were large enough to be tapped, only 0.3% of the rings exhibited pith fleck.

Table 3. Comparison of radial growth in tapped compared to reference trees. Standard error is shown in parentheses after the mean ring width. Sites with a significant difference between tapped and reference trees are indicated with an asterisk.

Site	Mean ring width (mm)		<i>t</i> -statistic	<i>P</i> -value
	Tapped (SE)	Reference (SE)		
Pennsylvania	1.559 (0.176)	2.406 (0.169)	-3.465	0.001*
New York	1.548 (0.207)	1.257 (0.199)	0.992	0.327
Ontario	1.589 (0.140)	2.139 (0.219)	2.163	0.037*

Discussion

Tapping influence on radial growth rate

At two of the three study sites, tapping reduced radial growth compared to growth in reference trees (Table 3), and at all three sites, tapping resulted in reductions in radial growth compared to growth rates prior to tapping (Table 4). The causes of reduced growth may be either loss of carbohydrates during the extraction of sap or reallocation of resources towards healing the holes in the bark, phloem, cambium and xylem caused by the taps used during sap extraction. If the reduction in growth was caused by loss of carbohydrates during extraction, the Ontario site should have experienced the greatest reduction because it has the shortest growing season (sugar maple growth is significantly correlated with temperature), which would not allow trees to compensate for the loss of carbohydrates occurred during tapping (Yin *et al.* 1994). However, Ontario did not appear to have experienced a more severe reduction in growth (Table

3 and Table 4); therefore, it is likely that growth reductions are a result of the physical damage to the stem during the tap placement and removal. The experience level of workers may also have contributed to the level of damage experienced by the stem during the tapping process. At the Pennsylvania site, where average annual radial growth was significantly lower in tapped (1.6 mm) compared to untapped trees (2.4 mm) and where tapping significantly reduced the average ring width (2.2 mm vs.

1.9 mm), tapping was carried out by college students. It may be that inexperienced students were more likely to cause damage to the cambium because each year brings a new cohort of untrained workers who must learn the proper procedure for placing taps in the stems. We did not find strong evidence that tapping method (metal bucket vs. plastic tubing) resulted in a difference in reductions in growth rates. Cooperative extension programs identify switching from bucket to tubing extraction systems as the most common change made by producers who attend their educational programs (Graham *et al.* 2006). The advantage of the plastic tubing system is that it increases sap yield. However, because we did not find evidence of a difference in growth reduction between metal bucket (lower sap yield) vs. plastic tubing (higher sap yield), this further confirms that the

Table 4. Comparison of average annual radial growth for the 10 years prior to tapping compared to the average growth 10 years after tapping. Standard error is shown in parentheses after the mean ring width. Sites with a significant difference between pre-and post-tapping periods are indicated with an asterisk.

Tapped trees	10-year mean of ring width (mm)		<i>t</i> -statistic	<i>P</i> -value	% change
	Pre-tapped (SE)	Tapped (SE)			
Pennsylvania	2.213 (1.164)	1.884 (1.059)	1.931	0.031*	-15%
New York	2.187 (0.951)	1.631 (0.711)	3.240	0.001*	-26%
Ontario	2.058 (0.639)	1.669 (0.779)	2.930	0.003*	-19%
Reference trees	10-year mean of ring width (mm)		<i>t</i> -Statistic	<i>P</i> -value	% change
	Pre-25 cm DBH	Post-25 cm DBH			
Pennsylvania	2.690 (1.007)	2.644 (1.389)	0.152	0.440	-2%
New York	1.838 (0.505)	1.572 (0.421)	1.581	0.065	-15%
Ontario	2.638 (0.811)	2.400 (1.021)	1.653	0.057	-9%

Table 5. Comparison of pith fleck caused by cambium miner activity in tapped trees compared to reference trees. Standard error is shown in parentheses after the mean percentage of rings with pith fleck.

