GROWTH RATES OF TREES TAPPED WITH HIGH-YIELD SAP COLLECTION PRACTICES - ARE CONSERVATIVE TAPPING GUIDELINES SUSTAINABLE?

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Each year, tapping a tree for sap collection permanently removes a small portion of wood where the spout is inserted. The tree's response to the wound also results in a column of wood extending above and below the taphole that remains permanently nonconductive to water and thus unavailable for future sap collection. Sap collection also removes a portion of the tree's carbohydrate (sugar) reserves, which are important for supporting the tree's growth and health. However, stem growth also adds new conductive wood to the outside of the tree each year, and photosynthesis during the growing season replenishes carbohydrate reserves.

For annual maple sap collection to be sustainable, the volume of nonconductive wood generated by tapping shouldn't exceed the volume of conductive wood that can be added by annual diameter growth. Also, the portion of sugar reserves extracted should not be large enough to reduce growth rates and hinder the replenishment of conductive wood. Tapping guidelines are a set of best practices aimed at ensuring these conditions are met, and that tree health is not compromised as a result of sap extraction.

Existing tapping guidelines were originally developed when collecting sap in buckets under gravity conditions was the predominant practice. They were also aimed mainly at mitigating the impacts of the wound caused by tapping, and did not account for the effects of removing tree carbohydrate reserves. Since that time, better vacuum pumps, improved tubing system materials and design, and tubing/spout replacement and sanitation strategies have led to significant increases in the amount of sap collected from tapholes. For example, the quantity of sap that can be collected each year from an individual tree using bucket collection is approximately 0.2 gallons of syrup equivalent, while the yield achievable using a system which incorporates high levels of vacuum and current equipment and practices is between 0.4 and 0.6 gallons. For these reasons, it is essential to determine whether existing tapping guidelines are appropriate to use with these current, "high-yield" sap collection practices which remove a much greater amount of a tree's sap.

METHODS

The overall objective of this work was to determine whether existing

Conservative Tapping Guidelines (Chapeskie et al. 2006) are appropriate and likely to result in sustainable outcomes when used with sap collection practices that result in higher sap yields. To accomplish this objective, three general questions needed to be answered:

1. What are the diameter growth rates of trees tapped with high-yield sap collection practices?
2. What are the minimum growth rates required for tapping to be sustainable when following Conservative Tapping Guidelines?
3. Are the growth rates of trees tapped with high-yield practices generally greater than these minimum rates?

Growth rates of trees tapped with high-yield sap collection practices

Research was first conducted to determine the diameter growth rates of trees tapped with high-yield sap collection practices. Eighteen cooperating maple production operations throughout Vermont that had used high-yield collection practices for at least the previous 5 years were identified. "High-yield" operations were defined as those that used vacuum levels ≥20"Hg and that had production yields of ≥0.4 gallons of syrup equivalent/tap.[1] Operations were selected to generally represent the typical range of stands tapped for maple production in Vermont; the site quality (evaluated by site characteristics and indicator plants) was considered "good" to "excellent" for sugar maple growth.

At each operation, a single stand with uniform site characteristics (including site quality, elevation, aspect, and basal area) and site history (including past management activities and occurrences of weather events, insects, and disease) was identified. Only stands that had not been thinned in at least the previous 10 years were selected. Stands with extensive histories of stress or large-scale disturbances (such as multiple years of insect outbreaks) were avoided.

Within each stand, healthy, codominant or dominant trees tapped annually with a single tap for at least the past 10 years were selected. Optimally, 7-10 trees from each of 6 size classes (8-9.9, 10-11.9, 12-13.9, 14-15.9, 16-17.9, and 18-19.9" diameter at breast height, DBH) were selected in each stand. This range was chosen to represent the sizes of trees maple producers are currently tapping with 1 tap per tree annually.[2] Care was taken to ensure each tree was selected from an area with conditions representative of the overall stand. All selected trees met the basic criteria established for tapping under current best practices for maple syrup production (Chapeskie et al. 2006).

In late-summer and autumn 2010, increment cores were collected from the

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[1]Only practices over the previous five years were considered, as the technology (vacuum pumps, spouts, etc.) necessary to produce very high sap yields became widely available between seven and ten years ago.

