

Defining modern, sustainable tapping guidelines for maple syrup production

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Completion date: July 2012

- The current, conservative tapping guidelines in place in the maple industry are appropriate for use with modern sap collection practices that result in greater sugar extraction than traditional practices; adherence to these guidelines when tapping trees with high-yield sap collection practices will generally result in long-term sustainable outcomes.
- Maple producers can follow these guidelines to help ensure that both the long-term economic and ecological sustainability of maple production in the Northern Forest are maintained.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.

<http://www.nsrcforest.org>

Project Summary

Maple syrup production is a traditional practice within the Northern Forest that generates jobs, provides income, and helps maintain the traditional working landscape of the region. The profitability and long-term economic sustainability of maple syrup production depend entirely on the sustainability of annual sap extraction from trees. To be sustainable, annual sap collection must not remove or damage more wood than can be replaced by annual growth, or extract a portion of sugar resources large enough to reduce growth rates and hinder the replenishment of functional wood. Maple producers follow 'tapping guidelines', a traditional set of best practices for sap collection, to ensure their practices meet these requirements. Now, however, modern sap collection equipment and practices facilitate at least twice the volume of sap extraction per tree than was possible with the technology used when the existing guidelines were developed, and evidence suggests even greater extraction rates are possible. Thus, the existing tapping guidelines may not be a sustainable approach for collecting sap with these 'high-yield' practices.

The overall goal of this study was to define sustainable guidelines for tapping trees using modern, high-yield sap collection practices and equipment. To accomplish this goal, we determined the annual growth rates of trees subjected to high-yield collection practices and developed a model that estimates the availability of functional wood in the tapping zone of a tree over time. We used the model to determine the minimum growth rates required for tapping trees to be sustainable using current tapping guidelines, and to define the practices required for sap collection with high-yield methods to be sustainable.

The average growth rates observed for trees tapped with high-yield sap collection practices were well over the minimum rates required for tapping to be sustainable when using the current, conservative tapping guidelines. These results indicate that the tapping guidelines currently in place in the maple industry are appropriate for use with high-yield collection practices; adherence to these guidelines will ensure that the long-term sustainability of sap collection is maintained when tapping trees using modern practices with greater carbohydrate extraction rates. As these collection practices also increase the productivity and profitability of maple syrup production, these guidelines will help ensure that both the long-term economic and ecological sustainability of maple production is maintained, and thus that the industry will continue to provide economic opportunities in the Northern Forest through an ecologically-sustainable use of its resources.



Photo: Brian Stowe

Background and Justification

Maple syrup production is a traditional practice within the Northern Forest with demonstrated long-term ecological sustainability. The activity involved in making maple syrup generates jobs, provides a direct source of income to farmers and woodlot owners, and helps maintain the traditional working landscape of the region.



Tapping a maple tree for sap collection with more "modern" equipment, including plastic spouts connected to a vacuum tubing collection system. (Photo: Catherine Stevens)



"Traditional" sap collection using horses to help gather sap collected in buckets hung on each tree.

In general, for annual maple sap collection to be sustainable in the long-term, the practice must not either damage a greater volume of wood than can be replaced annually with radial growth, or remove a quantity of the tree's carbohydrate resources large enough to significantly impact its growth rate and hinder the replenishment of functional wood. To help ensure their practices achieve these requirements for sustainability, maple producers follow voluntary 'tapping guidelines', a set of unofficial best practices that have been developed within the industry over time. Primarily the guidelines detail the minimum diameter tree to tap for sap collection and acceptable standards for other collection practices, such as tapping depth and the length of sap droplines.

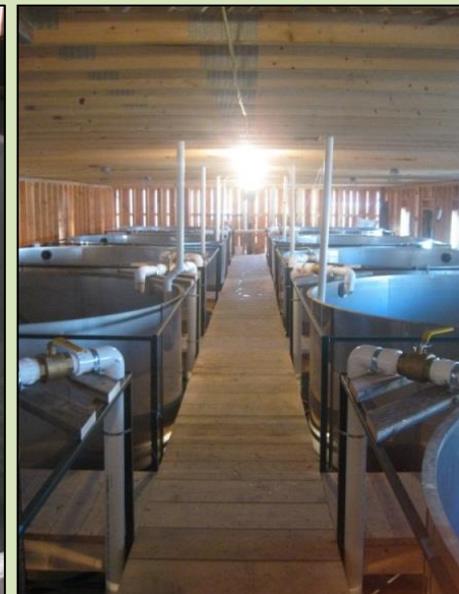
Background and Justification

Though evidence suggests that adherence to these guidelines when collecting sap using traditional maple production techniques and equipment is indeed sustainable, the guidelines may not be sufficient to ensure sustainability when sap is collected using more modern equipment and practices. The existing guidelines were developed when collection of sap in buckets was the predominant practice. However, recent improvements in sap collection practices and equipment, such as better vacuum pumps and spout/tubing replacement and sanitation practices, have substantially increased the quantity of sap, and thus the proportion of the tree's carbohydrate reserves, able to be extracted annually from trees.

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. A tree's carbohydrate reserves are critical to its overall health, as these stores are used for essential processes including growth and defense. Thus, it is possible that the existing tapping guidelines may not be a sustainable approach for collecting sap with these 'high-yield' practices.



Modern maple sap collection equipment that helps achieve higher sap yields. Check-valve spout that improves taphole sanitation (left) and wet/dry vacuum tubing collection system (right).



Large-scale sap collection tanks.

Background and Justification

The profitability and long-term economic sustainability of maple syrup production depend entirely on the sustainability of annual sap collection from trees. Thus, to ensure that maple production continues to provide economic opportunities in the Northern Forest and be an ecologically-sustainable use of its resources, it is critical to define guidelines for tapping practices that ensure the sustainability of annual sap collection with current, high-yield sap collection methods.



Photo: Catherine Stevens

The overall goal of this study was to define sustainable guidelines for tapping trees using modern, high-yield sap collection practices and equipment. This goal was met by accomplishing the following objectives:

- 1) Determine the annual growth rates of maple trees subject to high-yield sap collection practices.
- 2) Develop a model that estimates the availability of functional wood in the tapping zone of a tree over time, and which can be used to assess the sustainability of tapping practices.
- 3) Use the tapping zone model to determine the minimum growth rates required for tapping trees to be sustainable in the long-term using current tapping guidelines.
- 4) Use the growth rates determined for trees tapped with high-yield sap collection practices with the model to determine the practices required (tapping guidelines) for sap collection with these practices to be sustainable.

