Forestry 101 Curriculum

The UNIVERSITY of VERMONT

VERMONT TECH

NH Extension

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VERMONT TECH

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Contents

Module 1 – Introduction

The Forestry 101 curriculum developed under the NBRC *Forest and Wood Product Workforce Development* grant was created by Anthony D'Amato at UVM, Jim Frohn and Andy Fast at UNH, and Molly Willard at VTC. The curriculum was developed to: 1) augment existing CTE center forestry curriculums; 2) provide a region-wide resource to other educational entities promoting workforce development in the forest industry; 3) be incorporated into the VYCC Advanced and Pro experiential TSI Forestry work crews; 4) serve as a guide for learning outcomes required to understand and implement TSI practices; 5) serve as a starting point for a potential future credentialed timber stand improvement (TSI) professional; 6) create education and career pathways for students and work crew participants; 7) support the overall mission of the NBRC *Forest and Wood Product Workforce Development* grant by teaching and implementing practices to improve forest composition and resiliency.

This curriculum and document is focused on timber stand improvement. **Timber stand improvement** (TSI) refers to forest management practices that improve the vigor, stocking, composition, productivity, and quality of forest **stands**. The purpose of timber stand improvement is **improvement** resulting from removing lower quality trees and allowing crop trees to fully use the growing space.

Promoting high quality, high value trees through timber stand improvement is a goal since the products derived from these trees have had relatively stable markets over decades and encompass the majority of the value of a forest. In contrast, low value and poor quality trees (i.e., low grade markets) have experienced price volatility and market uncertainty. While financial returns of forestland are not the primary priority for many landowners, there is an underlying assumption that increasing the financial returns of forestland allow more flexibility to offset costs associated with non-monetary goals (wildlife habitat improvement, improved trail systems, etc.).

This curriculum supports TSI efforts and is comprised of the following areas: Tree ID, Tree Quality Assessment and Products, Forest Ecology and Silvics, Implementation and Equipment, and Work Crew Experience. Below is the NBRC 101 Curriculum map.

<u>Tree ID:</u>

- Identification of key tree species
- Identification of Invasive species

<u>Tree Quality Assessment and Products:</u>

- Define and ID a quality tree based on site objectives
- Influence of silviculture practices on wood quality
- Influence of pests and disease on form and quality

<u>Forest Ecology and Silvics</u>

- Site Assessment
- Silvics, Succession, and Stand Development
- Tree/stand Growth (stocking)
- Treatment Types (including invasives)

Implementation and Equipment

- Equipment
- Implementation

Work Crew Experience

VYCC offers a unique learning pathway for anyone interested in forestry, conservation and the outdoors.

The model is built off a national conservation Corps model that links the core methods of learning, service to community, and paying jobs for young people. These amazing experiences help develop each Corps Member's leadership, teamwork, understanding and embrace of inclusion and equity, and larger professional skills.

Here's a summary of some key skills gained by VYCC Forestry Crews:

- Increasing chain saw skill level and greater felling complexity
- Knowledge of USFS safety standards gained through literature and additional training
- An understanding of the operations and planning required to move that tree you just felled out of the woods
- Species identification with a focus on commercial viability and qualities that affect the felling process
- Understanding the components of a Forestry Management Plan: the process from beginning to end, regulatory requirements, field work, client relationships, and the direct links between the Plan and the work we're doing in the field.
- Productivity Review: what are changes in the field that could help us work faster without sacrificing safety? What are the meaningful metrics to monitor from the existing work site?
- Invasive management: approaches, both herbicide and non-herbicide; relationship to best silvicultural practices.
- How to use the skills learned to start or further a career, or towards an undergraduate forestry degree.

Module 2 – Dendrology TSI Identification Training Handbook

Objectives

- Ability to use appropriate references to look up unknown tree identification terminology. Recommended field guide: Forest Trees of Maine
- Ability to use the Dendrology TSI Identification Training Handbook to identify 12 most important species targeted for TSI in the field
- Identify 12 most important commercial species in the field
- Identify important invasive species

Introduction

The 12 key important species focused on here are: sugar maple, white ash, yellow birch, black birch, red oak, red maple, American beech, paper birch, aspen spp., red spruce, balsam fir, and white pine.

There are additional species that have less commercial value such as eastern hemlock, grey birch, pin cherry and black cherry. These, and other species, can help land managers identify site characteristics, land use history and value for non-monetary goals such as wildlife habitat value.

Pinus *strobus* (white pine)
Soft Pine
Leaves: 5 per fascicle, straight and flexible
Cones: 5" long, cylindrical, thin scales, often covered with white pitch
Silvics: Large, intermediate to intolerant, largest northeastern conifer, found in northeastern US, Appalachians and southeastern Canada, common pioneer on abandoned pastures. Develops best on fertile, well drained sites, also found on uplands and sandy soils. It competes well on sandy soils and can be a pure stand.

