



Supporting Sustainable Management of Private Woodlands

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What is tree vigor and why does it matter?

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Dead and dying trees are a normal part of woodlands, and have value for wildlife, aesthetics and nutrient cycling. However, woodland owners want predominantly healthy trees. Tree health is often thought of as the absence of biotic or abiotic factors that stress the tree and limit its physiological capacity. Stress results in less growth and an increased risk of death. Tree vigor is one way to describe aspects of tree health. The details of measuring tree vigor and using that in management decisions is the subject of considerable research.

Defining Tree Vigor

Tree vigor is variously defined depending on how the information of vigor is to be used. In the most rigorous assessment of vigor in research to determine how different events (e.g., defoliation, thinning) impact tree productivity and survival, vigor is the ratio of the annual growth of wood on the stem per unit of leaf area. Leaf area is usually described as square meters of leaf surface area. Vigorous trees grow more wood than less vigorous trees for the same amount of leaf area. This ratio describes the efficiency of photosynthesis to produce wood. In other applications of the use of tree vigor, it is defined by visual assessment for symptoms of the crown and stem for the likelihood the tree will have reduced growth, die or have reduced economic value.

Before further delving into details of tree vigor definitions, a similar term needs attention. The term tree vitality appears in some scientific literature, particularly European forest sciences that investigate tree response to environmental stressors. Tree vigor is commonly used in North America. Tree vitality and tree vigor



Figure 1. The ability of a tree to survive requires its ability to overcome direct and indirect stressors. These stressors either directly injure the tree or indirectly prevent the tree from acquiring the resources it needs.

share many attributes, though they seemingly are not synonymous. Tree vitality incorporates and is ultimately based on tree survival, which is an outcome of low tree vigor (Figure 1). There is significant overlap of these terms, but few attempts have been made to rigorously define their unique and shared attributes. Perhaps this isn't surprising given the nuances within the use of tree vigor as part of North American forest science, and presumed similar nuances for definitions of tree vitality.

The definition of tree vigor that is based on the ratio of wood growth to leaf surface area is known as “growth efficiency.” Tree growth happens because of photosynthesis that repackages carbon as a core component of starches and sugars used by the tree. Trees allocate the carbon they produce to different tissues (e.g., leaves, roots, wood, fruits) based on a priority of importance of that tissue to tree survival. From most to least important are:

1. Leaves
2. Roots
3. Buds
4. Storage tissues
5. Stem wood and defensive compounds
6. Reproductive structures.

Thus, the comparison or ratio of stem wood production and leaf surface area are at opposite ends of the spectrum of priorities. If the ratio of wood to leaves is high, the tree has been successful at producing sufficient carbon to allocate that carbon to a less important component. An analogy occurs in most families who each month consistently pay high priority bills first (e.g., mortgage, car payment) and only allocate funds to lower priority expenses (e.g., elaborate vacations) when possible.

Measuring Tree Vigor

Most people will neither want nor be able to directly measure tree vigor as growth efficiency. Other indirect metrics of tree vigor relate to either the growth of tree stems or to signs (i.e., direct evidence) and symptoms (i.e., potential evidence) associated with impaired stem growth (Figure 2). These indirect metrics of tree vigor would be approximately analogous to “biomarkers” in medicine, and similarly variable in their predictive power. Note that these indirect metrics focus on the tree's low priority or ability for growth of wood, and presumably assume a fairly constant leaf area. Vigor is ultimately an assessment of an excess of carbon available for stem diameter growth. The indirect metrics that measure stem growth have value only when compared to the same or similar metric for a time period that serves as a baseline (e.g., normal growth conditions), an alternative growth condition (e.g., prior to thinning, during a defoliation event), or a comparable tree thought to be “normal.”

A common and feasible metric for woodland owners is basal area increment (BAI). Basal area is the area of wood of a tree produced at a specific height (i.e., 4.5 ft) on the stem near the base of the tree.



Figure 2. Many causal agents can injure the stem. Depending on the nature and size of the injury, the vascular tissue that carries water and sugars may be reduced and the trees ability to feed the roots and crown may lessen its vigor.