Site	Mean % of rings with pith fleck		<i>t</i> -statistic	<i>P</i> -value
	Tapped (SE)	Reference (SE)		
Pennsylvania	2.1% (0.5)	6.8% (3.3)	-1.575	0.120
New York	7.0% (1.3)	6.2% (1.7)	0.357	0.722
Ontario	0.3% (0.2)	0.3% (0.3)	-0.029	0.977

reductions in radial growth are likely a result of damage to the stem during the tapping process and not the loss of carbohydrates during sap extraction.

The Ontario site, in addition to being used for syrup production, provides a large, seasonal customer base with a variety of agrotourism experiences, including horse-drawn rides. During the summer, the work horses forage in the sugar maple stand (Fig. 1) and previous work has shown that grazing by livestock reduces syrup yield (Dambach 1944). Therefore, it is possible that foraging by horses, combined with maple syrup tapping, may have contributed to the significant reduction in radial growth by tapped trees (Table 3 and Table 4). Forest soils grazed by cattle or sheep have a greater bulk density than soils in ungrazed stands (Tate *et al.* 2004, Sharrow 2007) and it is likely that similar changes in soil structure occurred at the tapped Ontario site.

In New York there was no significant difference in growth in tapped compared to reference trees (Table 3); however, when compared to growth rates before tapping, there was a significant decrease after tapping (Table 4). The New York site is owned by a small-scale hobby maple syrup producer who makes enough syrup for family consumption. Small-scale hobby producers usually have different tapping practices than commercial producers and generally use fewer taps per tree (Graham *et al.* 2007). The landowner told us that he determines the number of taps to place in each tree based on summer tree-crown vigor, which is an appropriate indicator of the impact of tapping on tree health (Walters and Shigo 1978). However, there still was a significant reduction in growth rate that occurred in trees with the onset of tapping (Table 4).

A reduction in growth caused by tapping does not prevent a stand from yielding a sustainable supply of syrup. This is especially evident at the Pennsylvania site where the tapped trees experienced significant reductions in growth (Tables 3 and 4), but the site has been producing syrup for over 50 years. However, reduced radial growth may decrease future syrup production. The presence of many large-diameter trees in a localized region increases the value of a site for potential syrup production (Farrell 2013). Therefore, it is advantageous for syrup producers to reduce the impact of tapping on tree growth in order to maximize the number of large trees in their stands. This means producers should use conservative tapping intensity (fewer taps per tree) and exclude livestock from their stands to maximize future production.

Tapping influence on cambium miner activity

Phytobia setosa disproportionately affects younger trees (Hanson 1965). Given that trees are generally not tapped until they reach 25 cm DBH, the highest period of cambium miner activity occurred prior to tapping and therefore we failed to detect an influence of tapping by cambium miners (Table 4). Regardless of the lack of connection to tapping, the results did reveal a site-specific difference in cambium miner activity. The Ontario site had the lowest densities of pith fleck and the New York site the highest (Table 4). Cambium miners favor trees with high sugar content (Wallner and Gregory 1980) and it is possible that New York's trees had higher sugar content but we did not measure this. The site-specific differences in cambium miner density do not appear to be strongly climatic because both in this study (Tables 1 and 5) and another with sugar maple and *P. setosa* in the

Great Lakes region of Michigan and Wisconsin, there was no apparent relationship between temperature and precipitation and cambium miner activity (Miller *et al.* 1978, Fuller *et al.* 1995).

Conclusions

Sap extraction by metal buckets and plastic tubing significantly reduced the radial growth of trees. Results suggest that, although syrup production reduces radial growth, this reduction does not appear to reduce the sustainability of a sugar maple stand because trees had been repeatedly used for syrup production for decades. However, the reduction in growth will result in less vigorous trees and intense tapping may reduce future sap production because of reduced growth rates. This study also found that having livestock forage in sugar maple stands may significantly reduce tree growth rates and, therefore, excluding livestock would be a good practice.

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