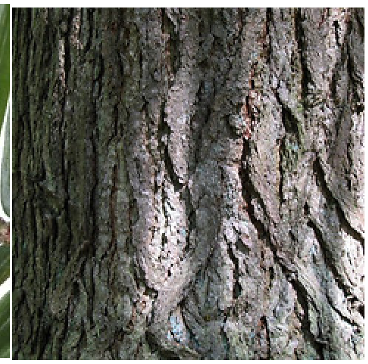


Picea *rubens* (red spruce)
Needles: ½" long, yellow-green, angles forward, somewhat pricky
Twigs: Orange brown, pubescent in twig grooves
Cones: 1 ½" long, ovoid, scales rounded on margin, margin more or less entire, dangle down, drop in autumn or early winter and are gone from branches by summer.
Silvics: Small to medium, common in northern New England and upper elevation in the Appalachians south to GA, Very tolerant in understory, most important northeastern spruce, used for dimensional lumber – 2x4s, 2x6s



Tsuga *canadensis* (eastern hemlock)
Needles: ½” long, tapering from base to apex, 2 lines of stomata, 2 ranked
Cones: 2/3” long, ovoid scales, with entire margins, pendant. Mature during first autumn and remain on branch until next spring, seeds are winged and fall in winter
Silvics: Medium sized tree, most tolerant gymnosperm, Wood is coarse, strong and heavy, Tannin in bark once used for tanning leather.



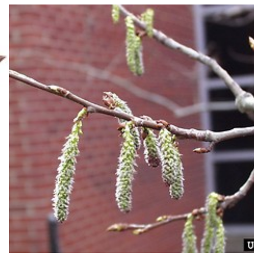


Abies b*alsamea* (balsam fir)
Needles: ¾”. 2 ranked or clustered toward upper surface, dark green, shiny, 2 rows whit stomata below.
Cones: bracts shorter than cones scales, 3-4” long, dark purple before maturity, ripen in Aug and Sept.
Silvics: Smooth bark with resin blisters, wood is soft, light and used for construction, Christmas trees

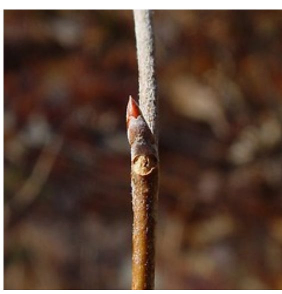
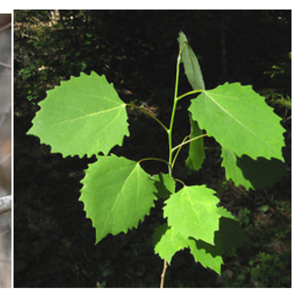


Populus *tremuloides* (quaking aspen)
Leaves: to 3” long. Broadly ovate, margin finely serrate crenate, glabrous, petiole flattened
Twigs: Slender, red-brown, shiny, buds sharp pointed, slightly resinous, appressed
Fruit: Ripens in June, small light cottony capsule, wind.
For all poplars and willows: Woolly bear caterpillar like staminate and pistillate catkins, borne on different trees.

Bark: Initially smooth and green/white to cream colored, becoming furrowed and dark gray to brown
Silvics: Medium sized, fast growing, short lived tree, common pioneer on variety of sites, sprouts vigorously, important pulp species, food for beavers, deer, rabbit, grouse



Populus *grandidentata* (bigtooth aspen)
Leaves: 2-3”, suborbicular, coarsely dentate, petiole flattened, young leaves with whitish tomentose
Twigs: Dull brownish-gray, buds gray, usually pubescent, usually divergent
Fruit: ripens in May
Bark: Orangish0 green when young becoming brown and furrowed
Silvics: Similar to *tremuloides*, but often occupies better quality sites and has great longevity, restricted to northeastern US, the Lake States and southern Canada



Acer *rubrum* (red maple)
Leaves: generally 3 lobed, serrate, glaucous below
Twigs: Buds obtuse with imbricate, reddish scales, RED
Fruit: Wings only slightly divergent, matures late spring-early summer
‘Bark: Gray scaly plates, variable, often with targets
Silvics: Medium sized tree, variety of sites throughout eastern US, soft maple

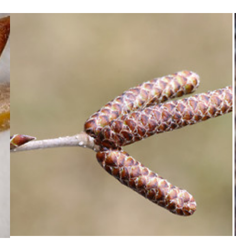
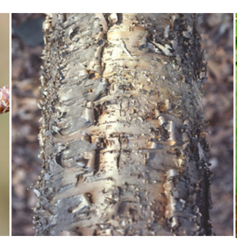



Acer *saccharum* (sugar maple)
Leaves: 5 lobed, entire margins
Twigs: Lustrous, buds imbricate, brown, sharply pointed
Fruit: U-shaped, fall
Bark: Gray (often with brown tinge) furrowed-scaly, variable
Silvics: Very tolerant, medium sized, valuable tree for timber, sap production, and foliage




Betulaceae (Birch Family)
Betula *alleghaniensis* (yellow birch)
Leaves: 3-5”. Ovate, base somewhat inequilateral
Twigs: Slender, smooth, wintergreen taste, acute buds, ovate, ciliate margins, bud scales fattest in the middle
Fruit: Ovoid, erect strobili, tardily deciduous. Flowers in catkins, usually 3-4 not clustered, open in early spring. Those appearing in fall are dormant staminate catkins
Bark: Bronze to silvery peeling into papery strips, becoming scaly
Silvics: Medium sized, intermediately tolerant, quality hardwood, most valuable of the birches. Cool, moist sites mixed with beech, sugar maple or hemlock.