(Note – the basal area of the stand, usually reported in square feet per acre, is a related but different concept) The “increment” is the amount of stem basal area growth for a particular growing season. The increment is calculated as the additional stem wood added between two points in time. Basal area is easy to calculate based on the measurement of tree diameter; for tree vigor calculations a diameter tape, not a scale stick, is required (Figure 3). One use of BAI is a comparison of the direct value between time periods or relative BAI (rBAI) which is BAI as a percentage of total basal area for that tree at the beginning of observation, and the change of rBAI through time.



Figure 3. A diameter tape is wrapped around the circumference of the tree, and the unique calibration allows direct recording of tree diameter. A 3.5 ft staff is placed on an aluminum nail about 1 ft above the ground for accurate repeated measurement.

An example of basal area, BAI and rBAI may help (Table 1). At Cornell’s Arnot Forest there are numerous tagged sugar maple trees in the research sugarbush. These trees are annually measured for stem diameter (and other variables) to inform syrup production management practices. The trees reported here were all upper canopy co-dominants of similar size (Table 1). Observe that tree growth is not assured; tree #2805 had no measurable growth in 2018. Also that rBAI can be similar among trees in similar conditions as seen for 2018. The utility of rBAI to assess changes in tree vigor is illustrated for 2019 where the values differ. Continue reading below to learn what changed for each tree as related to growth and thus vigor. The measurements to calculate BAI are quite simple and involve annual measurement of tree diameter at the same height (Figure 3). Woodland owners who are participating in the Cornell/NYFOA Northeast Timber Growing Contest (www.timbercontest.com) already have these data.

The other category of metrics to assess tree vigor relate to features of the trees that are thought to impact tree growth, or tree longevity. These potential indicators of tree growth and longevity are easier to assess as compared to tree dbh measurement and may have utility in decisions regarding tree selection for harvest.

Indicators of longevity may or may not also predict growth. These visual metrics are typically called defects, and represent a range of conditions that either reduce tree growth (e.g., stem cankers, crown dieback) or increase the likelihood of tree death (e.g., open seams in forks (Figure 4), tree lean greater than 10°).



Figure 4. Forks having an acute angle are prone to splitting, as shown in this basswood tree. Snow loading and wind on the branches prevent healing. The lack of structural integrity destines this crown to fail.

Applying the Concepts of Tree Vigor

The utility that owners expect from their trees likely influences whether a change in vigor elicits concern. Few events trigger an owner’s concern more than seeing a tree, especially a group of trees, in poor health and thus showing low vigor. Some owners are particularly interested in optimizing the health of trees for a variety of tangible outputs such as timber, fruit crops for wildlife, or maple

Table 1. Example calculations of basal area increment and relative basal area increment as an index of tree vigor in sugar maple trees at the Arnot Forest. (P. Smallidge, 2020, unpublished data)

Tag #	dbh 2017	dbh 2018	dbh 2019	dbh 2020	ba2017	ba2018	ba2019	ba2020	baI2018	baI2019	baI2020	rBAI2018	rBAI2019	rBAI2020
2805	17.3	17.3	17.4	17.4	235.1	235.1	237.1	237.8	0.00	2.04	0.68	0.00	0.87	0.29
333	20.3	20.6	20.7	20.8	323.6	331.7	335.2	338.2	8.02	3.56	2.93	2.48	1.10	0.90
2814	16.3	16.5	16.7	16.8	208.7	213.8	217.7	220.3	5.15	3.91	2.62	2.47	1.87	1.26
2824	15.9	16.0	16.2	16.3	197.3	201.1	206.0	208.7	3.75	4.93	2.68	1.90	2.50	1.36

- dbh = diameter at breast height (4.5 ft), measured after the cessation of growth for that year. (after leaves change color or drop)
- BA = Basal area (sq. inches) = $(0.005454 * dbh^2) * 144$
- BAI = Basal area increment (sq. inches) = basal area in one year – basal area in the previous year (e.g., BAI2019 = BA2020 – BA2019)
- rBAI = relative basal area increment = (BAI for a particular year / baseline BA in a particular year) * 100 In this example, the base year used for calculations is 2017.

