Sugarbush Management in the Central Appalachian Region

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Welcome! The goal of this comprehensive guide is to provide you with tools and information to manage sugarbushes in the central Appalachian region. The workbook provides step-by-step instructions on how to assess the current density of your trees, how to determine the ideal density for your specific forest, and how to implement effective management strategies to achieve that density. It's a valuable resource for anyone who wants to optimize the health and productivity of their sugarbush trees.

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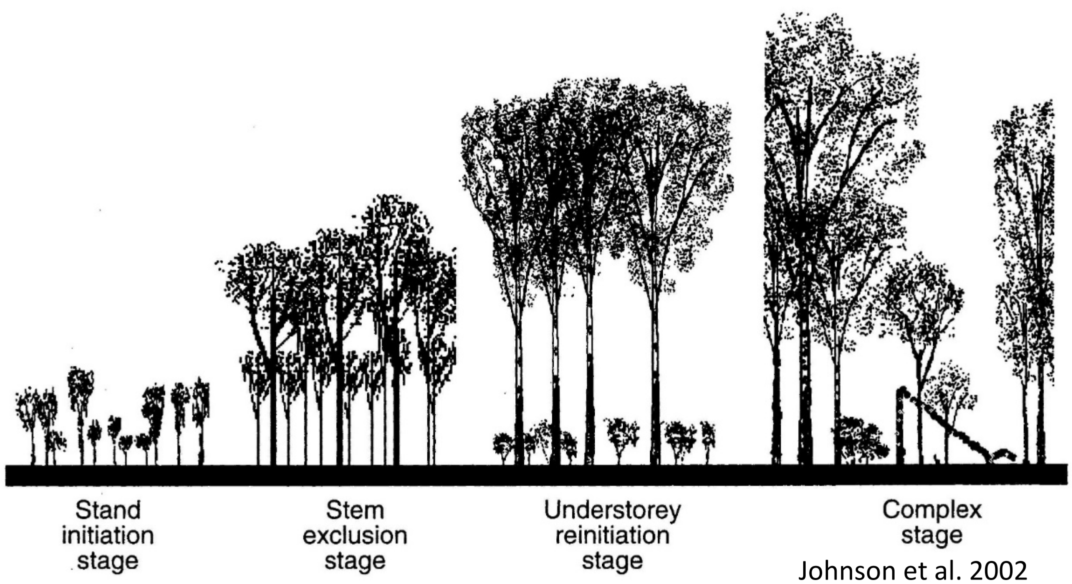
Sugarbush Stand Improvement

There is no such thing as a “typical” maple stand. Maple stands across the region vary enormously by their origin, their beginning mixture of different species, and their stand history--the events that have happened to the stand through time. However, maple forests commonly have two components that can be addressed to improve sap production and overall resiliency within the forest: overstocking and health. The goal of this guide to address the first, how to manage overstocked (or crowded) maple stands.

Forest stands follow predictable patterns of development from beginning to end. These patterns allow us to model development and make assessments on what a “good” stand should look like. This pattern of development is described as four stages of stand development (Oliver and Larson 1996).



Johnson et al. 2002

The first stage, stand initiation, describes the beginnings of site occupation. Significant disturbances, like devasting storms or timber harvesting, take down large trees to create open and exposed conditions and initiate a new process of site colonization. Regardless of the type of disturbance, when there is a new opening in the forest, the vegetation essentially starts over. During the initiation phase, the site is re-colonized by newly germinated seedlings and by existing seedlings, saplings, stump sprouts, and root suckers. During the next 5-10 years, the small seedlings and sprouts grow within the pioneering grass, forb, and vine-dominated community and eventually overtower the smaller plants and form a tree-dominated community. The trees continue to increase in size until their crowns--their twigs and leaves--touch one another and form a closed canopy. Trees that get their crowns in the full sunlight will survive while only species tolerant of shade will survive if they are overtopped. Intense shading from this crowded canopy prevents light from reaching the forest floor and severely limits the further recruitment of seedlings and other vegetation.

The second stage of forest development--stem exclusion--begins when the canopy becomes crowded and closed. The trees that have the largest crowns up in full sunlight are the "dominant" and "co-dominant" trees. The intense shade under the closed forest canopy creates environmental conditions where only shade-tolerant species can survive. The upper canopy (dominant and co-dominant stems) are generally healthier and more vigorous, while trees below them in lower canopy positions ("intermediate" or "suppressed" trees) tend to die off due to lack of sunlight. For the next 60 – 100 years, the stand will continue to lose trees (we call this "self-thinning" or "density-dependent mortality").

In order for trees to grow in size (usually measured by stem diameter), their crowns must grow proportionally. The amount of space a tree occupies is called its "growing space." There is a finite amount of growing space in a forest. If all the growing space is used or occupied by existing trees, then some trees have to die in order to free up growing space as surviving trees expand their crowns.

Each tree species has a different level of tolerance to shading and crowding. For example, yellow-poplar trees need a lot of light, whereas most oaks are moderately tolerant of shade, and maples, hemlocks, and spruce can persist in shady conditions for many years. This means that under limited light conditions--whether from crowding or overtopping--yellow-poplar trees will likely have higher mortality than oaks, and oaks will have higher mortality than maples. A list of tolerance and other characteristics is provided in the table below (Table 1).

Interestingly, growing space requirements are predictable, with maximum and minimum sizes (Fig. 1). A minimum crown size is required for trees to maintain a positive carbon balance; that is, carbon taken in by the tree to produce sugars and other structural elements is greater than the sugars burned for tree growth and maintenance. If a particular crown recedes to the point where there are few leaves and insufficient sugars produced through photosynthesis, the tree will die. If too many trees crowd together in this manner, there will be much mortality in the stand. There is also a biological maximum limit to crown size for a given tree diameter and species--each tree can only use so much. If all trees in a forest stand have more space than they can use, the unused growing space will reduce overall or total stand growth. Between these minimum and maximum levels is where we manage tree growth (Fig. 2). Trees do not exceed the maximum and if their crowns drop below the minimum, they have increased likelihood if dying.

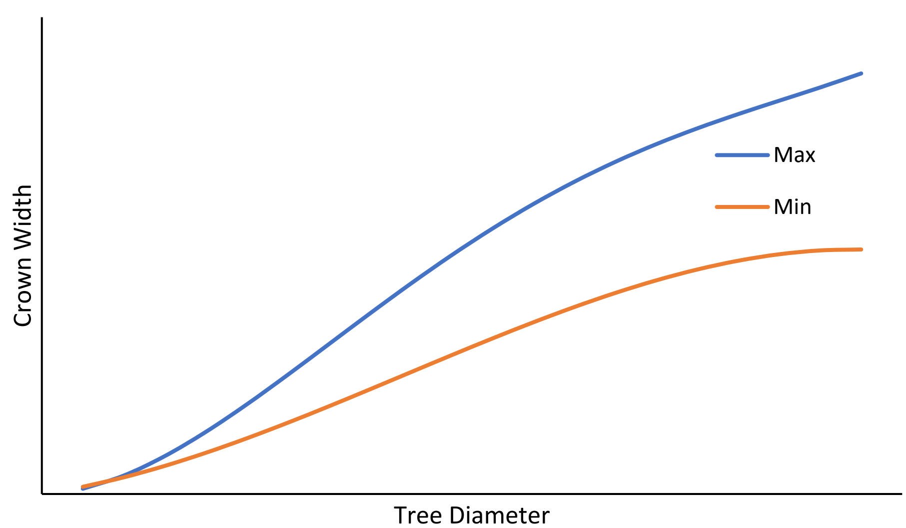


Figure 1. Trees have a maximum crown size (width) and a minimum crown size.