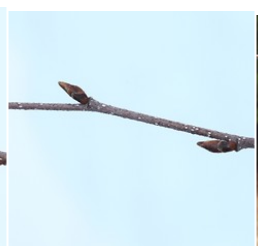



Betula lenta (black birch/sweet birch)
Leaves: Similar to alleghaniensis: 3-5”. Ovate, base somewhat inequilateral
Twigs: Slender, smooth; strong wintergreen taste; buds acuminate
Fruit: Similar to alleghaniensis: but oblong
Bark: Nearly black; smooth with lenticels when young; irregular scaly patches on old trees
Silvics: A medium sized intermediately tolerant on moist well drained sites. Wintergreen taste in the bark.

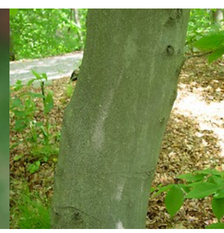



Betula *papyrifera* (paper birch)
Leaves: 2-4”. Ovate-oval, coarsely doubly serrate
Twigs: Slender, lenticels, buds ovoid, resinous, look sticky
Fruit: Cylindrical pendant, deciduous catkins, open early spring before leaves come out. Dormant staminate catkins in clusters of 3
Bark: Red-brown at first, then separating into papery strips. Any white has to be paper birch. Goes through stage where similar to yellow birch.
Silvics: Medium sized, intolerant pioneer, transcontinental, most widely distributed birch. Occurs in pure stand or mixture.

Betula *populifolia* (grey birch)
Leaves: Doubly serrate, deltoid, acuminate tip
Twigs: Slender with warty lenticels, non-aromatic, buds ovoid, when squeeze- glazed
Fruit: Cylindrical, spreading or ascending, deciduous, single pair of catkins in winter and spring.
Bark: Dull, gray to chalk white, thin and tight, black patches below branches.
Silvics: Small, intolerant, pioneer, infertile sites, found in old fields, burns and heavily cut area. Appears in clumps that lean.

Fagus *grandifolia* (American beech)
Leaves: Deciduous, 3-6”, elliptical to oblong ovate, serrate with sharp incurved teeth, somewhat papery
Twigs: Slender, terminal bud about 1” long, lance shaped, imbricate
Fruit: 2 or 3 edible nuts within a small bur with soft spikes
Bark: Thin, smooth, light gray
Silvics: A medium sized very tolerant tree of eastern US, component of climax hardwood forests, root suckers. Beech bark diseases causes significant mortality (beech scale insect is invaded and killed by fungi). Strong, hard wood but not durable

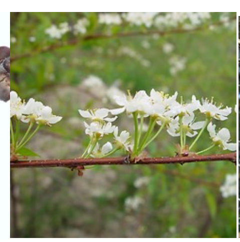


Quercus *rubra* (northern red oak)
Leaves: Deciduous, lobes separated by regular sinuses, glabrous except for occasional axillary tufts
Buds: ¼” ovoid, sharp, reddish brown, scales often with ciliate margins
Fruit: To 1-1/8” long, enclosed at base in thick saucer like cap with small scales. The flowers appear in May, the fruit ripens the 2^{nd} season.
Bark: Flat topped ridges with shallow fissures (ski-trail bark) Light red inner bark, very tight.
Silvics: Most common oak species in VT, good competitor on enriched sites, found on moist well drained upland sites throughout eastern US, except southern coastal plain, moderately tolerant. Hard, string, heavy wood

Fraxinus *Americana* (White Ash)

Leaves: Usually with 7 more or less elliptical entire- serrate petioled leaflets, purple in the fall
Twigs: Stout, glabrous, buds broadly ovoid with 4-6 brownish scales, 1st pair of laterals at same level as terminal, leaf scar usually notched
Fruit: Wing generally rounded at apex, generally ending at apex of seed cavity, single samara occurring in clusters
Bark: Ashy gray, initially smooth, later interlacing ridges. Diamond bark and more precise then green
Silvics: Uplands throughput the eastern US, quality hard wood, used for implements, paddles, tool handles, baseball bats. EAB is a threat. Rich rather moist soil of low hills

Rosaceae (rose family)
Prunus pensylvanica (pin cherry)
Leaves: Deciduous, lanceolate, finely serrate, yellow-green, petiole glandular
Twigs: Reddish, with slight bitter taste, buds reddish-brown, small, tending to be clustered at tip
Fruit: Light red drupe, very sour, borne in an umbel, bright red, almost translucent, ripens from first July to August.
Bark: Thin burgundy with prominent orange lens-shaped lenticels
Silvics: Small, short-lived, intolerant pioneer tree, transcontinental across Canada, New England and Lake States south into Rockies and Appalachians, often reproduces from seed long buried in duff that germinate following forest disturbance. Has little economic value, but serves critical ecological function after disturbance in protecting soil, maintaining nutrients, and providing soft mast for wildlife.