Table 2. Response of relative basal area increment (rBAI) following sugarbush thinning in August 2018 and drought in 2020. Relative basal area increment serves as an index of tree vigor. The canopy was closed prior to thinning. (P. Smallidge, 2020, unpublished data)

Number of sides of crown free to grow after the 2018 thinning	Number of trees	Median dbh (inches)	Average BA (sq in)	rBAI2018	rBAI2019	rBAI2020	% rBAI Reduction in 2019 vs. 2020
0	3	15.1	162.2	0.4	0.8	-0.2	-125
1	14	12.9	158.7	0.9	1.5	0.4	-73
2	8	15.8	193.7	1.2	1.7	0.7	-59
3	8	14.1	167.4	1.6	2.6	1.1	-58
4	10	14.4	176.9	1.3	2.9	1.6	-45

syrup production. Note that these tangible outputs are “low priority” when the tree allocates carbon, thus low vigor compromises production. In addition to tangible outputs, vigorous trees are often less vulnerable and more resilient to insects and pathogens.

Woodland owners interested in tree vigor can tag 10 to 15 healthy trees of their favorite species and measure tree diameter at the identical height each year on approximately the same date (Figure 3). See Table 1 for formulas to calculate basal area, BAI, and rBAI. Make note if the trees are upper or lower canopy and any defects (see below) they have. As you manage your woods, see how these trees respond to your different activities, and also change through time as a result of temperature and rainfall.

Several factors influence whether a tree is vigorous, and some of these factors can be influenced through management. Management can either alleviate or complicate the direct and indirect influence of stressors on how trees allocate carbon to foliage, roots, buds, storage tissues, stem wood and defense compounds, and reproductive structures. Direct stressors damage tree tissue. Examples include defoliation, root damage, and injury to stems. Indirect stressors reduce access of the tree to necessary resources such as sunlight, water, minerals, nutrients, and temperature. Examples include competition for sunlight, poor site conditions, or changes in soil hydrology.

In our northeastern forests there are some factors that influence tree vigor, but that are not typically prioritized for influence via management. The most notable factor not prioritized is the genetics of the tree; the regulation of tree genetics is more common in plantation forestry found in other regions. Tree genetics could be influenced, but the cost is high relative to the benefit. Exceptions, such as the black walnut genotype that received a US patent, exist. In other cases factors are disregarded because of infeasibility. An example might be dominance of a stand by a tree species that is not ideally suited to that site; dominance might be a result of an unexpected twist of post-agricultural successional fate.

With this understanding for how stress impacts tree vigor, management activities should strive to reduce direct and indirect stressors. It is worth recognizing that activities can reduce a stress (e.g., thinning to reduce competition for sunlight) and also a stress might be reduced because an activity is avoided (e.g., not driving your tractor on saturated soils resulting in root damage).

The annual measurements of trees, or a subset of trees, is practical and instructive in assessing tree vigor. More often owners and foresters can only judge a tree based on features they can see at the time when they are looking at the tree. The visual symptoms associated with indications (favorable and unfavorable) of tree vigor include:

- A crown is ideally full of leaves and is sufficiently dense that it lacks transparency. Assessing transparency is easier said than done, and its effective use requires training and calibration. The principle is that leaves photosynthesize and crowns full of dark green foliage and a high density of foliage are likely more vigorous. However, a drought during the growing season might not change the appearance of the foliage, but could reduce vigor and growth efficiency. Recall that a high priority for a tree is the growth of leaves and buds, which annually form twigs. A tree of

low vigor has reduced elongation of twigs which results in the clustering or “tufting” of foliage at the tips of the twigs rather than along the length of the twig. Tufting produces a transparent crown.