Methods

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.* 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) ranged from “below average” to “excellent”, but most operations were on sites considered “good” for sugar maple growth.



Crown assessment during study tree selection.

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.** 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.¹

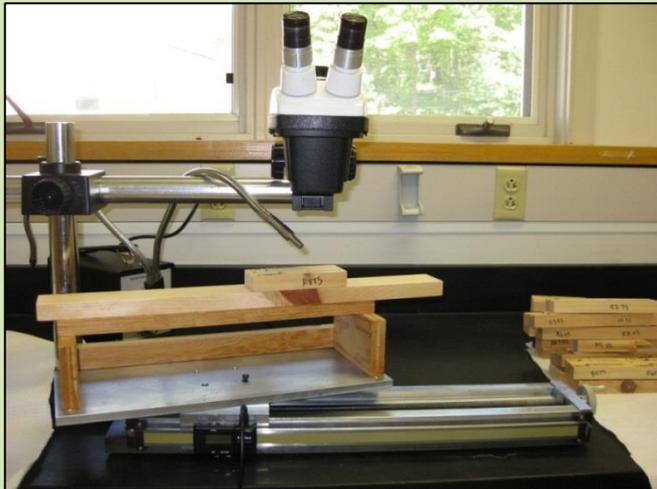
Methods

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

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



Collecting increment cores.



Assembly used for measurement of tree core ring widths.



Tree cores mounted and prepared for measurement of annual rings.

After collection, cores were mounted onto 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 0.001 mm 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. (The 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.

Methods

Model of functional wood in the tapping zone

The tapping zone of a maple tree is a radial band of wood based at the point on a tree where the sap dropline meets the lateral tubing of the sap collection system (Figure 1a,b). Its boundaries are defined by the depth of the taphole, the length of the sap dropline, and the circumference of the tree. Each year, tapping for sap collection not only permanently removes a small portion of wood where the spout is inserted, but the wounding response of the tree also renders a column of wood surrounding the taphole permanently nonfunctional for water transport and future sap collection (Figure 2). However, radial growth adds new functional wood to the outside of the tapping zone each year, and this outward growth also shifts the tapping zone so that some of the nonfunctional wood from older tapholes is embedded deeper into the tree and is thus no longer within the tapping zone boundaries. So at any point in time, the volume of wood available for tapping is simply the proportion of the total tapping zone volume that is comprised of functional wood unaffected by previous tapping (Figure 3). This amount, and how it changes over time, can be calculated relatively simply from known or measureable parameters.



Figure 1a. "Tapping Zone" of a maple tree.

A tree's radial growth rate determines how rapidly the volume of wood removed by tapping is replenished. To be sustainable, tapping must not remove a portion of a tree's carbohydrate reserves large enough to substantially reduce a tree's radial growth rate. Thus, we can conclude that a tapping practice is sustainable if growth rates are sufficient to maintain a proportion of functional wood within the tapping zone that is very high over a long period of time. For this work, this level was defined by project cooperators as 90%; this would mean that the likelihood of tapping functional wood in a given tree each year was approximately 90%.

Based on these premises, a spreadsheet model was developed that estimates the proportion of functional wood within the tapping zone of a tree over time given user-input values of tree diameter, and management practices of dropline length, tapping depth, and spout size (Figure 4). This model enables estimation of the growth rates required for a tree to maintain a proportion of functional wood in the tapping zone large enough to be considered sustainable, and assessment of how changes in tapping practices affect the long-term sustainability of tapping.*Model details