Prunus *serotina* (black cherry)
Leaves: to 6”, deciduous, oblong-lanceolate, finely serrate, dark green, lustrous above, orange pubescence along mid-vein below, petiole glandular
Twig: Slender red- brown, sometimes with gray epidermis, bitter almond taste, buds with brown imbricate scales (with some green into the fall). As with pin cherry twigs and branches are commonly distorted by a black, warty fungus growth called black knot

Fruit: Almost lack drupe borne in racemes, ripen June-October, edible, important wildlife food. The flowers are produced in racemes 4-5 "long in late May-June when leaves are half grown.
Bark: Red-brown to black with conspicuous light horizontal lenticels when young, later with platy scales.
Silvics: Medium sized tree, well drained sites throughout eastern US, quality hardwood. Best growth on rich moist land. It is a valuable soft mast tree.






Invasive Species:

Disclaimer: There are a number of laws and safety considerations when controlling invasive species with pesticides. For chemical treatment options, consult state regulatory agencies and a state licensed commercial pesticide applicator.

1.) Autumn Olive

- *Elaeagnus umbellata* is a deciduous shrub from 3-20 ft. (0.9-6.1 m) in height with thorny branches. It is easily recognized by the silvery, dotted underside of the leaves.
- Leaves are alternate, 2-3 in. (5-8 cm) long and 1 in. (2.5 cm) wide. The margins are entire and undulate. Leaves are bright green to gray green above and silver scaly beneath with short petioles
- Small, yellowish tubular flowers are abundant and occur in clusters of 5 to 10 near the stems in early summer
- Fruits are round, red, juicy drupes which are finely dotted with silvery to silvery-brown scales. Each drupe contains one seed. Fruits ripen from August to November.

- Common look alike- Russian Olive- has silvery scales on both sides of leaves

Mechanical Control

- Removal of plants on site may only be a temporary solution. Plants will continue to seed in from adjacent areas causing a reoccurring control issue. Autumn olive also resprouts vigorously after mowing, cutting or burning, often becoming more vigorous with each regrowth even when repeated for many years.
- Mechanical controls, including pulling and digging, can be effective at eliminating small seedlings and sprouts. Pulling should take place when adequate soil moisture is available to allow the removal of the entire root system. Autumn olive is easily seen in the spring since it leafs out when most other native vegetation is still dormant.

Chemical Control

- Chemical control, through cut stump and foliar herbicide applications, is an effective method for controlling autumn olive. State licensed herbicide applicators can provide specific recommendations.

2.) European/Japanese Barberry

- *Berberis vulgaris/thunbergii* is a deciduous shrub that can reach 13 feet in height. Arching branches which come into contact with the soil can produce new plants.
- The leaves are oval, 0.75-2 inches long, 0.25-0.75 inches wide, serrate (European) or smooth (Japanese) and occur in clusters of 2-5. Each cluster of leaves is subtended by a short, three-branched spines (European) or 1-branched spines (Japanese)
- Flowering occurs in May to June, when small, yellow, less than 0.25 inches wide flowers develop in dangling racemes. The flowers have an unpleasant odor.
- Berries are red ellipsoids which are less than 0.3 inches in length and contain 1-3 small black seeds. The fruit is dispersed by birds and other wildlife.


Mechanical Control

- Barberry is easy to identify in spring because it is one of the first shrubs to leaf out. Using thick gloves, small plants can be pulled by hand, while larger plants should be dug up. Be sure to remove the entire root system and to bag and dispose of any plant material, including fallen fruits. Mowing or cutting is not advisable except to make removal easier. This plant is sensitive to fire; prescribed burns and weed torches are good options.

Chemical Control

- Systemic herbicides, such as glyphosate and triclopyr, are approved in managing barberry in many states. Herbicide can be applied as a basal bark or cut stump application. State licensed herbicide applicators can provide specific recommendations.

3.) Oriental Bittersweet

- Asiatic bittersweet is a deciduous, woody vine that climbs saplings and trees and can grow over 60 feet in length.
- The alternate, elliptical to circular leaves are light green in color and 2-5 inches long.
- Small, inconspicuous, axillary, greenish-white flowers bloom from May to early June. Oriental bittersweet closely resembles American bittersweet (*Celastrus scandens*). The main difference: *Celastrus scandens* has flowers and fruits at the terminal ends of branches; *Celastrus orbiculatus* has flowers scattered along the entire stem.
- The small globose fruits are green when young; ripen to yellow; then split to reveal showy, scarlet berries that persist into winter.


Mechanical Control

- Use extreme caution when hand pulling. Even tiny fragment of the root can resprout, quickly multiplying the problem. Hand pull entire plants, including all roots and runners. Place everything into a plastic bag for disposal. For large plants: Cut climbing or trailing vines close to root collar. Repeat every two weeks.