Table 1. Shade tolerance and age longevity of maples and their commonly co-occuring species

Species	Shade Tolerance	Longevity
American beech	tolerant	long
American sycamore	intermediate	moderate
basswood	tolerant	moderate
black birch	intermediate	moderate
black cherry	intolerant	moderate
black locust	intolerant	short
black oak	intermediate	moderate
black walnut	intolerant	moderate
blackgum	tolerant	moderate
chestnut oak	intermediate	moderate
cucumbertree	intermediate	moderate
eastern hemlock	tolerant	long
green ash	intolerant	moderate
mockernut hickory	intermediate	moderate
northern red oak	intermediate	moderate
pignut hickory	intermediate	moderate
pitch pine	intolerant	moderate
red maple	tolerant	moderate
red spruce	tolerant	long
sassafras	intolerant	moderate
scarlet oak	intolerant	moderate
shagbark hickory	intermediate	moderate
shortleaf pine	intolerant	moderate
silver maple	intermediate	moderate
sugar maple	tolerant	long
sweetgum	intolerant	moderate
trembling aspen	intolerant	short
Virginia pine	intolerant	moderate
white ash	intolerant	moderate
white oak	intermediate	long
white pine	intermediate	moderate
yellow birch	intermediate	long
yellow-poplar	intolerant	moderate

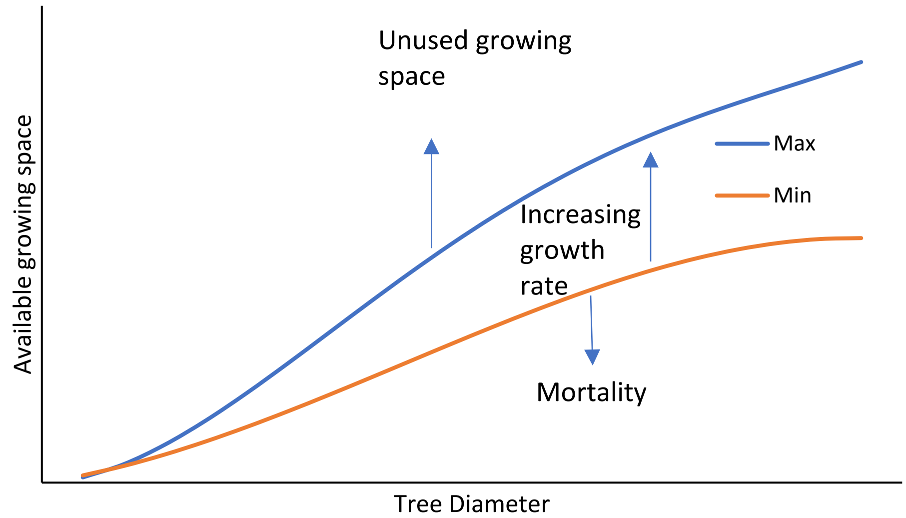


Figure 2. Illustration of growing space availability.

The development or tree growth pattern in the stem exclusion phase is relatively predictable. In fact, many management guides use this predictability to develop models depicting stand growth over time. These guides allow users to assess how their stand compares to what is typical. For example, a maple stand with trees averaging 10 inches in diameter will have about 220 trees per acre. As the stand ages and trees grow and become more crowded, the same stand will have fewer but larger trees, typically 160 trees per acre with trees that average 12 inches in diameter; hence, 60 trees will die over the next 10-20 years due to crowding.

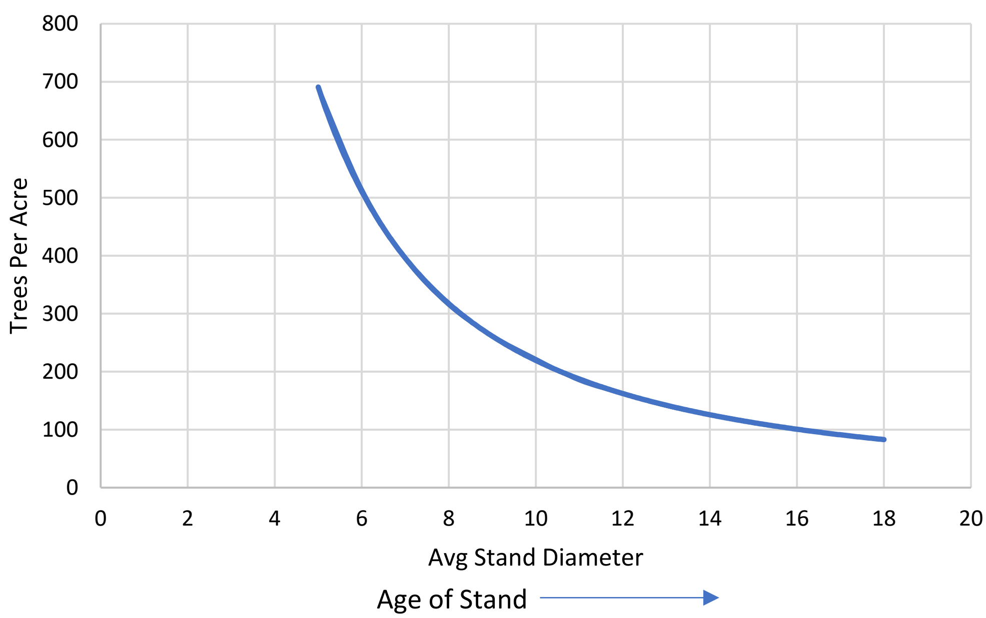


Figure 3. Natural pattern of stand development highlighting density-dependency relationship to stand diameter.

So as a maple producer concerned with maintaining a vigorous stand of healthy trees, the question is, which trees will die? The preferable way to answer this is to select “the less desirable” individuals and thin these from the stand.

Defining which trees to cut and remove can be challenging. Cutting too few trees will provide insufficient space in the forest canopy for the remaining trees to expand their crowns and improve overall stand growth, health, or sap production. Cutting too much can lead to underutilization of the site (i.e., reduced sap production), stress due to exposure, and increased windthrow and potential for stem damage associated with tree felling.

In an idealized maple stand, trees would have large crowns with branches extending almost to the ground. Most unmanaged forests are dense with trees that shade and limit the crown expansion and the persistence of lower limbs on neighboring trees, so there is a maximum extent to which trees can laterally expand for a given tree size.From a timber management perspective, sugarbush stands with minimal or no recent management should have as a central goal to reduce the number of trees in the stand to the point where the residual trees have enough room to grow to occupy the site at their maximum crown expansion level. Using the same example above, in a stand with trees averaging 10 inches in average tree diameter, we expect about 140 trees per acre to fully occupy a site if given adequate room to grow. This density level is just over a third (36%) fewer stems than were originally in the stand.

The goal in sugarbush management is to allocate the growing space of the entire stand to as few trees as necessary to occupy the site completely. Significant advantages appear by carefully selecting which trees to retain, resulting in better growth on the residual trees and more room for future growth. Ultimately, choosing suitable trees to thin will reduce the density of the stand and lead to improved growth that leads to faster tap hole healing, more sustainable tapping, increased sap production, and healthier trees that will also be more resilient to climate, insect, and disease pressure into the future.