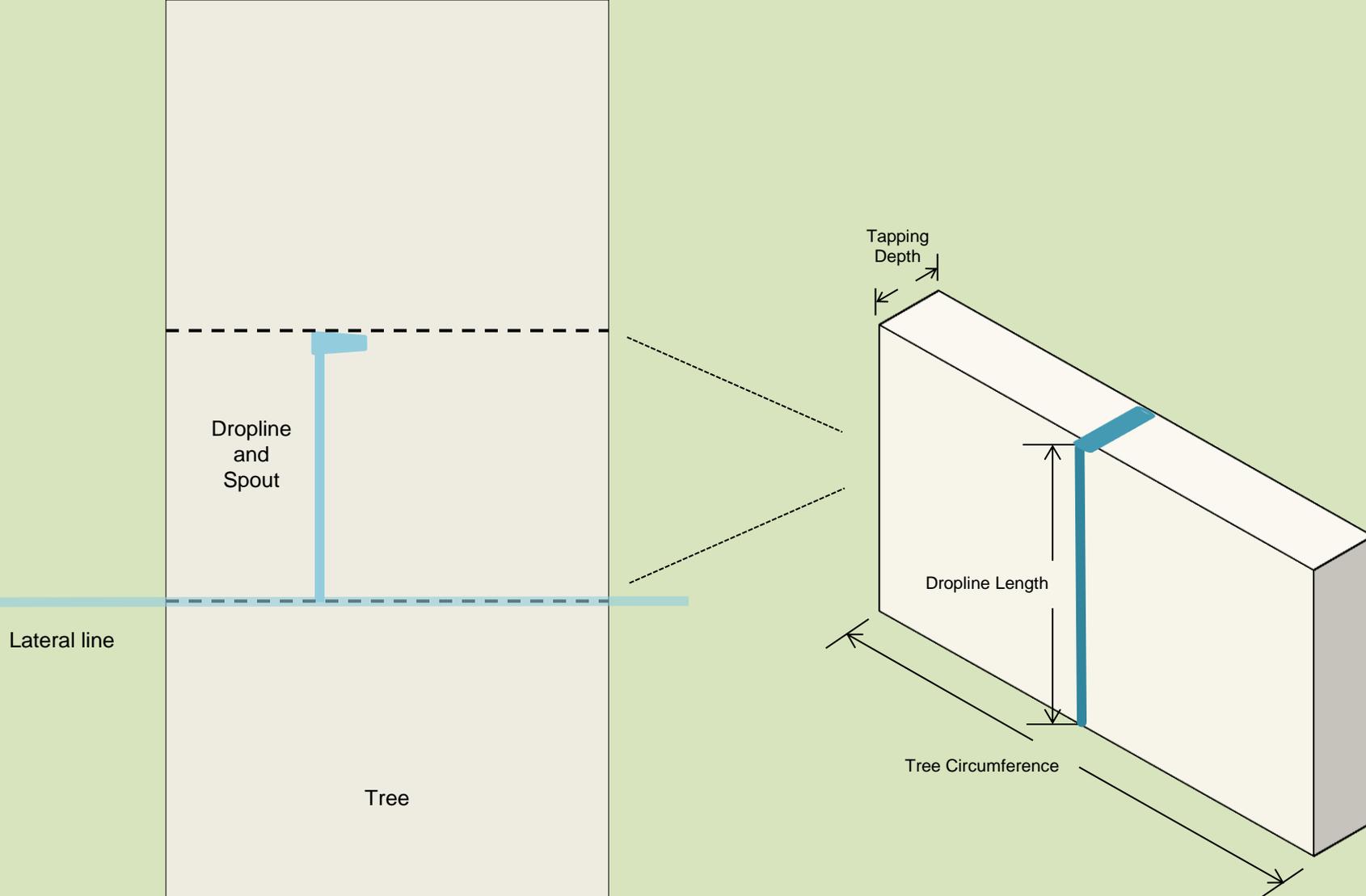


Figure 1b. Illustration of the “tapping zone” of a maple tree tapped for sap collection, the portion of each tree accessible for annual tapping to collect sap. The spout inserted into the tree is connected to a lateral line of the larger tubing collection system via a piece of tubing termed the “dropline”. Each year, the taphole is placed in a new location within this area in order to avoid tapping into old tapholes or nonconductive wood associated with old tapholes. The dimensions of the tapping zone are defined by the circumference of the tree, the length of the dropline, and the depth to which the spout is inserted.

Photos: Mark Issehardt

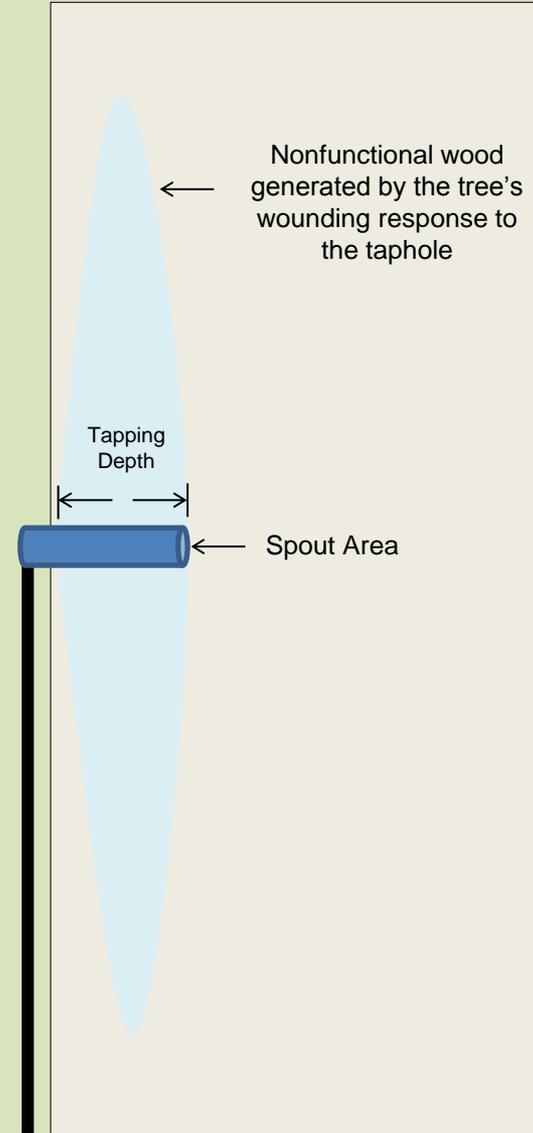


Figure 2. Illustration of the volume of nonfunctional wood generated by each taphole. The volume of wood removed by each taphole is defined by the depth and area of the hole drilled for tapping (the area is determined by either the size of the drill bit or the spout used). As part of the wounding response of the tree, tapping also generates a column of nonconductive wood surrounding the hole such that the total volume of wood rendered nonfunctional by each taphole is between 50 and 150 times greater than the amount removed by the taphole.