Chemical Control

- Foliar spray is often used for dense populations.
- While foliar spray or cut stump application can be used, some specialized concentrations are necessary for cut stump treatments. Consult state licensed herbicide applicators for specific recommendations.

4.) Common / Glossy Buckthorn

- Buckthorn is a deciduous shrub or small tree that can grow to 25 feet in height. The bark is dark gray and the inner bark is orange (easily seen when the tree is cut). Twigs are usually tipped with a sharp spine.
- The leaf arrangement is usually subopposite, but examples of opposite and/or alternate arrangements are commonly found. Leaves are dark green, oval, 1.5 to 3 inches long, slightly serrate with 3 to 4 pairs of curving veins and a somewhat folded tip.
- Flowering occurs in the spring, when yellow-green, 4-petaled flowers develop in clusters of 2 to 6 near the base of the petioles. Plants are dioecious (male and female flowers occur on separate plants).
- Fruits are small, black berries that are 0.25 inches in diameter.


Mechanical Control:

- Any time of year when the ground is soft, especially after a rain, hand pull small plants by the base of the stem. Be sure to pull up the entire root system. Hang from a branch to prevent re-rooting. For larger plants, use a wrenching tool. Continue to monitor the area every year for new seedlings.
- Cut plants back any time of year. Wrap a few layers of burlap or thick plastic over the stump and tie tightly with twine. You will need to check stumps periodically and cut back any new growth.

Chemical Control:

- Cut stump and [low volume] foliar spay herbicide options are available. State licensed herbicide applicators can provide specific recommendations.

5.) Japanese Knotweed

- Japanese knotweed is an upright, shrublike, herbaceous perennial that can grow to over 10 feet in height. As with all members of this family, the base of the stem above each joint is surrounded by a membranous sheath.
- Stems of Japanese knotweed are smooth, stout and swollen at joints where the leaf meets the stem. Although leaf size may vary, they are normally about 6 inches long by 3 to 4 inches wide, broadly oval to somewhat triangular and pointed at the tip.
- The minute greenish-white flowers occur in attractive, branched sprays in summer and are followed soon after by small winged fruits. Seeds are triangular, shiny, and very small, about 1/10 inch long.

Mechanical Control:

- Cut stalks at least once per month throughout the growing season. Use a scythe, loppers or another method of cutting, depending upon the ground surface you are working on, being careful not to spread fragments (which can resprout). Repeat cuts for five years. Do not replant until the knotweed is under control and the plants are much smaller and have lost their vigor. Replant with good sized natives.Check out this video to learn more about Japanese knotweed control

  Smothering is also an effective means of control. Check out this resource from NH Dept. of Agriculture, Markets & Food on BMPs for knotweed removal.

Chemical Control:

- Cut stalk applications are often used for small infestations.
- For larger infestations low-volume foliar sprays can be affective. State licensed herbicide applicators can provide specific recommendations.

6.) Multiflora Rose

- *Rosa multiflora* is a multistemmed, thorny, perennial shrub that grows up to 15 feet tall. The stems are green to red arching canes which are round in cross-section and have stiff, curved thorns.
- Leaves are pinnately compound with 7-9 leaflets. Leaflets are oblong, 1-1.5 inches long and have serrated edges. The fringed petioles of *Rosa multiflora* usually distinguish it from most other rose species.
- Small, white to pinkish, 5-petaled flowers occur abundantly in clusters on the plant in the spring.

- Fruit are small, red rose hips that remain on the plant throughout the winter. Birds and other wildlife eat the fruit and disperse the seeds.

Mechanical Control

- Young plants can be pulled by hand. Frequent, repeated cutting or mowing at the rate of three to six times per growing season, for two to four years, has been shown to be effective in achieving high mortality of multiflora rose. In high-quality natural communities, cutting of individual plants is preferred to site mowing to minimize habitat disturbance

Chemical Control

- Cut stump and low-volume foliar spays are both options. State licensed herbicide applicators can provide specific recommendations.

Module 3 – Forest Ecology and Silvics

Objectives

- Understand which tree species grow where and why
- Summarize forest disturbances and their influence on stand development
- Describe the basics of how trees grow
- Contrast basic silvicultural characteristics of trees
- Introduce the concept of forest stands
- Describe how forests develop over time
- Measure forest stocking to determine level of competition in forest stands

Introduction

Forests and the trees that comprise them are a defining characteristic of Earth's terrestrial ecosystems. They provide habitat and food for millions of species of bacteria, insects, birds, fish, and mammals, and they clean the air and produce a large portion of the Earth's oxygen. In addition, forests provide an essential resource for society: wood. Nevertheless, what exactly is a tree? How does it grow? How do forests form, and what factors influence the types of trees that compose these systems? Why are forests so different across the globe? How do they function and grow back after disturbance? These are all questions that can be answered through the study of **forest ecology**. The ecology of forest ecosystems varies across different regions, but there are key factors that influence all forests and are essential to understanding their development and function. This chapter will introduce you to those key factors and cover the basics of forest ecology through four parts: (1) Understanding the Forest Environment, (2) Basics of Tree Biology, (3) Tree Silvics, and (4) Forest Stands, Stand Dynamics & Stocking.