- Crown dieback (Figure 5) can happen when foliage demands exceed the capacity of the root system to provide water and mineral nutrients. Root systems might be impaired due to mechanical damage from equipment or when a tree is “off-site” (see below). Crowns with dieback greater than 50% are considered of low vigor because something caused the dieback and because there is less foliage for photosynthesis. Most owners will notice and be concerned when dieback occurs on 20% to 25% of the crown. Prior dieback can be apparent for many years, and is less concerning if the limitation is corrected and there is robust regrowth of twigs. Dieback doesn’t necessarily reduce the timber value of the tree, but may limit growth which reduces the accumulation of volume and value. If the cause of dieback isn’t resolved, dieback will likely reduce tree longevity.
- Wounds on stems (Figure 6) and seams on stems (Figure 7) that have soft or “punky” wood as evidence of decay are good indications of poor vigor. This conclusion is amplified for wounds greater than 100 square inches and for seams that spiral for more than 1/3 of the circumference of the stem. Wounds without decay and less than 100 square inches are of less concern especially if the callus tissue (Figure 8) around the edge of the wound is thick and appears to be closing the wound. The location and size of wounds and seams can reduce the timber value of a tree and may reduce the accumulation of volume and value.
- Trees with lean may not have reduced vigor if the crown is healthy, but lean greater than 10° is associated with an increased chance the tree will fall. If there are straight sections of the stem of sufficient length for a commercial sawlog, there may be no reduction in value. Similarly, tapping for maple sap may not be negatively impacted while the tree is standing.
- Open seams below forks (Figure 4) are a sign of high risk for structural failure. They are also of high risk for someone to fell the tree. These trees often have large and healthy crowns, but they lack structural integrity and thus reduced longevity. They are typically destined to fail, but will compete for sunlight with neighboring trees until they fail.
- Crown competition reduces photosynthesis and vigor. Competition can occur through lateral shading or by trees overtopping neighbors. The latter describes crown height class among trees of the same age that results in upper and lower classes or strata (Figure 9). The trees in the lower crown class have less access to light, smaller crowns, reduced growth efficiency, and thus reduce vigor. The



Figure 5. This sugar maple crown shows extensive crown dieback with modest recovery. It is growing in a poorly drained pocket of soil and likely has a poorly developed root system that makes it vulnerable to periodic droughts.



Figure 6. This maple tree was wounded by a tractor tire. The wound did not heal and the wood has started to decay.



Figure 7. Seams may form as a result of various injuries, such as abrasion by tires or falling trees, or cracks from localized thawing in winter. Seams may heal with little impact on tree vigor.



Figure 8. A nail in this tree created a small wound of about 15 square inches. The center section is bare but solid wood. The next band of smooth bark is the callus tissue that is growing over the wound. Beyond the callus tissue is bark.

impact of lateral shading and the beneficial release via thinning has a seemingly favorable response in the first growing season after release (Table 1, 2). The trees (Table 1) are arranged such that the first tree (#2805) had no release from competition and the release of the other trees was, in order: 45, 115, 225 degrees open (i.e., 90 degrees open is one of four sides free to grow). Compared to the rBAI before harvest (2018), the post-harvest rBAI (2019) is more linear (Table 2). Note that the use of rBAI as an index of vigor showed a consistent pattern in 2019 and 2020. Also, the drought of 2020 was of greater impact on trees with low vigor (those with fewer sides of their crown free to grow). A full analysis of these data is in process.

All trees grow well on good sites (i.e., adequate but not excessive moisture, good

mineral nutrition, deep soils, etc.), but some trees are less tolerant of less than perfect conditions. Sugar maple is a good example of a “finicky” tree that doesn’t tolerate overly moist or nutrient poor soils (Figure 5). Trees growing on a site for which they are not adapted will always have low vigor because of impaired root growth and inadequate access to soil nutrients. Their low vigor may well result in premature death, but not before they hamper the growth of neighboring trees that might be better adapted.

Tree vigor is a fascinating expression for how trees respond to their local conditions. There is no obligation for owners to try to influence tree vigor. Woodlands continue to survive in the absence of interventions, but the trees that survive may not be the owner’s priority. Understanding tree vigor, and applying management treatments to enhance vigor, will deliver specific benefits to the owner.

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Figure 9. The upper crown class includes dominant and codominant trees, and the lower crown classes include intermediate and suppressed. Crown class is the height of a tree relative to its neighbors and corresponds to the amount of light it receives. Lower crown class trees, especially suppressed trees, have low vigor.

For additional information on woodland management go to:
www.ForestConnect.com & www.CornellForestConnect.ning.com



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