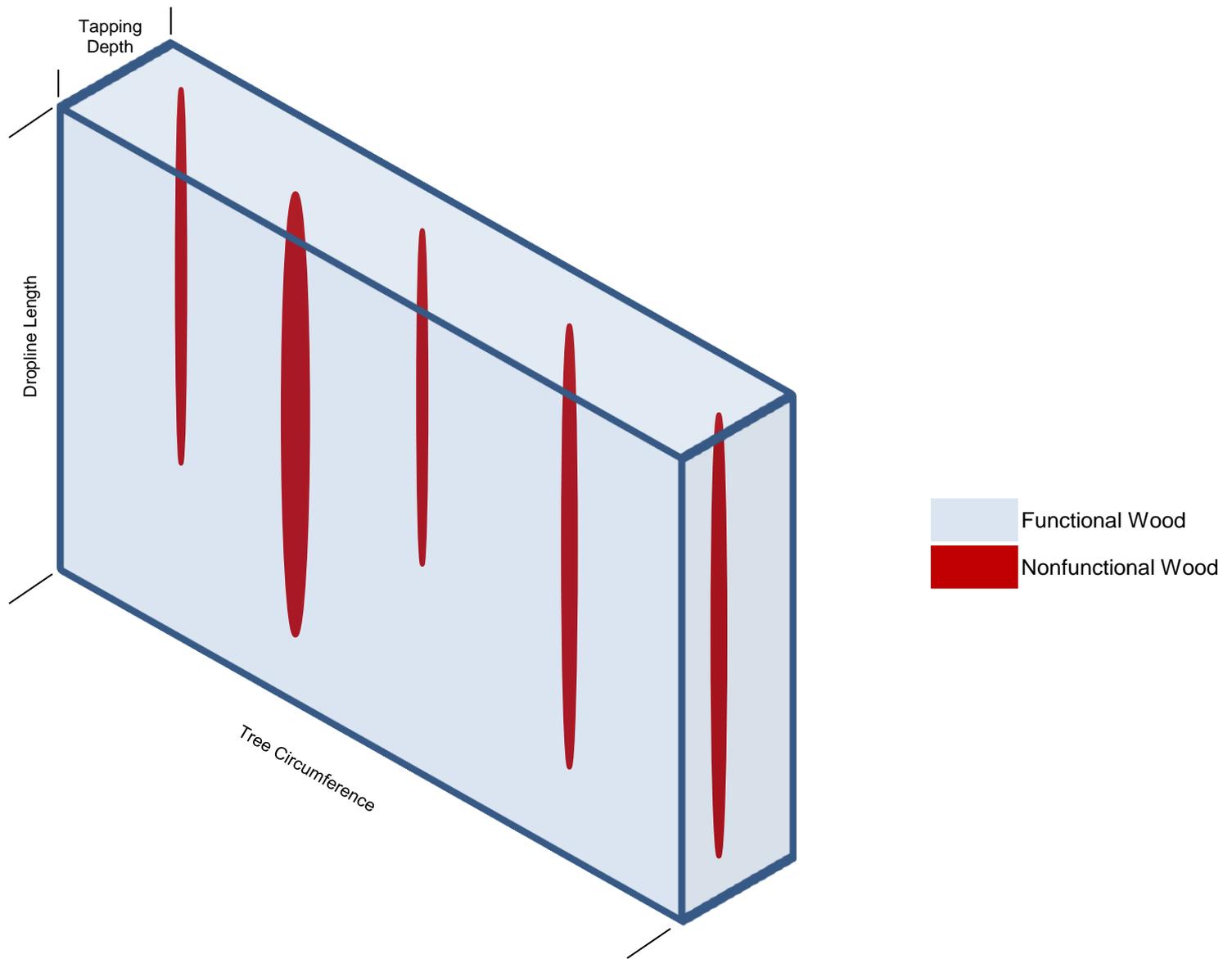


Figure 3. Illustration of the functional and nonfunctional wood within the tapping zone of a tree. At any point in time, the total amount of nonfunctional wood within the tapping zone is the total volume of nonfunctional wood within the zone's boundaries from all previous tapholes. The remainder of wood in the zone is the portion of functional wood available for tapping. The proportion of the tapping zone comprised of functional wood is equivalent to the probability of tapping into functional wood annually. To be considered sustainable, the proportion of functional wood within the tapping zone should remain greater than 90%.

Results

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

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.

In general, BAI increased with increasing diameter class, and rates were generally within ranges published for sugar maple in other studies.^{2,3}

It is important to note that the trees included in this study were healthy, dominant or co-dominant trees selected to represent those typically tapped for maple syrup production under current best practices¹, 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.

Table 1. Mean annual radial growth rates (basal area increment, \pm 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 \pm 0.3
10-12	16	1.8 \pm 0.2
12-14	18	2.3 \pm 0.3
14-16	17	2.7 \pm 0.2
16-18	17	2.9 \pm 0.2
18-20	15	3.3 \pm 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.

Results

Tapping zone model

The model estimates the proportion of functional wood in the tapping zone of an individual tree over time (Figure 4), and thus the probability of tapping functional wood. The probability of tapping functional wood is a way to assess the sustainability of tapping – in order for tapping to be sustainable, the probability of tapping functional wood must remain at a high level over a long period of time. This level was defined as 90% by the project team.[†]

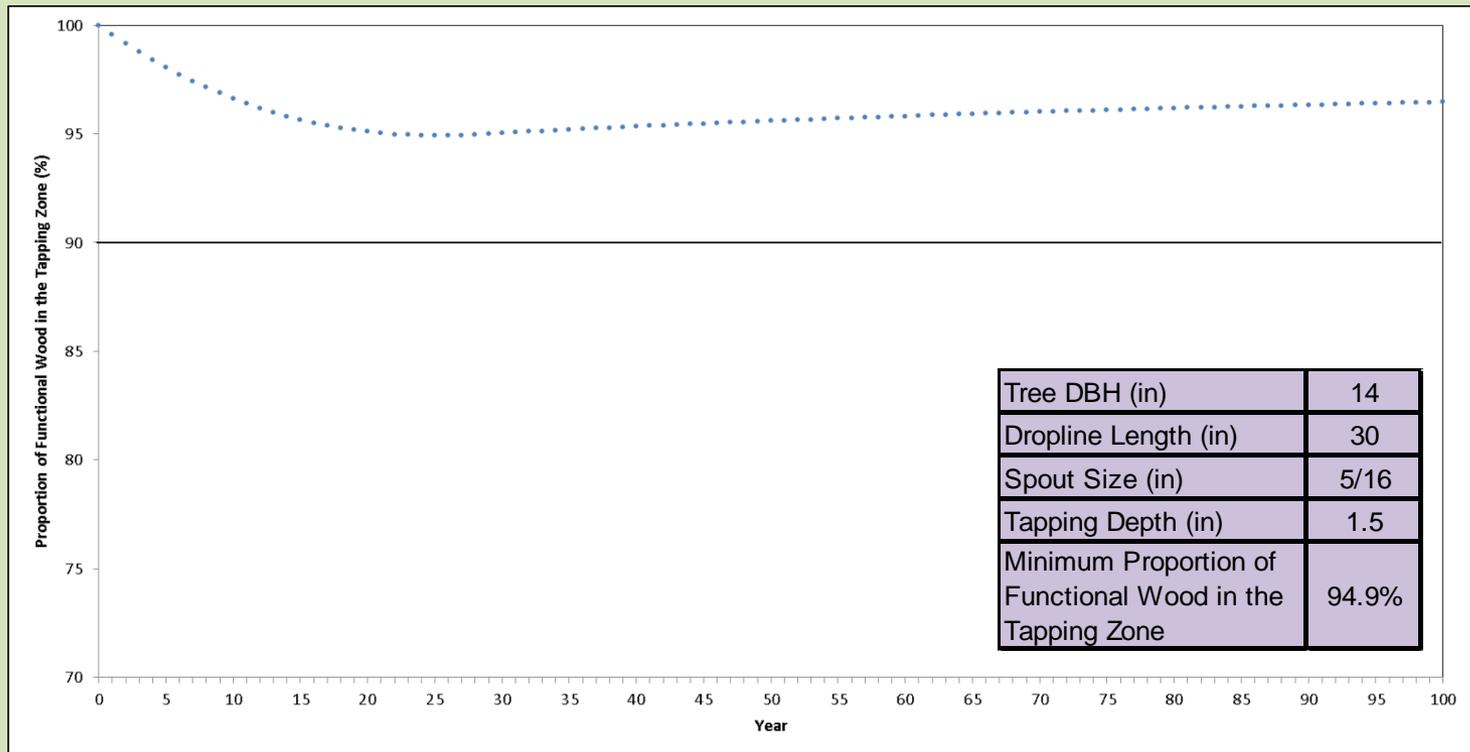


Figure 4. Example output of the tapping zone spreadsheet model showing the proportion of functional wood available for tapping (and thus the annual probability of tapping functional wood) over 100 years in the tapping zone of a 14-inch diameter tree tapped following current conservative tapping guidelines. (Conservative tapping guidelines specify a minimum dropline length of 30", tapping depth of 1.5", and spout size of 5/16".) To be sustainable, the proportion of functional wood within the tapping zone should not fall below 90% (the black line denotes this threshold).