Alternatively, a stocking guide helps managers understand the level that trees use the growing space in the woods (Fig. 4). These charts require simple measurements collected during regular field inventories. Using the guide below, the user applies any two of the three measurements listed: basal area per acre, trees per acre, and average diameter. Based on these measurements, the stocking guide estimates the percentage of growing space that trees of this size and density occupy. Without any thinning or other disturbance, the natural trajectory of stand development should rise to and follow the “A-line.” That is, the trees in the sugarbush will increase in basal area and diameter while decreasing in the number of trees per acre.

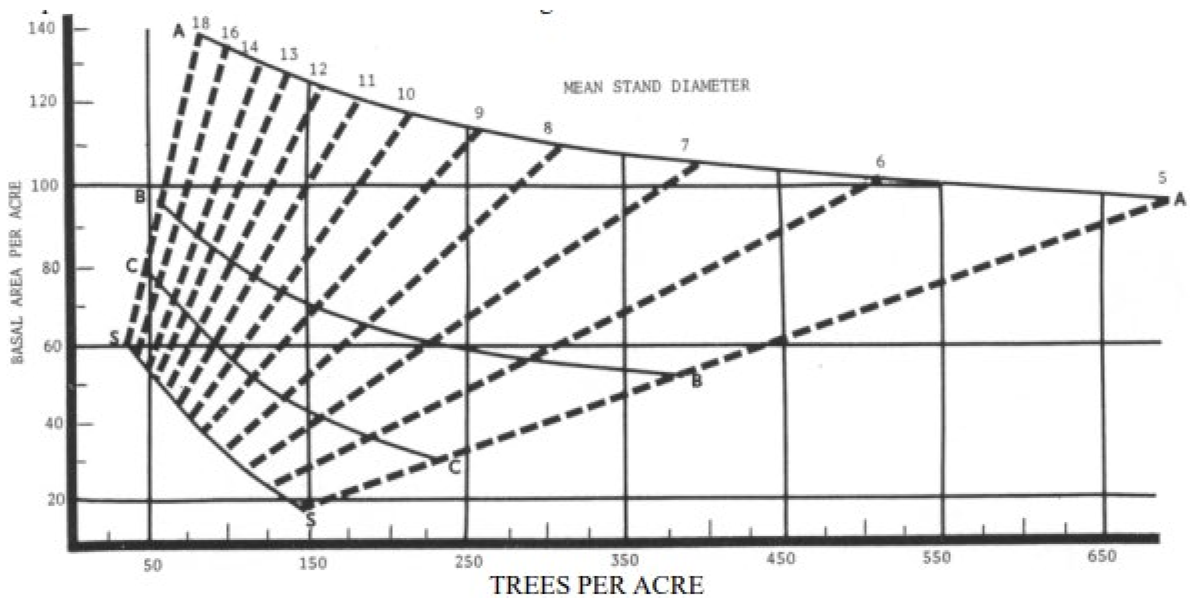


Figure 4. Stocking guide developed for use in sugar maple-dominated stands (Lancaster et al. 1974).

The A-line represents an average condition with the maximum number of trees possible for a given average tree size, and all the available growing space is utilized (100% stocking). Above this level, trees will be so crowded they will have decreased individual tree growth and have high mortality rates. From the stocking guide, when the average stand dbh reaches 6”, there should be roughly 500 trees/ac. In 15 years, the stand might grow 2 inches, after which we would expect to have about 300 trees/ac.

The B-line is often used to describe the lower limit of full stocking. Stands at this level still utilize all the growing space but do so with as few trees as possible. Essentially, this represents trees that have maximum crown sizes. Traditionally, this is the target for timber management. It is also a good target for unmanaged sugarbush stands.

The C-line represents an understocked condition for timber management. Usually, a stand between the B- and C-lines will reach full stocking within 10 yr. The open canopy condition at these lower stocking levels is desirable for sugarmakers because they allow for more light penetration into the lower canopy and maintain deeper crowns. Although the trees at this level use only a low amount of growing space in the stand, the larger/deeper crowns will have increased sap production and potentially higher sugar levels. Maintaining good sap production by controlling stand stocking requires an incremental approach to density management; frequent but light tree thinning is optimal.

Using the stocking guide is fairly straightforward, but requires data from a forest inventory. The x-axis represents tree/ac, the y-axis basal area, and the diagonal dashed lines represent average diameter. With any two of these measurements from a forest stand inventory, you can determine a point on the guide that estimates the stocking level for that stand. For example, a forest inventory found that a sugarbush had 250 trees/ac and 68 ft2/ac basal area (and averages 7” dbh). Using these data, the point on the graph below shows the stand is close to the B-line, a condition suggesting the stand is in good condition from a stocking/density standpoint (Fig. 5).

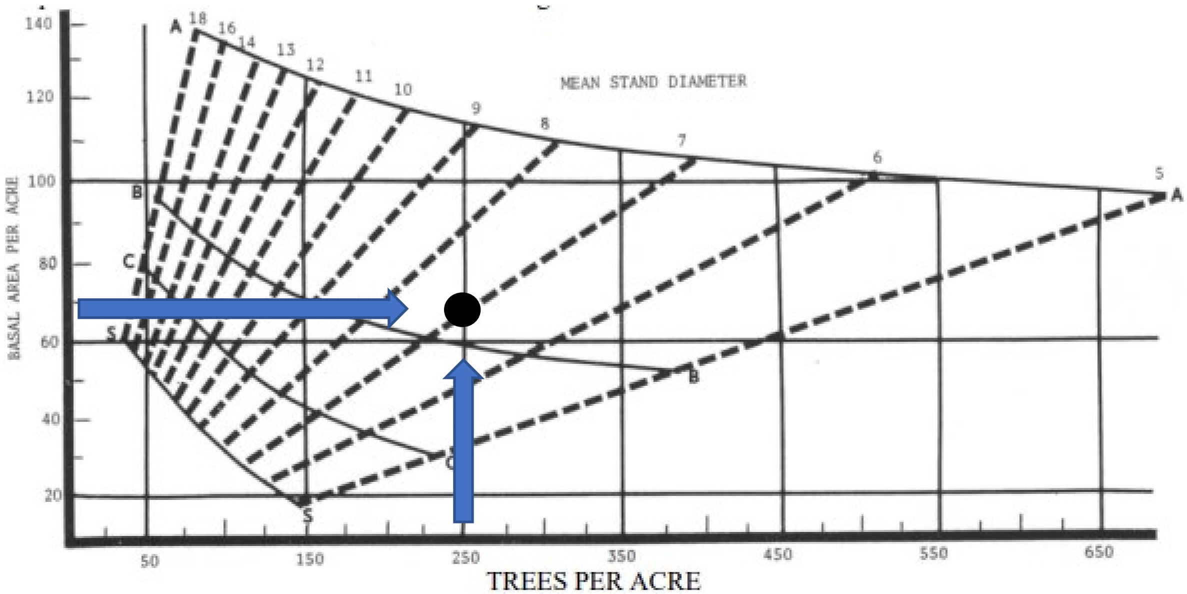


Figure 5. Stocking guide depicting a stand with 250 tpa and 68 ft^2/ac of basal area, with adequate stocking.