Understanding the Forest Environment

Physiography: What Grows Where & Why

Contrary to how it may seem, there are patterns to the distribution of tree species across the landscape. These patterns are driven largely by the basic physical characteristics, or ***physiography*** of the site. Such characteristics include climate, topography, geology, soils, and hydrology. In forestry, these attributes are often referred to as ***site factors*** and play key roles in how forest management plans are designed and implemented. In short, physiography and site factors essentially determine *what plants can grow where and why they can grow there*.

Climate

Climate is one of most important factors affecting the distribution and composition of forests around the globe. It is why there are lush, dense forests around the equator and sparse, desolate grasslands in the far north. Even across the U.S. there are large changes in climate that result in vastly different forest types, including mixed hardwoods in the Northeast, temperate rainforests dominated by Douglas-fir and Sitka spruce on the northwest Pacific coast, and fire-adapted lodgepole pine forests in the Rockies. These climatic variations are largely due to latitude, continental weather patterns, topography, and the presence of large bodies of water.

Vermont's climate is classified as "*humid continental*", meaning summers are typically warm and humid, while winters are cold and snowy. Although changing, our coldest winter months have tended to have average temperatures below 32°F, whereas are warmest summer months average above 72°F (Thompson & Sorenson, 2000). As with the rest of New England, Vermont's climate is relatively moist, allowing abundant vegetation, including forests, to flourish across the state. The favorability of Vermont's climate to supporting forests is reflected in the high proportion of the landscape currently covered by trees (~76%); an amount that was even greater at the time of European settlement in the region in the 17th and 18th centuries (>90%; Foster et al. 2010).

Topography

Aspect, or cardinal direction (North, East, South, West), affects how much direct sunlight a given site receives and, as such, has a large impact on what vegetation grows where and how well it grows and competes. South-facing slopes intercept almost all of the sun's direct energy during the day, and thus, are hot and dry. On the other hand, north-facing slopes receive most of their sunlight from light reflected off the atmosphere, producing cooler and wetter conditions. East and west-facing slopes get about the same amount of direct sunlight during the day, but by the time the sun moves into the western sky, the air temperature is usually already at its highest point of the day. As a result, west-facing slopes start getting direct sunlight when they are already warm, making them warmer and drier than east-facing slopes. Typically, the heat and moisture gradient goes as follows, from hottest and driest to coolest and wettest: south, west, east, and north.

There is a large variation in elevation across Vermont. Burlington sits in the Champlain Valley at a low elevation of 200 ft, whereas the highest peak in the state, Mt. Mansfield, rises to 4,393 feet above sea level. This variation in elevation has a large effect on forest composition throughout the state and is one of the key reasons why large oaks, maples, and pines fill valleys but only stunted Krumholtz and a few grasses and lichen can survive on summits of the highest mountains. The change in forest and vegetation conditions observed at different elevations largely reflects changes in average temperature and moisture with increasing altitude. As prevailing winds carry moist air up mountain slopes, that air expands and cools, dropping most of its moisture on the way as either rain, snow, sleet, or hail. Thus, higher elevations tend to receive more moisture and experience colder temperatures, which is why you can ski late into the spring at Stowe and Killington when the snow has long disappeared from the Champlain Valley. In Vermont, every rise in 1000 ft of elevation results in an average drop in temperature of 3.5°F under normal weather conditions, with high winds and atmospheric moisture conditions making those temperature differences even larger. Trees, as with all vegetation, are largely adapted to the conditions that allow them to grow the best, so many of the changes you observe in forest composition along elevation gradients reflect different species adaptations to temperature and moisture regimes.

Slope is another aspect of topography that greatly influences vegetative composition on a site through its influence on determining the depth of soils. Deeper soils are able to retain more moisture and nutrients, so, typically, deeper soils support larger trees at higher densities. On steep slopes, sediments are pulled downslope by gravity and precipitation resulting in shallow soil conditions in these areas. Sediments from upslope areas are often transported to flatter downslope areas, such as toe slopes, resulting in the buildup of deep, nutrient-rich soils in these locations. As such, forest soils located higher on a slope tend to be shallower and nutrient poor, while soils downslope tend to be deeper and more fertile.

Geology

Vermont has a complex geologic history that includes continental movement, volcanic activity, and the construction and destruction of mountains. For most of its geologic history, Vermont sat on the edge of the continent, which led to large deposits of oceanic sediments, forming sedimentary rocks that makeup much of Vermont's current bedrock. As the continental plates moved, Vermont shifted inland and great mountains and valleys were born. In this process, much of the state's sedimentary rocks were battered by intense heat and pressure, melting, twisting, and reforming into new rocks—a process called ***metamorphism***. These metamorphosed sedimentary rocks are now called *metasedimentary*, many of which can be found in the Green Mountains. In eastern Vermont, volcanic activity has produced different bedrock, primarily granite, some of which has also been exposed to metamorphism.