Results

Tapping zone model

The values of several model parameters can be altered to assess how changes in tapping practices affect sustainability. Although best practice values are specified by tapping guidelines¹, dropline length, tapping depth, and spout size are ultimately determined by individual producer practices. Because these parameters determine the values for the model calculations of tapping zone and nonfunctional wood volumes, changes in these practices can strongly influence the probability of tapping into nonfunctional wood. For example, the length of the sap dropline determines how large of an area of the trunk is accessible to tapping (Figure 1); thus simply reducing the length of sap droplines can dramatically increase the probability of encountering nonfunctional wood within the tapping zone (Figure 5a). Likewise, spout size and tapping depth determine how much nonfunctional wood is generated by each taphole (Figure 2), and changes to these practices can also increase the proportion of nonfunctional wood (Figure 5b). The model thus enables rapid assessment of how changes to tapping practices, such as altering dropline length, using larger or smaller spouts, or tapping at shallower or deeper depths, affect the long-term sustainability of sap collection.

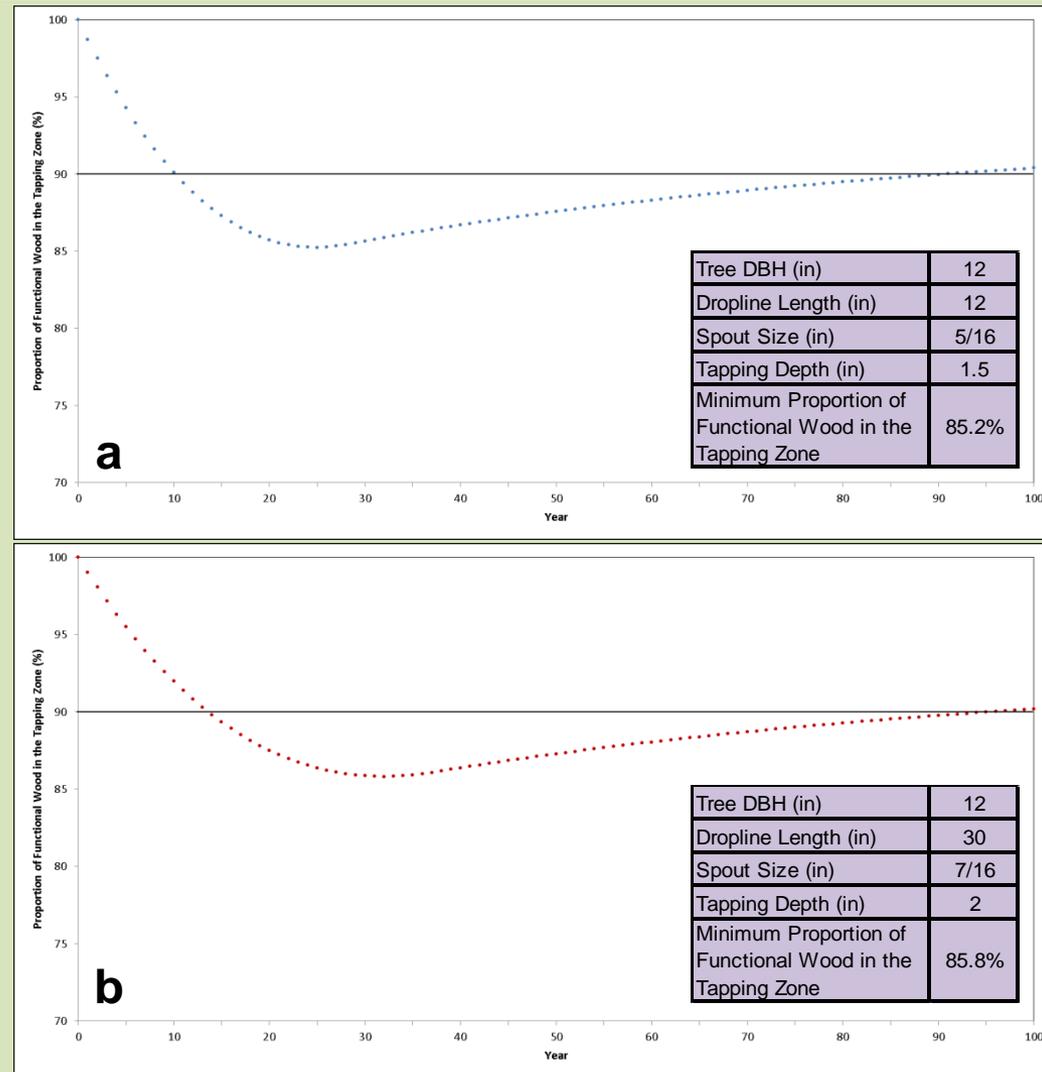


Figure 5. Estimated proportion of functional wood within the tapping zone of a 12-inch diameter tree under two scenarios: **a)** tree tapped following conservative tapping guidelines but with droplines shorter than the recommended minimum length, and **b)** tree tapped with larger spout size and deeper tapping depth than recommended by tapping guidelines. (Conservative tapping guidelines specify a minimum dropline length of 30", tapping depth of 1.5", and spout size of 5/16".) To be sustainable, the proportion of functional wood within the tapping zone should not fall below 90% (the black line denotes this threshold).

Results

Minimum growth rates required under current tapping guidelines

The model of the tapping zone was used to determine the minimum growth rates required for tapping trees to be sustainable in the long-term using the current maple industry tapping guidelines. Values for model parameters were set to match those of the most conservative existing tapping guidelines.¹ For tapping with vacuum sap collection, these guidelines specify a minimum dropline length of 30", a tapping depth of 1.5" (this is the middle of the range specified), 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 functional wood within the tapping zone would not fall below 90% over 100 years of annual tapping (Figure 6). The results of this analysis are shown in Table 2.