Similarly, if a stand averages 12 inches dbh and has 150 trees/ac, the stand is considered fully stocked. However, this stand is close to the A-line. At this level, competition from crowded trees limits growth on individual trees, and mortality is evident—suggesting the need for thinning. In this case, a thinning could drop the trees/ac down to 100. Note that instead of using trees/ac as a metric for controlling the thinning intensity, an experienced forester might use basal area and reduce the stand basal area from 120 ft^2/ac down to about 80 ft^2/ac. Each of these methods would give the same result.

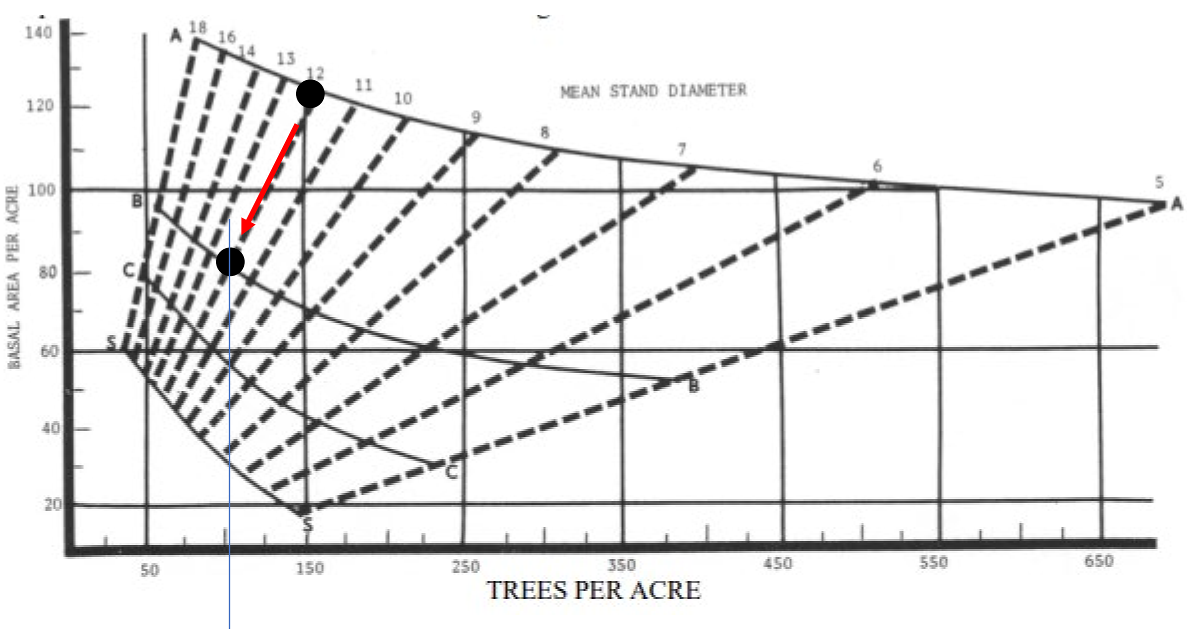


Figure 6. Stocking guide depicting a thinning from 150 to about 100 trees/acre.

This stocking guide also targets future stand conditions when the stand of interest is young. Previous research and experience suggest residual stocking levels for young stands should be between B- and C-lines. Using this chart, a desired future minimum stocking level might equate to 80-100 trees/ac when the average tree size is 12”, which is the suggested conservative minimum diameter for tapping (Perkins et al. 2022).

Besides using stocking levels of stocking percentages, which are specific to stocking guides, some foresters/landowners use relative density measures. Relative density is a term used to describe density in even-aged stands that is more useful than absolute terms like basal area and diameter. Species composition and average tree diameter can greatly impact absolute terms. As an example, black cherry (smallest), red maple (intermediate), and sugar maple (largest) of the same diameter have very different crown sizes; hence, you can many more 10” black cherry trees per acre than you can 10” sugar maples. If we account for these differences and express the amount of growing space used as a percent of the total possible, we have a measure of relative density. As mentioned earlier, 100% relative density has all the growing space utilized and we would expect slow growth and increased mortality into the future. By contrast, 60% relative density is near the lower limit of full site utilization, where the trees have good diameter growth and low mortality—an ideal condition! In terms of relative density, once a stand exceeds 80%, one can expect growth rates to reduce and mortality start to increase. If possible, one should aim to keep a sugarbush below the 80% threshold.

The are limited relative density equations available that were specifically developed for southern sugarbush management. The Sugarbush Density Management Toolkit is an Excel program developed to assist with these calculations and are based on equations developed by the US Forest Service in the Silvah decision support system (Marquis et al. 1992). The output of the toolkit are relative density calculations that the manager can use to future management decisions (i.e., thinnings, regeneration treatments) in sugarbush stands.

Thinning Treatments

Sugarmakers must plan for thinning treatments. There are many factors to consider: Who is doing the cutting? Do I have access? Will the condition of my woods and local markets allow for commercial operations? Do I have the skillset to make proper thinning prescriptions, or should I consider calling a forester? Then there are logistical concerns if the sugarbush is already in operation. Harvesting trees in stands already tubed with sap lines is very difficult, while bucket systems offer more flexibility. Plan to time thinning operations with tubing replacement or before initial installation. Remember, trees and their crowns are constantly growing. Therefore, one should plan for periodic entries every 10-20 years to provide ample room for tree growth. Depending on tree size and stand conditions, there are many ways to mark a sugarbush for thinning. Regardless of the technique, the focus of a thinning should be on what remains after the thinning, a focus on the *residual* stand. The goal is to keep the best trees with the most long-term potential. Marking trees to remove should prioritize as follows:

1. High-risk trees. Mark trees that may not survive until your next planned thinning. These are often trees with significant visible rot, fungal conks, or mushrooms on or nearby the tree. High-

risk trees may have dead or dying branches in the upper crown, appear in poor health, or show root instability.

2. Less desirable species. Remove trees of species that do not align with your management objectives and may be occupying space better suited for maples or other high-valued timber species.

3. Trees of poor quality. Trees damaged from ice, snow, or wind damage are next on the priority list. Some might be good sap producers if these are maples, but these trees are only optimal for limited uses. Cut any other tree species of poor quality.

Healthy but inferior maples. Cut any maples with smaller, less vigorous crowns that crowd--even slightly--the more superior trees.

Remember, it is okay to cut a maple tree! It may seem counterintuitive, but “sacrificing” a few for the greater good will help maintain a healthy and resilient sugarbush. But thinning must be done in a very informed and objective manner. Again, the specifics of each thinning treatment will vary depending on stand conditions and age.

Young Stands

Young sugarbushes are dynamic—expect lots of mortality and competition for superior crown positions in these stands. Slower-growing maples (especially sugar maple) tend to be in lower crown positions while faster-growing species (e.g., birches, yellow-poplar, cherry trees) and sprouts rise to more competitive crown positions. Young stands with small average diameters (<6” dbh) are very malleable. Aggressive thinning in young stands can accelerate their development because the trees grow fast and respond quickly to the added growing space. Thinning can also remove overtopping competitors and allow the manager to regulate tree spacing to facilitate sap collection. In maple-dominated stands, there are usually more than enough trees to ensure “options” that allow managers to choose the best trees to leave. There are often too many trees, most of which will be small and non-commercial. Thinning operations in young stands will be an investment in time, money, or both. Pre-commercial thinnings are cut and generally left on site to decay and compost or are removed for firewood. A benefit to working in small-diameter stands is that felling damage is minimized, and large mechanized equipment that can damage the residual trees is unnecessary. Crop tree management (Fig. 7) works well in small-diameter sugarbushes. Area-wide thinning- going through and removing all the undesirable stems- would be a considerable undertaking and unnecessary. By contrast, crop tree management removes only the individual stems directly competing with “crop trees.” In sugarbushes, crop trees are maple trees with good form and position within the stand that we look at as future tap trees. At this early stage, we strive to find approximately the best 100 trees per acre, which equates to a tree every 20-25 ft.