Bedrock composition has a key influence on forest composition given it strongly affects the levels of nutrients found on a given site. Vermont contains large areas of carbonate rich rocks, like limestone and dolomite, which weather and erode easily, providing abundant sources of calcium, magnesium, and other nutrients vital to plant growth. These sites often support rich northern hardwood forests dominated by sugar maple and other rich site species, like blue cohosh, wild leek, and maidenhair fern. On the other hand, non-carbonate rich rocks, such as granite and gneiss, resist erosion, creating more nutrient poor conditions, and tend to produce more acidic soils. On these sites, species that can tolerate lower nutrient conditions, such as American beech, are often quite competitive.

As described above, localized differences in slope can influence soil properties for supporting tree growth, so bedrock should be considered alongside ***parent material*** (partially-eroded bedrock and glacial deposits) and soils (see next section) when assessing site quality for timber production and forest operations.

There are state specific resources that can provide more natural heritage information such as natural community types, indicator species and more.
(https://vtfishandwildlife.com/conserve/conservation-planning/natural-heritage-inventory)

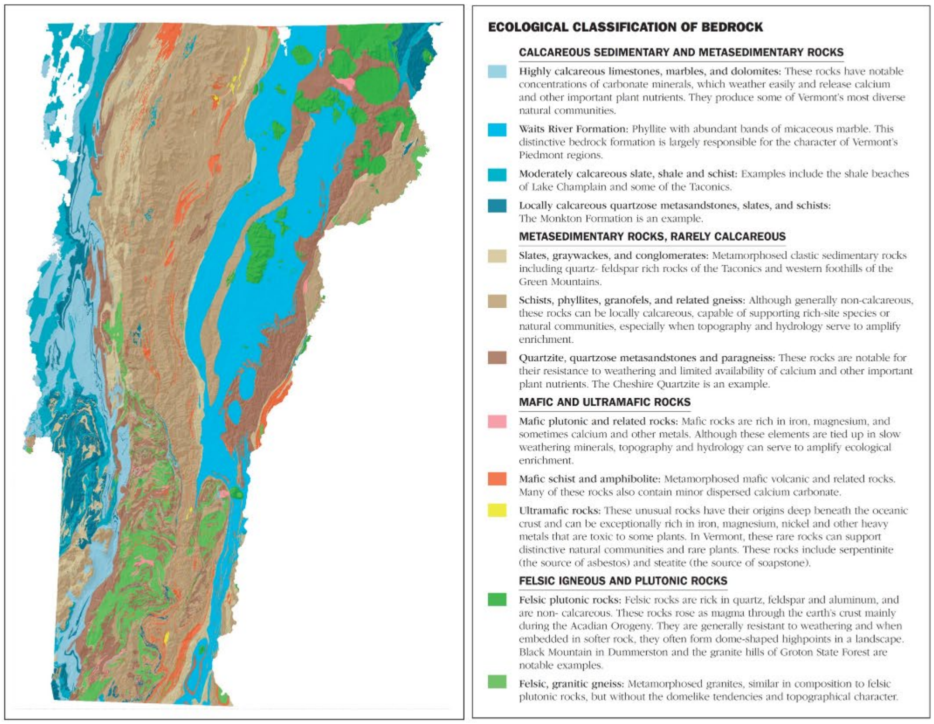


Figure 1: Map of Vermont's bedrock geology grouped into major classes and descriptions of those ecological classifications. From Thompson et al. (2019)

Soils

Soils represent the foundation of a forest and play a key part in determining what can grow there and whether it will merely survive or thrive. Soil lies at the interface between the ***lithosphere*** (Earth's crust), ***atmosphere*** (air), ***hydrosphere*** (water), and ***biosphere*** (organic life). As the intersection between these major Earth components, soils play four major roles in forest ecosystems. First, they serve as the key medium for plant growth, supplying water and air, delivering nutrients essential for growth, and acting as a critical medium for anchoring and supporting tree stems. Second, soils play a major role in the regulation water quantity and quality through storage and filtration. Third, soils, aid in the recycling of organic matter and serve as a main component in nutrient storage and cycling. Last, soils provide key habitat for soil organisms like insects, bacteria, and fungi, who themselves help soils perform their essential ecosystem roles.

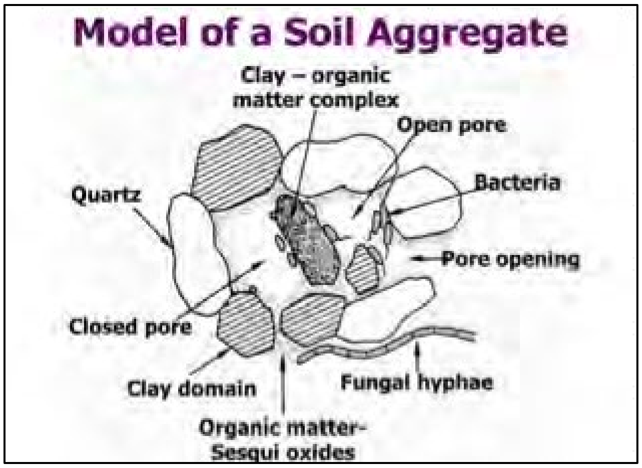


Figure 2: Diagram of soil colloid

Soils are comprised of 4 main parts: mineral solids (eroded from bedrock and parent material), air, water, and organic matter. Over time, these components combine to form soil aggregates called ***colloids***, which create a blocky matrix within the soil. Within the matrix, gaps between colloids allow for water filtration, oxygen exchange, and root penetration. The colloids themselves retain water and hold onto important ***macronutrients*** such as nitrogen, phosphorus, potassium, sulfur, and calcium, as well as ***micronutrients*** including boron, zinc, manganese, iron, copper, chloride, and manganese.