[2]The analyses in this report only examine the impact of a single tap per tree annually. Current Conservative Tapping Guidelines specify a minimum tree diameter of 12 inches for tapping (Chapeskie et al. 2006), although 10 inches is also generally considered acceptable. Smaller trees were included in the study as some producers report tapping trees less than 10 inches dbh.

north and south sides of each selected tree at each operation. Cores 6-8 cm in length were collected using a 5-mm diameter increment borer approximately 0.75 m from the ground, in order to avoid areas of the trunk affected by previous tapping. Diameters at breast height and at the height of core collection were recorded for subsequent calculations. A total of 1,076 cores from 538 trees were collected.[3]

After collection, cores were mounted in wooden blocks and prepared for analysis by sanding to enhance the visibility of annual rings. The widths of each core's annual rings were measured to the nearest 0.001mm using a digital micrometer linked to a measuring sledge. These data were used to calculate the average annual basal area increment (BAI) over the previous 5 years (2005-2009) for each core. (Basal area increment is the area of new wood added each year at breast height, and is a standard way to report and analyze the radial growth rates of trees.)

Basal area increments of each core (north and south) were used to calculate the mean BAI for each tree. These data were then used to calculate the mean BAI of trees in each diameter class at each site; from these data, the mean BAI's of trees in each diameter class across all sites were calculated to express the overall average annual growth rates of trees in each diameter class.

Minimum growth rates required under Conservative Tapping Guidelines

For annual sap collection to be sustainable, growth rates must be sufficient so that the amount of nonconductive wood generated by tapping is replaced annually by diameter growth, and thus that the amount of conductive wood in the tapping zone of a tree remains very high over time. For this study, sustainability was defined as maintaining a proportion of conductive wood in the tapping zone ≥90% for at least 100 years. This equates to a probability of hitting white, conductive wood when tapping in 9 out of every 10 trees, and was chosen after consultation with producers and maple extension personnel.

Research was conducted to determine the minimum growth rates required for tapping to be sustainable when using the Conservative Tapping Guidelines outlined in the 2006 North American Maple Syrup Producers Manual (Chapeskie et al. 2006). To do this, a model was first developed that estimates the amount of conductive and nonconductive wood in the tapping zone of a tree over time.[4] Values for model parameters were then set to match those of

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[3]Cores from an additional 259 trees that were outside this diameter range, and/or that had suppressed or intermediate canopy position were also collected and analyzed. Data from these trees were not included in this report, but are being used in more extensive calculations for formal tapping guideline revision.

[4]Details of the Tapping Zone Model development and calculations have been described elsewhere (van den Berg 2012). An interactive version of the Tapping Zone Model that enables users to assess the sustainability of tapping practices is available to download from the UVM-PMRC website. A technical report describing its development and use is also available to download (van den Berg and Perkins 2013), and will be published in a forthcoming issue of The Maple Syrup Digest.

the Conservative Tapping Guidelines. For tapping with vacuum sap collection, these guidelines specify a minimum tree diameter of 12" for a single tap, a minimum dropline length of 30", a tapping depth of between 1-2" (1.5", the middle of this range, was used in model analyses), and a spout size of 5/16"-diameter. For each tree diameter class, the growth rates used in the model calculations were then adjusted to determine the minimum BAI required so that the proportion of conductive wood within the tapping zone would not fall below 90% over 100 years of annual tapping. These minimum rates were then compared to the growth rates of the trees sampled in the research, to see if the average growth rates of trees tapped with high-yield practices generally exceeded the minimum rates required for tapping to be sustainable.

RESULTS AND DISCUSSION

The average annual basal area increments of trees in 6 DBH classes tapped using high-yield sap collection practices are presented in Table 1. These values represent the average annual growth rates over a 5-year period of healthy, dominant or co-dominant sugar maple trees from 18 stands representing a range of stands tapped for maple production in Vermont. Trees had been tapped using high-yield sap collection practices for at least the previous 5 years using only 1 tap per tree annually.