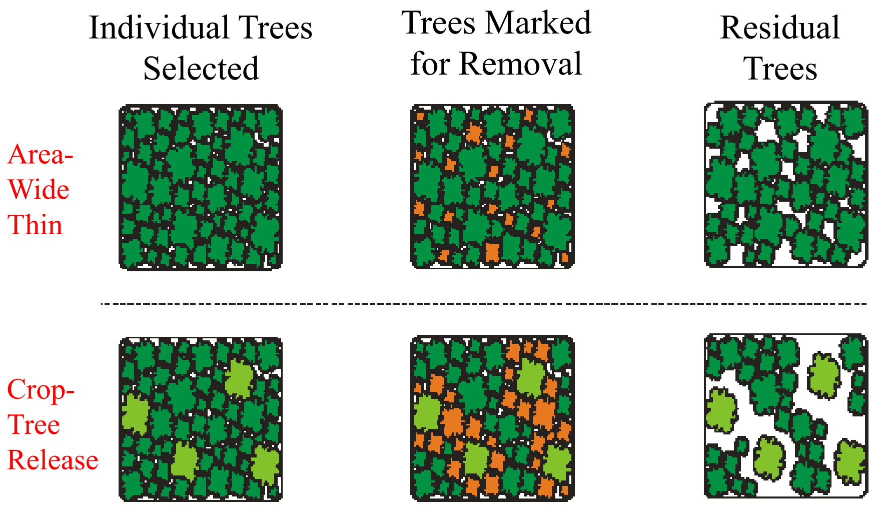


Figure 7. Depiction of crop tree release (after Perkey and Wilkins 2001).

Releasing crop trees is commonly done with a small chainsaw or herbicides by removing undesirable trees with crowns touching or competing for the same growing space as the crop tree. Trees situated between crop trees but are not directly competing with them remain for future treatments or other objectives (e.g., timber, wildlife).

Trees should be released on at least three but preferably four sides to maximize the release treatment and ensure the best growth and survival of the crop tree. If two crop trees are next to one another, both can be left, each receiving a 3-sided release. In traditional crop tree management, managers retain small trees if they do not directly interfere with crop trees' crown expansion or shade more desirable trees. Often they remain to protect the lower trunks and "help prune" lower limbs by shading them, causing them to drop naturally. In sugarbush stands, where the goal is to maintain fuller and deeper crowns, cutting the smaller stems may be warranted (Fig. 8). Still, the small suppressed trees have little impact on overall growth. Ultimately, focusing light and water (and other growth resources) on crop trees can accelerate their growth and reduce the time until they are tappable trees.

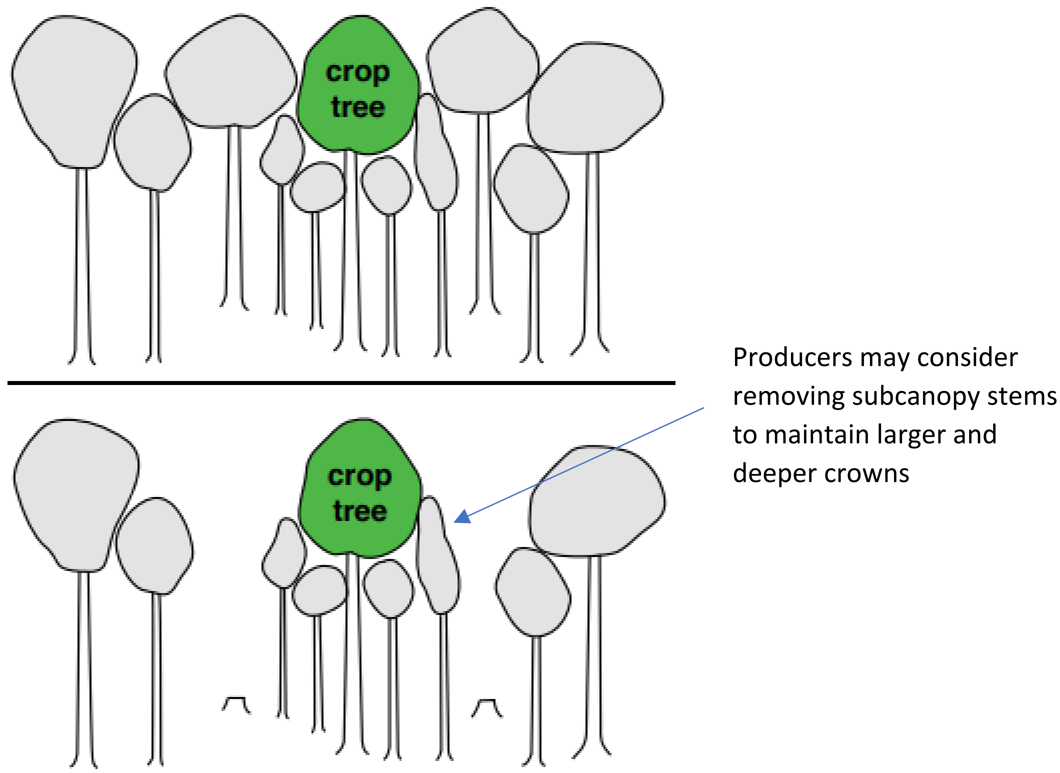


Figure 8. Side view of crop tree management illustrating a traditional release (after Miller et al. 2008).

Pole-sized Stands

Pole-sized stands (6-12" dbh) are easier to work with because access is much better (Fig. 9). After all, trees are more spaced out and have stratified into upper and lower canopy positions. Generally, the lower or suppressed canopy positions are trees with smaller diameters, and the trees of the upper or dominant canopy positions are larger. Pole-sized maples are nearly large enough to tap. Even if little to no management has occurred, these sugarbushes have plenty of opportunities. Depending on markets and stand conditions, thinning treatments can be commercial or at least break-even operations. The goal of thinning pole-sized trees should be to reduce tree density to leave a preponderance of maple trees with good long-term potential. Specifically, these trees have good form (i.e., no significant forks or steep branch angles), are single-stemmed (widely-spaced multiple stems are acceptable but not preferred), and have no signs of stress, decay, or other health issues (Fig. 10).

Figure 9. Pole-size stand of red and sugar maple.

Figure 10. Not all stump sprouts are bad. Sprouts on the left figure are well-spaced and low origin, resulting in acceptable sprouts. The sprout on the right photo have included bark and are high origin, making them poor candidate for retention.