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 functional 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

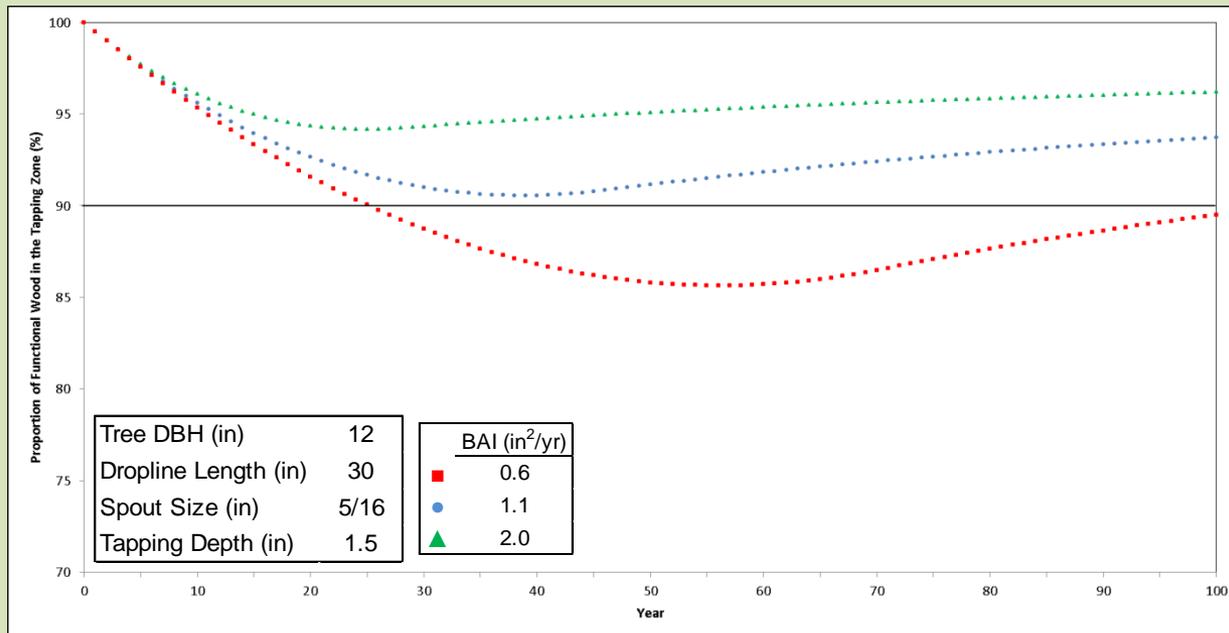


Figure 6. Example output generated during analyses using the tapping zone model to determine the minimum growth rates required for tapping trees with existing conservative tapping guidelines to be sustainable in the long-term. The output shows the proportion of functional wood in the tapping zone of a 12-inch tree with 3 different growth rates (basal area increments) tapped following these conservative guidelines. To be sustainable, the proportion of functional wood within the tapping zone should not fall below 90% (the black line denotes this threshold).

Results

Minimum growth rates required under current tapping guidelines

The results indicate that only relatively moderate growth rates are required using current conservative tapping guidelines for tapping to be sustainable in the long-term. However, this analysis can also be used to demonstrate the importance of strict adherence to the guidelines in order to ensure tapping is sustainable. For example, for a 12-inch tree with the minimum growth rate of 1.1 in²/yr, using a dropline length only 5 inches shorter than the minimum results in the availability of functional wood falling below levels considered sustainable within the first 25 years of tapping (Figure 7). Using an 8-inch tree in the same scenario surpasses the threshold in just 16 years (data not shown). This illustrates how easily the sustainability of tapping, particularly for smaller trees, can be offset by relatively small changes in practices when growth rates are at these minimum levels. Likewise, this helps to emphasize that the growth rates specified here are only minimums, and that rates should optimally be higher than those given. Thus, although these minimum rates can allow for sustainable tapping, tapping guidelines must be strictly adhered to in order to ensure the sustainability of sap collection, and exceptional caution must be used when tapping smaller trees.

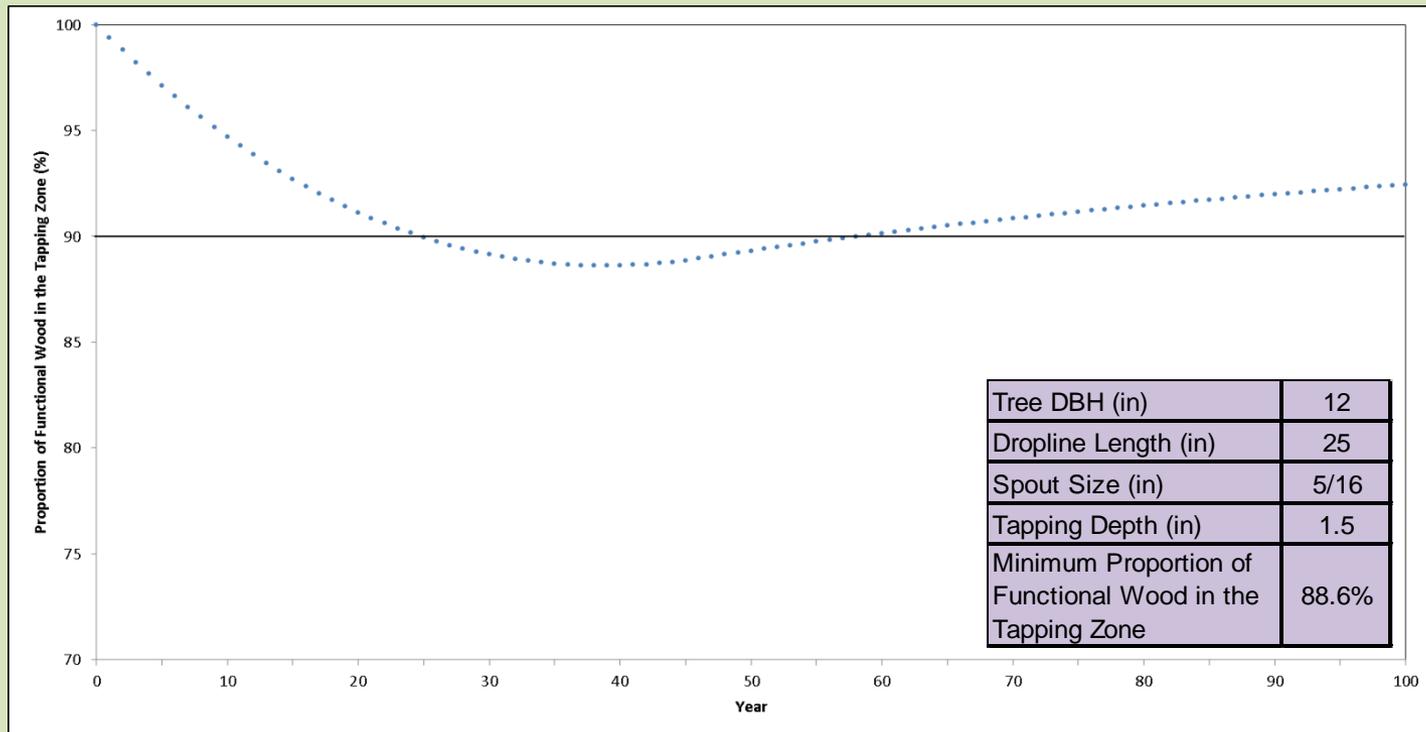


Figure 7. Proportion of functional wood over time in the tapping zone of an 12-inch diameter tree with the minimum growth rate required for tapping to be sustainable when using current conservative tapping guidelines (Table 2; basal area increment = 1.1 in²/yr), but tapped using droplines shorter than the minimum length (30 inches) specified by these guidelines. To be considered sustainable, the proportion of functional wood within the tapping zone should not fall below 90% (the black line denotes this threshold).