Table 1. Mean annual radial growth rates (basal area increment, ± standard error of the mean) from 2005-2009 for healthy, dominant or co-dominant sugar maple trees tapped with high-yield sap collection practices from 18 stands in Vermont representative of typical stands tapped for maple syrup production. n = the number of stands.*

DBH class (in.)	n	BAI (in^2)
8-10	7	1.4 ± 0.3
10-12	16	1.8 ± 0.2
12-14	18	2.3 ± 0.3
14-16	17	2.7 ± 0.2
16-18	17	2.9 ± 0.2
18-20	15	3.3 ± 0.3

* The data for each diameter class were averaged by stand, however these means are comprised of data from 538 individual trees: 8-10" = 28 trees; 10-12 = 85; 12-14 = 135; 14-16 = 130; 16-18 = 98; 18-20 = 62.

In general, BAI increased with increasing diameter class, and rates were generally within ranges published for sugar maple in other studies (Long et al. 2009, Long et al. 2011). It is important to note that the trees included in this study were healthy, dominant or codominant trees selected to represent those typically tapped for maple syrup production under current best practices (Chapeskie et al. 2006), and these growth rates should not be extrapolated beyond trees tapped with high-yield practices which meet these criteria. These growth rates should also not be considered reflective of trees that are growing on poor quality sites, that have suppressed or intermediate canopy position, or that are otherwise stressed or unhealthy due to disease or other factors. Indeed, trees with suppressed and intermediate canopy positions sampled in this research had substantially lower growth rates (data not shown).

To be sustainable, the growth rates of tapped trees must be sufficient so that the amount of nonconductive wood generated by tapping is replaced annually by diameter growth, and thus that the amount of conductive wood in the tapping zone of a tree remains very high over time. For each DBH class studied, Table 2 shows the minimum growth rates required for tapping trees to be sustainable when following Conservative Tapping Guidelines (Chapeskie et al. 2006) that were determined using the Tapping Zone Model. The average growth rates of the trees sampled in this study (Table 1) typically exceeded these minimum rates (Table 2). This suggests that, in general, for healthy trees that have dominant or codominant canopy position and are growing on good quality sites, current Conservative Tapping Guidelines are generally appropriate to use when tapping with high-yield sap collection practices. The limits and practical application of this conclusion are discussed in greater detail below.

Table 2. Minimum annual growth rates (basal area increment) required for healthy, dominant or co-dominant sugar maple trees growing on good quality sites for annual sap collection to be sustainable in the long-term using current, conservative tapping guidelines (Tapping Depth = 1.5", Dropline Length = 30", Spout Size = 5/16"). Sustainability is defined as a proportion of conductive wood within the tapping zone no less than 90% for at least 100 years.

DBH class (in.)	Minimum BAI (in^2)
8-10	1.1
10-12	1.1
12-14	1.1
14-16	1.2
16-18	1.5
18-20	1.8

It is important to note that the trees sampled in this study had been tapped with high-yield practices for a relatively short period of time, <10 years, and thus the growth rates observed might not reflect those of trees tapped with these practices over a longer period of time. A study at UVM-PMRC has been initiated to address the question of whether there are any potential long-term effects of high-yield sap collection practices on tree growth rates.

GENERAL RECOMMENDATIONS

This research was part of a larger effort underway at UVM-PMRC to evaluate and revise existing tapping guidelines to incorporate the results of recent research, and particularly to ensure they are appropriate for current sap collection practices that facilitate much higher sap yields than those achievable using past collection methods. The new guidelines will aim to incorporate the results from research on the effects of tapping practices on both sap yields and tree health, as well as to reflect a balance between costs and benefits of various practices. The new guidelines will be included in the upcoming 3rd Edition of the North American Maple Syrup Producers Manual, which is expected to be published in 2016. Until the final guidelines are available in the new Producers Manual, we can make the following general recommendations based on the results of the present study:

The results of this study indicate that for healthy trees that have dominant or codominant canopy position and are growing on good quality sites, current Conservative Tapping Guidelines are generally appropriate to use when tapping with high-yield sap collection practices. It is important to note that this recommendation applies only to healthy trees with dominant or codominant canopy position growing on sites that are generally of good quality for sugar maple growth, and only when all best practices specified in the tapping guidelines are followed (Chapeskie et al. 2006). The complete description of best tapping practices outlined in the Manual should be consulted, but they include these basic guidelines:

- Minimum tree diameter (at breast height) = 12 inches
- Minimum dropline length = 30 inches[5]
- Maximum tapping depth = 1.5 inches[6]
- Spout Size = 5/16 or 19/64 inches

The recommendations based on this research do not apply to trees that have suppressed or intermediate canopy position, or those that are growing

[5]The length of droplines strongly influences the total area of the trunk available to tap, so shorter droplines can rapidly result in nonconductive wood making up a large proportion of the tapping zone. 30" should be considered a minimum length, and longer droplines, ~36", are recommended. Also, if your practices include annual or periodic spout replacement, remember to factor this in when making droplines - a few years of cutting spouts off droplines for replacement can quickly turn 30" droplines into 20" droplines, and greatly reduce the potential sustainability of tapping practices.

[6]1.5" is the middle of the tapping depth range specified by the guidelines. For very healthy trees with good growth rates, it may be acceptable to tap to a depth of 2". (UVM Maple Extension Specialist Tim Wilmot is currently conducting a study to determine the tapping depth which optimizes sap yield while considering the damage generated by the taphole, and these recommendations will be updated as needed upon the conclusion of that research. More information about tapping depth can be found in the following article: http://www.uvm.edu/~pmrc/wilmot_deep.pdf.

on poor quality sites. They are also not applicable to trees that are slow-growing, less healthy, or show signs of stress or disease (poor crown condition, smaller or fewer leaves than normal, slow-healing wounds, major trunk wounds, branch dieback, etc). Tapping practices should be modified if any of these conditions is present. Caution should also be used in stands that are very dense, as even healthy trees in dense stands can have very slow rates of diameter growth.[7]

Though the recommendations outlined are generally applicable to the types of trees and stands indicated, it is important to remember that the only way to explicitly determine whether tapping following these guidelines will be appropriate for a particular tree is to determine its growth rate. County or consulting foresters can provide assistance with assessing the growth rates of trees.

SMALLER TREES

Some tapping guidelines specify that trees smaller than 12" in diameter can be tapped. For example, the "Traditional" tapping guidelines outlined in the Manual specify 10" as a minimum diameter (Chapeskie et al. 2006), and the Vermont organic guidelines specify 9" as a minimum (NOFA-VT 2012). Results from this study indicate that tapping trees in the 10-12" size class will generally be sustainable, as long as the criteria outlined above are met and followed (canopy position, health, site quality, tapping practices, etc.).

Trees smaller than 10" dbh should be tapped cautiously - trees this small rapidly accumulate large amounts of nonconductive wood in the tapping zone (van den Berg and Perkins 2013), and sap collection removes a much greater proportion of their carbohydrate reserves than in larger trees. Also, trees in this dbh range often have suppressed or intermediate canopy positions. These trees are likely to have much slower growth rates, and will thus accumulate nonconductive wood even more rapidly. Optimally, growth rates of small trees should be determined before tapping, and should exceed a basal area increment of 1.1 in^2/yr. For more information about tree diameter growth, please see the following article: http://www.uvm.edu/~pmrc/wilmot_diameter.pdf.

ADDING A SECOND TAP

The Conservative Tapping Guidelines specify that a second tap can be added in trees greater than 18" in diameter. This is likely an acceptable practice for trees tapped with high-yield collection practices, however caution should be used when deciding which trees will receive a second tap. This research examined only the growth rates of trees that were tapped with a single tap, and results from trials with the model suggest that putting a second tap in less vigorously growing trees can result in a proportion of damaged wood in the tapping zone greater than 10% after only a few years of tapping.

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[7]Information on evaluating the site quality of stands can be found in the North American Maple Producers Manual, and in the following article: http://www.uvm.edu/~pmrc/fertilization_brochure.pdf.

For this reason, we recommend putting a second tap only in very healthy trees with excellent growth rates. If you begin hitting discolored wood (brown, non-white) more frequently after adding a second tap, you should consider reducing tapping intensity.

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