The optimal production of tree growth in the pole-sized stage depends on full site occupancy and tree crown size. Larger and deeper crowns will produce more remarkable growth. Managers should use relative density calculations or stocking guides to set appropriate targets. Other objectives for this stage of stand development are to improve spacing, species composition, and quality (Fig. 11). Operations in pole-sized stands set the future for the sugarbush. Monocultures of maple in sugarbushes can lead to problems. Retaining 15-25% basal area in other species (e.g., timber trees) can help generate future value, support different services or values, such as pollinator trees and aesthetics, and reduce the spread of disease and insects.

Figure 11. A pole-sized maple stand with well-spaced residual trees.

Operationally, thinning in stands similar to the one shown above is done using the crown thinning technique. Crown thinnings remove stems in the main canopy to free up space for the best individuals. Remember, some thinning occurs in intermediate and lower crown positions, but the relative impact of removing lower canopy trees is small. Keeping some smaller trees to support the sugarbush collection tubing is also helpful. Applying a thinning to a sugarbush is an art. Inexperienced landowners and managers can use a spacing rule to help estimate and achieve residual density targets. Table 2 provides some of these spacing rules for stands with average dbh between 6-12 inches and various ranges of tree density (TPA).

Table 2. Residual density targets and spacing recommendations for pole-sized sugarbushes

Avg. dbh (in)	Min. TPA	Spacing (ft)	Max. TPA	Spacing (ft)
6	188	15.2	290	12.3
8	130	18.3	188	15.2
10	102	20.7	137	17.8
12	80	23.3	103	20.6

Healthy trees need large full crowns rather than narrow crowns that are restricted. Also, remember that the crowns of healthy trees expand rapidly. In overstocked sugarbushes, especially those with little to no past thinning, tree crowns will be compact (think lollipops). Opening growing space for lateral expansion is the only way to increase crown size (Fig. 11). As crowns expand, trunk diameter will accelerate.

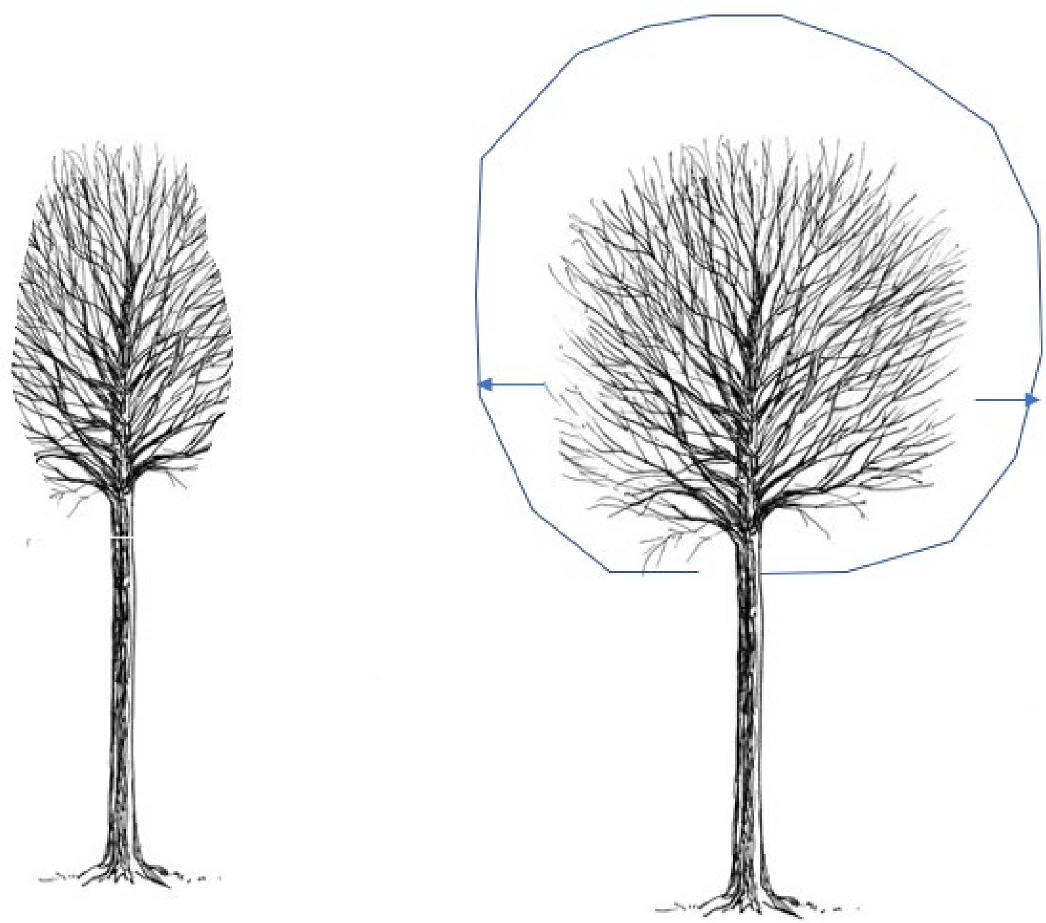


Figure 11. Thinning gives trees room to expand their crowns over time.

On the other hand, the height growth of upper canopy trees is more controlled by site quality conditions than tree density. Sites with rich soils, suitable lower slopes, and moderate exposure to the sun will have taller trees than drier, nutrient-poor sites. Additionally, lower branches in most sugarbushes have already self-pruned due to shading—these don't grow back and hence are not expected to promote increased tree growth and vigor.   The figure below (Figure ##) illustrates the same tree at two different densities—overstocked with no thinning and fully stocked but thinned. The crown on the thinned tree is much larger and can support more carbohydrate-producing leaves. With suitable thinning, one can expect the crowns to continue expanding.

Sawtimber stands (>12" dbh)

When trees are in the sawtimber-sized stage of development, your sugarbush should be in its prime production years. Large-diameter trees and well-stocked forests will produce large quantities of sap (Fig. 12). At this point, there are few opportunities to make big changes to the structure of your stand. However, this doesn't mean there are no opportunities for management.

Figure 12. High quality sawtimber trees managed for maple sap production.

Often, the goal for managing sawtimber-sized stands is to maintain the health of the stands and acceptable growth rates. Thinning small sawtimber-sized stands can support good diameter growth and ensure rapid tap hole healing. Sugarbush managers should remove trees showing signs of low vigor and or disease. In most cases, a loss of production will occur with heavy thinning. For stands without previous management, a conservative approach is to thin lightly and often. By doing so, you create temporary canopy openings quickly filled in by expanding crowns (Fig. 13).

Figure 13. Light thinning to maintain tree vigor and growth.

Since trees are much larger in this size class, the density targets for maintaining good growth rates are lower than those for pole-sized stands (Table 3). Again, remember that only some of the residual trees should be maple trees. Maintaining diversity will help maintain biodiversity and overall stand health and resiliency.

Table 3. Residual density targets for sawtimber-sized sugarbushes

Avg. dbh (in)	Min. TPA	Max. TPA
12	80	103
14	65	83
16	53	73
18	48	55

Over time as trees mature, growth rates tend to decrease. Sugar maple is a long-lived species capable of reaching ages over 300 years, while few red maples survive past 150 years. Regardless, most trees die well before these maximum ages. As stands reach maturity, the objective should shift towards planning for the next generation of maple trees. Regenerating seedlings and saplings to replace the inevitable death of overstory trees can occur all at once, using a "reproduction harvest" or in stages to convert the stand into a multi-aged sugarbush. Depending on the size of the sugarbush, a reproduction harvest will start the sugarbush over and negate production for many decades. Many sugarbushes in the region developed from large-scale timber harvesting, and this approach works well to regenerate forests. However, this will take the stand out of production for most producers' lifetime.