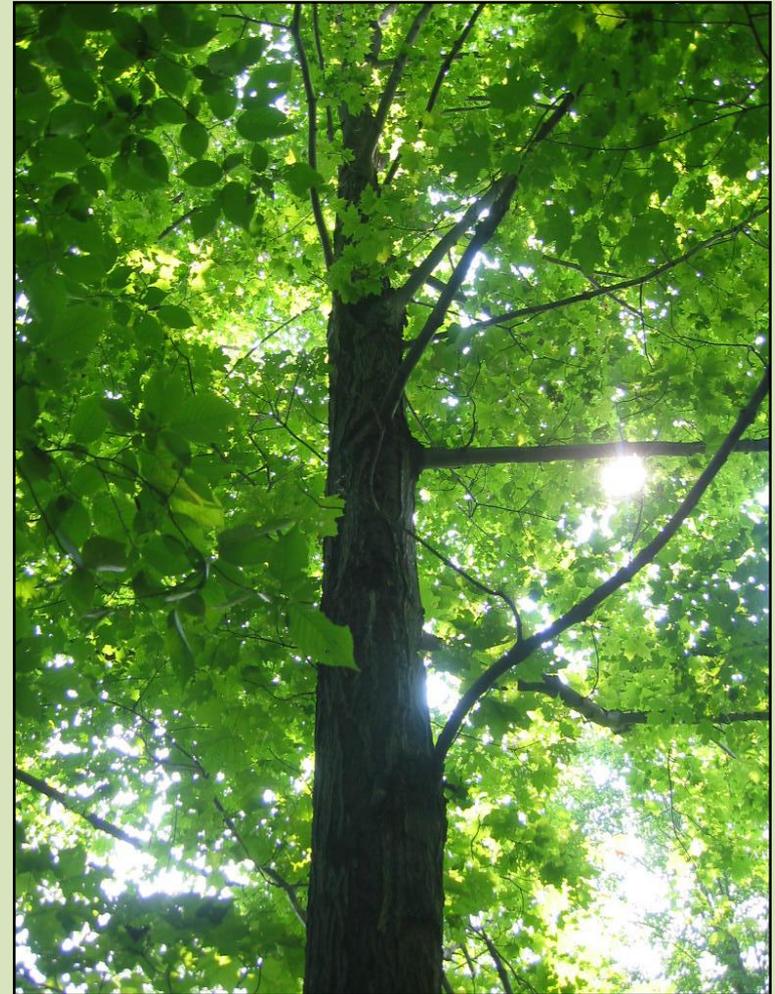
Results

Tapping guidelines for trees tapped with high-yield sap collection practices

The average growth rates observed for trees tapped with high-yield sap collection practices in this study (Table 1) were well over the minimum rates required for tapping to be sustainable when using the current conservative tapping guidelines (Table 2). This suggests that, in general, the growth rates of healthy, dominant or co-dominant trees growing on good quality sites that are tapped with high-yield sap collection practices are typically sufficiently high to maintain the long-term sustainability of sap collection when *existing* guidelines are followed. These results also suggest that, for these trees, the higher rates of carbohydrate extraction achieved with high-yield practices do not result in effects on the radial growth of trees substantial enough to impact the long-term sustainability of tapping for sap collection. These findings are important, as they indicate that collection practices which help increase the productivity and profitability of maple production do not adversely impact the health of trees or the ecological sustainability of this use of forest resources.

Thus, these results indicate that alternative tapping guidelines for high-yield sap collection practices with greater carbohydrate extraction rates are not required. Rather, the conservative tapping guidelines currently in place are generally appropriate for use with high-yield collection practices, and adherence to these guidelines when tapping trees with high-yield sap collection practices will generally be sustainable in the long-term.

It must be emphasized that the appropriateness of the current conservative guidelines for trees tapped with high-yield collection practices applies only to healthy overstory trees growing on good quality sites, and that *all* practices outlined in the guidelines must be followed.^{1††} Also, tapping trees smaller than the minimum diameter specified in the guidelines (10-12" dbh) is not generally recommended at this time.^{†††}



Conclusions

- The conservative tapping guidelines currently in place in the maple industry are generally appropriate for use with modern, high-yield sap collection practices. Adherence to these guidelines when tapping healthy, co-dominant or dominant trees on good quality sites will generally be sustainable in the long-term.
- This conclusion applies only to trees specified as appropriate for tapping in the current tapping guidelines, and does not apply to trees growing on poor quality sites, that have a suppressed or intermediate canopy position, that are experiencing significant stress from disease, weather, insects or other factors, or that are not otherwise apparently healthy.
- By adhering to current conservative tapping guidelines, maple producers can use high-yield sap collection practices to increase the productivity and profitability of their operations, while ensuring that the long-term ecological sustainability of their practices is maintained.



Maple tree tapped for sap collection. (Photo: Tim Wilmot)

Implications and Applications in the Northern Forest Region

- Maple syrup production is a traditional practice within the Northern Forest that provides economic opportunities to its residents through a historically sustainable use of its forest resources.
- This work established appropriate tapping guidelines that producers should follow to ensure that tapping trees using more modern sap collection practices with higher sugar extraction rates remains sustainable over the long-term. The conservative tapping guidelines currently in place in the maple industry are generally appropriate for use with modern, high-yield sap collection practices, and adherence to these guidelines when tapping healthy, co-dominant or dominant trees on good quality sites will generally be sustainable in the long-term.
- Maple producers will use these guidelines to ensure that tapping trees with high-yield sap collection practices, which increases the productivity and profitability of maple syrup production, is sustainable in the long-term and does not adversely impact the health of trees.
- Thus, the outcomes of this work will help ensure that both the long-term ecological and economic sustainability of maple production in the Northern Forest are maintained, and that maple production continues to provide economic opportunities in the region through an ecologically-sustainable use of its resources.