Alternatively, harvesting individual or small clusters of trees scattered throughout the stand will create a mosaic of age classes. Here the objective is to remove over-mature, damaged, and non-producing trees to create canopy gaps to allow young seedlings and saplings to become established and grow. Over time, these new trees will ascend into the middle and upper canopies and become new sap producers.

Stands Under Long-term Management

Stands managed at low densities from when the trees were young have wide-spreading crowns extending close to the ground. These types of stands are uncommon and not typical; however, they can be very productive. Sustaining their productivity requires maintenance of the lower portions of the trees' crowns, accomplished by well-planned thinning.

Figure 14. Widely spaced, old mature stand of sugar maple with little undergrowth.

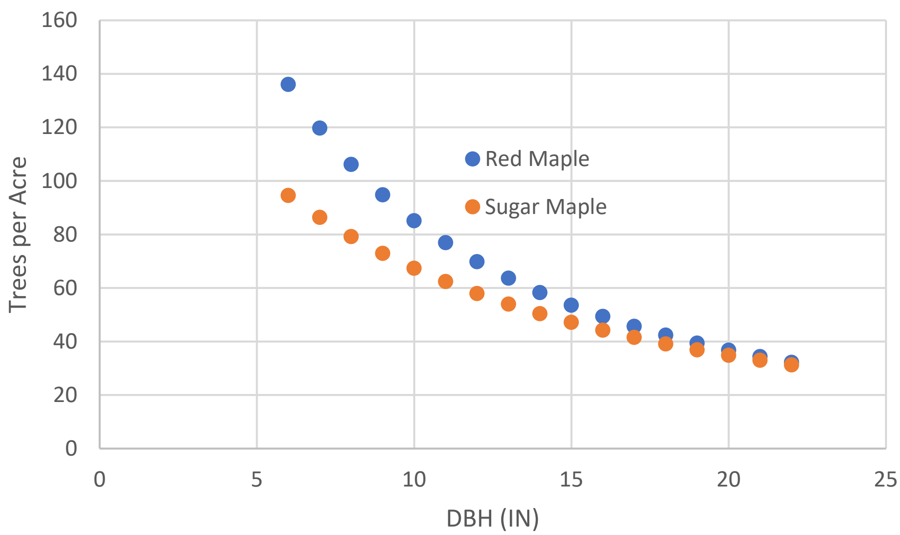


Figure 15.

The average tree size will dictate the total number of open-grown trees. Appropriate densities can be maintained using simple spacing rules. The spacings below (Table 4) represent the maximum growing space requirements between sugar maple trees. For example, two sugar maples with 12- and 16-inch diameters will have their crowns touching when the trees are 33 ft apart.

Table 4. Maximum spacings for sugar maple trees.

DBH(in)	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
6	24.2																
7	25.3	25.3															
8	26.5	25.9	26.5														
9	27.6	26.5	27.0	27.6													
10	28.7	27.0	27.6	28.1	28.7												
11	29.8	27.6	28.1	28.7	29.3	29.8											
12	30.9	28.1	28.7	29.3	29.8	30.4	30.9										
13	32.1	28.7	29.3	29.8	30.4	30.9	31.5	32.1									
14	33.2	29.3	29.8	30.4	30.9	31.5	32.1	32.6	33.2								
15	34.3	29.8	30.4	30.9	31.5	32.1	32.6	33.2	33.7	34.3							
16	35.4	30.4	30.9	31.5	32.1	32.6	33.2	33.7	34.3	34.9	35.4						
17	36.6	30.9	31.5	32.1	32.6	33.2	33.7	34.3	34.9	35.4	36.0	36.6					
18	37.7	31.5	32.1	32.6	33.2	33.7	34.3	34.9	35.4	36.0	36.6	37.1	37.7				
19	38.8	32.1	32.6	33.2	33.7	34.3	34.9	35.4	36.0	36.6	37.1	37.7	38.2	38.8			
20	39.9	32.6	33.2	33.7	34.3	34.9	35.4	36.0	36.6	37.1	37.7	38.2	38.8	39.4	39.9		
21	41.0	33.2	33.7	34.3	34.9	35.4	36.0	36.6	37.1	37.7	38.2	38.8	39.4	39.9	40.5	41.0	
22	42.2	33.7	34.3	34.9	35.4	36.0	36.6	37.1	37.7	38.2	38.8	39.4	39.9	40.5	41.0	41.6	42.2

If they were closer, the lower branches would begin to die over time due to shading. However, if the trees were further apart, their potential productivity would decline since their crowns could not capture all the incoming sunlight. Poor-quality stands at these low densities are probably good candidates for regeneration/harvest. The landowner/manager should consider establishing new trees and creating a multi-aged stand for older stands with better quality stems to ensure long-term sap production.

Uneven-age Management

Depending on stand history, the ages of trees (age class structure) vary among different sugarbushes. During the 1900s, the Appalachian region experienced heavy cutting in many forest stands. As a result, these stands regenerated back to form a single-age class (that is, an even-aged stand). Other forest stands received varying levels and frequencies of partial cutting over time, which resulted in new seedlings established with each entry (multi-aged stands). While the age structure is generally unimportant from a sugaring perspective, managing these two types of age structures--even-aged and multi-aged- is different but critical to understanding the methods to do this. For multi-aged (also called "uneven-aged") stands, tree diameter and height reflect tree age. Small-diameter and shorter trees are generally younger than large-diameter and taller individuals. Importantly, diameter does not reflect vigor or potential (Fig. 16). Simply put, small trees in multi-aged stands are small because they are young. This is entirely different in even-aged stands (most of what we discussed in earlier sections). Generally speaking, for trees of the same species, small trees are low-vigor trees with poor long-term management potential. Management should favor upper-canopy individuals. In even-age stands, small-diameter trees are not necessarily younger. They are typically similar in age but are less vigorous than their larger/taller associates; they are the losers of the long-term battle for sunlight. Releasing lower canopy position trees in even-aged sugarbushes is not good practice.

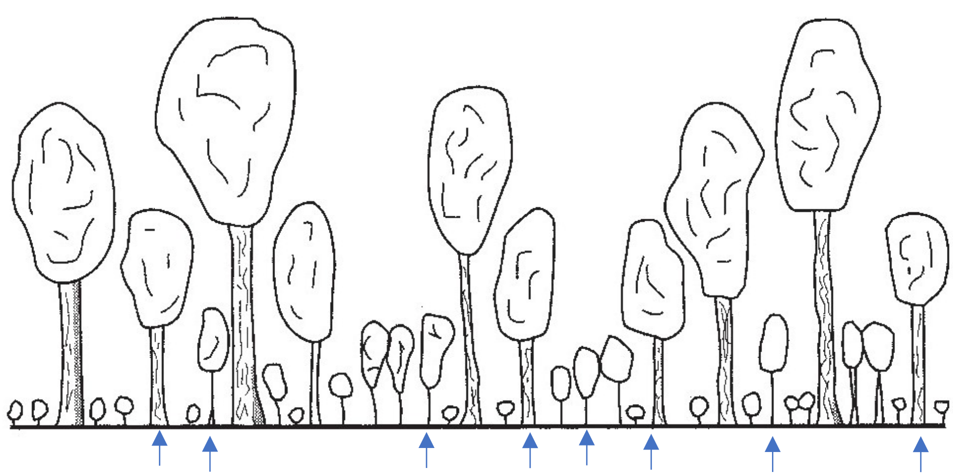


Figure 16. Uneven-aged stand where smaller trees (arrows) have long-term potential.