Maple spout and dropline.

Future Directions

Though the results of this work suggest that the radial growth rates of trees tapped with high-yield sap collection practices are not significantly impacted, the effect of these practices on tree growth cannot be fully assessed without direct comparison to the growth rates of trees that have not been tapped, or that have been tapped with more traditional (lower-yield) methods. These data do not currently exist. An experiment to determine whether the growth rates of trees tapped with high-yield practices differ significantly from those of untapped trees or those tapped using traditional practices is required, and will be the focus of future work.



Photo: Catherine Stevens

Project Outcomes, Products and Outreach

- The primary output of this work is a set of tapping guidelines producers can follow to ensure that sap collection using high-yield practices remains sustainable in the long-term. The conservative tapping guidelines currently in place in the maple industry are generally appropriate for use with high-yield sap collection practices for healthy dominant or co-dominant trees on good sites, and will result in sustainable long-term outcomes.

Other publications

- The information is being made available to producers through a technical bulletin that will be posted on the UVM PMRC and Extension cooperator websites (expected completion date December 2012). Physical copies of the bulletin will also be distributed UVM PMRC and cooperators.
- The data from this study are also being used together with project cooperators to formally revise the existing tapping guidelines for maple production, which will be included in the upcoming revision of the North American Maple Syrup Producer's Manual to be published in October 2016.

Conference Presentations

- These results will be presented to maple producers at meetings and conferences, including the UVM Extension Maple conferences in January 2013.

Other tangible products

- A web-based tool is also being developed that will allow producers to input their tapping practices, tree size, and/or growth rates to rapidly assess sustainability (expected completion date December 2012). The tool will be posted on the UVM PMRC and Extension cooperator websites.

Acknowledgements

- We would like to express our exceptional gratitude to the maple producers who participated in this research project. These producers generously donated their time and effort to the project, gave us access to their properties, and allowed us to collect cores from their trees. Without their contributions this project would not have been possible.
- We thank Mark Isselhardt for his invaluable assistance throughout the project, Will Lintilhac for help with field work, and all project cooperators for their assistance with project completion and dissemination of results.



Photo: Mark Isselhardt

Footnotes

*Only practices over the previous 5 years were considered, as the technology (vacuum pumps, spouts, etc.) necessary to produce very high sap yields only became widely available between 7 and 10 years ago.

**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 tapping¹, 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.

***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.

†Because growth rates contribute to the probability of tapping functional wood over time, this assessment of sustainability integrates the effects that tapping practices might have on carbohydrate reserves or other aspects of overall tree health due to higher levels of carbohydrate extraction, in addition to simply assessing the effects of tree wounding.

††Producers should refer to the guidelines for a complete description, but these practices include using minimum dropline lengths of 30", a tapping depth of no greater than 1.5", and the use 5/16"-diameter spouts. This also includes tapping only trees that are healthy and show no signs of major stress (such as slow-healing wounds, branch or crown dieback, etc.) from disease, drought, insect outbreaks, or other factors.

†††Because the sustainability of tapping these smaller trees can be affected by small changes or variations in site, practices, or tree health, the decision to tap trees of this size should be made on a case-by-case basis, and *only* when the actual growth rates of the trees under consideration have been determined.

¹Chapeskie, D., Wilmot, T.R., Chabot, B. and Perkins, T.D. 2006. Maple sap production –tapping, collection, and storage. *In* North American Maple Syrup Producers Manual (R.B. Heiligmann, M.R. Koelling, T.D. Perkins, Eds.) pp 81-116. The Ohio State University, Columbus, OH.

²Long, R.P, Horsley, S.B., Hallett, R.A., and Bailey, S.W. 2009. Sugar maple growth in relation to nutrition and stress in the northeastern United States. *Ecological Applications* 19(6):1454-1466.

³Long, R.P, Horsley, S.B., and Hall, T.J. 2011. Long-term impact of liming on growth and vigor of northern hardwoods. *Can. J. For. Res.* 41:1295–1307.

Footnotes

*Model Details

- The model calculates the total volume of the tapping zone, which, for smaller trees, is equal to Tree circumference × Dropline length × Taphole depth (Figure 1).
 - For larger trees, where the dropline cannot reach fully around the tree, the volume of the tapping zone is only as big as the dropline can reach. For these trees the tapping zone is only the area of the half-circle that the dropline makes, so it's calculated as: $(\pi \times \text{Dropline length}^2) / 2 \times \text{tapping depth}$.
- Because the tapping zone is defined partly by tree circumference, which will increase over time as the tree grows, the model also adjusts tree circumference (and thus total tapping zone volume) over time to incorporate radial growth.
 - The basal area increment (growth rate) of trees varies with tree diameter. The growth rates of trees determined in this study were used to estimate the basic pattern for how tree BAI changes in proportion to tree size. These values were used to generate a best-fit regression equation ($y = -0.0024x^2 + 0.6435x - 4.2231$, $r^2 = 0.99$) of BAI versus tree DBH. This equation was used in the model to estimate tree growth rate as DBH changes over time. To estimate the growth rates required for the sustainability of specific tapping practices, the y-intercept of this equation can be altered to simulate either higher or lower rates of growth.
- The model calculates the volume of nonfunctional wood generated by each annual taphole, which is equal to Spout Area × Tapping Depth × “Staining Multiplier” (Figure 2). Each taphole generates a column of nonfunctional wood surrounding the taphole that is proportional to the size of the wound. The size of this column has been determined in previous research, and can range from 50 to 150 times the size of the taphole. The model uses 75 as a “staining multiplier” to calculate this volume.
- To account for the quantity of nonfunctional wood “removed” from the tapping zone as radial growth shifts the tapping zone outward, the model also calculates an annual reduction to the volume of nonfunctional wood associated with each taphole present in the tapping zone.
- The model calculates the total volume of nonfunctional wood present in the tapping zone in a given year by summing the volume of nonfunctional wood from all tapholes present at that time (Figure 3). The total amount of functional wood is divided by the total volume of the tapping zone at that time to calculate the proportion of functional wood in the tapping zone each year, or the probability of tapping functional wood each year (Figure 4).
- The model makes several assumptions and has several limitations that should be noted. It does not account for decreases in growth rates that might occur as the result of tree ageing, changes in site conditions or management practices, or events such as drought or disease. It assumes no preexisting nonfunctional wood is present within in the tapping zone. The growth it models generally reflects that of healthy trees in typical stands managed for maple production, and with relatively good edaphic conditions for sugar maple growth.