In the uneven-aged stand depicted above, the range of size classes represents varying age classes. The arrows highlight smaller individual trees (for example) that may have long-term potential and be good candidates for future management.

The even-aged stand below represents one age class, with dominant and co-dominant overstory trees and lower canopy intermediate and suppressed trees (Fig. 17). The lower canopy trees shown here are often unsuitable candidates for future management.

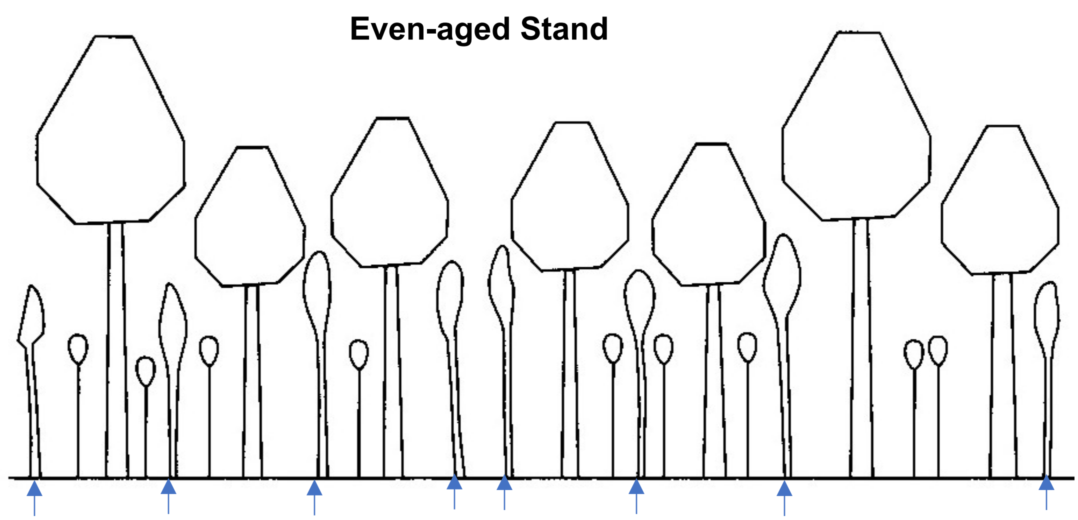


Figure 17. In even-aged stands, smaller trees (arrows) often have poor growth rates and low long-term potential.

Recognizing the age structure is an inherent challenge in navigating the management between even- and uneven-aged stands. An experienced forester discerns these differences based on species composition, stand structure, and knowledge of past activities. However, a more definitive method is to count growth rings.

Trees harvested during firewood operations or as part of timber stand improvement cutting can serve dual purposes. By aging tree rings near the ground, one can get a reasonable approximation of the total age of a tree. Doing this for several tree sizes should reveal the general age class structure. Alternatively, one can use an increment borer to remove a core from the tree without cutting it down (Figure xx).

Figure 18. An increment borer used to extract a core. Once sanded, rings are readily apparent. Note that in this case, we were only interested in the recent growth rates. If we wanted a longer growth period, or to know the age of the rtee, we would need to core the tree to the pith.

Growth rates vary greatly among stands, trees, and years. However, a certain amount of growth is necessary each year to maintain long-term tapability. As diameter growth increases, the time until tap holes heal reduces. Similarly, faster growth rates reduce the chances of tapping non-conducive wood. Trees that are slow growing do not add enough new growth rings to avoid tapping into stained wood, which reduces yields. Models estimating the sustainability of tapping practices are available (van den Berg and Perkins, 2014), which are dependent on indivdual tree growth rates. Diameter growth rates for unmanged maples are typically around 0.15 inches per year. Managed stands can exceed 0.25 inches per year.

If you have an uneven-aged stand, it is essential to recognize that there must be periodic releases for the small-diameter trees to maintain their vigor and develop into the upper canopy. These releases are necessary to sustain sufficient light conditions in the lower canopies to give the younger trees the resources and time needed to grow.

Suppose seedlings and saplings show signs of being flat-topped or increased mortality. In that case, it is past the time for light harvesting. A good rule of thumb would be to reduce the overstory every 10-15 years and strive to allocate the same amount of area to each age class (not the same number of trees!).

Soil Fertility

Sugar maple trees are more sensitive to certain soil characteristics than many other maple species. While sugar maple is generally found on higher elevation sites, north to east aspects, and more mesic topographic positions, it is also sensitive to the acidification occurring on many of the forest sites in the Appalachian region. A long history of acid deposition (acid rain) has depleted base cations (e.g, calcium, magnesium) and buffering capacity of these generally acid soils (Elias et al. 2009). Soils throughout the region are weathered from sandstone, shales and siltstones. pH values for upper soils horizons are often in the 4.0 to 4.5 range (Fowler et al.2022).

Liming treatments have been used throughout New England and eastern Canada to restore the heath and vigor of sugar maple. Broadcast applications using ground-based equipment or helicopters at rates equivalent to 3-5 tons/ac are common. Common carbonate materials include calcium carbonate ($CaCO_3$) and dolomitic lime ($CaMg(CO_3)_2$), which has high levels of magnesium in addition to calcium. Soil sample thresholds derived from maple stands in northern Pennsylvania, New York, Vermont, and New Hampshire identified foliar calcium and magnesium as >5500 mg/kg and >700 mg/kg, respectively, and soil thresholds for calcium >0.2 $cmol_c$/kg, Mg >0.05 $cmol_c$/kg, and Ca:Al molar ratio >0.03 (Moore et al. 2015). Foliage is commonly sampled from upper crowns of dominant and co-dominant sugar maple trees in mid- to late August using a shotgun to collect leaves from the outer branches. Soils were sampled from B-horizons. Most state agriculture agencies have the capacity to analysis foliage and soil samples.

Figure 19. Shooting foliage from upper canopy trees is an efficient method to collect foliage.

Interfering Vegetation

The long-tern sustainability of a sugarbush will ultimately depend on regenerating new seedlings over time. Both native and non-native species can prevent or significantly delay recruitment. For example, the native hay-scented fern (*Dennstaedtia punctilobula*) is an aggressive competitor that form dense groundcover that excludes tree seedlings. Similarly, small statured trees and shrubs (e.g., spicebush, *(Lindera benzoin*) *and American beech (Fagus grandifolia) thickets*) can create dense layers limiting seedling development. There are many non-native plant species that commonly inhabit southern maple forests. Many of them are considered invasive. Japanese stiltgrass (*Microstegium vimineum*) is becoming well-established in forests, especially long roads and skid trails. Other concerning species include tree-of-heaven (*Ailanthus altissima*), oriental bittersweet (*Celastrus orbiculatus)*, and garlic mustard (*Alliaria petiolate*) to name a few. Management of native and non-native plants involves either the use of herbicides or mechanical removal. Regardless, repeated and sustained effort is usually required. About 30% overall coverage of interfering plants is often used as a management threshold.

Figure 20. Native (hay-scented fern) and non-native (J. stiltgrass) species retarding the development of new seedlings.

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