Soil chemistry can be quite complex, but for the purposes of this guide, we will only dive into soil *pH*. The pH (acidity or alkalinity) of a soil affects both the properties of the soil itself and the plants growing in it by affecting nutrient availability. For example, Northern white-cedar (*Thuja* occidentalis) and sugar maple (*Acer saccharum*) both thrive on more alkaline soils (higher pH), which is reflected in northern white cedar dominating limestone cliffs and sugar maple representing a large component of forests growing on deeper, limestone-derived soils. In contrast, species like black spruce (*Picea mariana*) are quite tolerant of acidic (low pH) conditions resulting in their dominance in peatlands, as well as high mountain peaks.

In contrast to agricultural settings, foresters rarely apply fertilizers or other amendments to change soil chemistry in Vermont; however, there are still aspects of forest management that can have a large impact on soil properties. In particular, given the size and weight of machinery used for forest operations (e.g. harvesting, skidding, trucking, etc.), there is the potential for soil damage during harvests, particularly through ***compaction*** by machinery like skidders, tractors, and forwarders. Soil compaction occurs when pressure and vibration is applied to a soil surface, which results in compression of soil air spaces (i.e. “macropores”). Beyond reducing plant growth, compacted soils also have lower levels of water infiltration, which can lead to more surface water runoff and erosion, and a loss of long-term soil productivity (Figure 4). As a result, forest operations need to account for local soil conditions with harvest planning following acceptable management practices (AMPs) for protecting water quality. These guidelines not only protect soil quality, but are also designed to minimize impacts to important hydrologic features, such as streams, seeps, vernal pools, and other forested wetlands.

Figure 3: Rutting and soil compaction on skid trail resulting from forest harvest that occurred under wet, unfrozen ground conditions.

Site classification

No two forests are the same; however, there are shared characteristics associated with soil conditions and vegetation that can be used to classify sites into like units. Many ways exist for classifying sites, with two traditional systems being ***Site Index***, which is related to the productivity of the site in relation to the growth of commercial tree species, and ***Forest Cover Type***, which breaks the landscape down into units based on the most common tree species found there. These methods of classification are useful; however, they are often based solely on the tree species currently present and may not provide insights to other potential species to manage for or patterns of succession and regeneration expected for the site. As an alternative, ***Ecological Classification Systems*** (ECS) classify sites according to canopy and understory vegetation and soil moisture and fertility. In Vermont, unique units are called ***Natural Communities***, whereas other regions use the terms habitat types or native plant communities for these classifications. These units are defined based on what one might expect to exist on a given site if only natural processes predominated and hence are a good representation of the potential range of species one could manage for (Thompson et al., 2019). As such, this level of classification is what foresters will often use to help them determine appropriate silvicultural treatments for a forest parcel and require a working knowledge of understory plant species that are good indicators of site conditions (Figure 5).

Figure 4: Understory plants indicative of rich northern hardwood forest natural communities in Vermont, including blue cohosh, plantain-leaved sedge, and toothwort.

Disturbance: Agents of Change

Beyond the site factors mentioned above, ***disturbances,*** like windstorms or fires, are key to forest development and function and occur on a wide variety of scales. These discrete events can generate both immediate and long-term changes in the characteristics of forest ecosystems, including the species present and size and distribution of structures, like living and dead trees. A long history of natural and human-generated disturbances have created the variation we see in Vermont's forests today and are crucial to maintaining a range of habitat conditions for supporting biodiversity.

Natural Disturbances

Disturbances, like insect outbreaks, microbursts, and ice storms, are referred to as natural disturbances given they occur without human action. These and human-made or anthropogenic disturbances are central to forest development given they drive ***succession***, the process of change in species composition in a community over time. Decades of research and careful observation have revealed that certain disturbances are likely to result in specific patterns of succession and hence forests of varying composition and structure over time and across the landscape (Figure 6). For example, stand-replacing disturbances, such as fire or clear-cut harvesting are likely to favor development of even-aged communities composed of light-demanding, early successional species, such as pin cherry, paper birch, and aspen. In contrast, partial disturbances, like windthrow or root disease, are likely to favor the development of multi-aged forest conditions with a large component of late-successional species, such as sugar maple, eastern hemlock, or American beech. The species that dominates an area following disturbance is determined based on both the availability of propagules (e.g., seeds) and the amount of area disturbed, as certain species, particularly pioneering tree species, are more effective at colonizing and dominating large disturbed patches for the first several decades following a disturbance event.

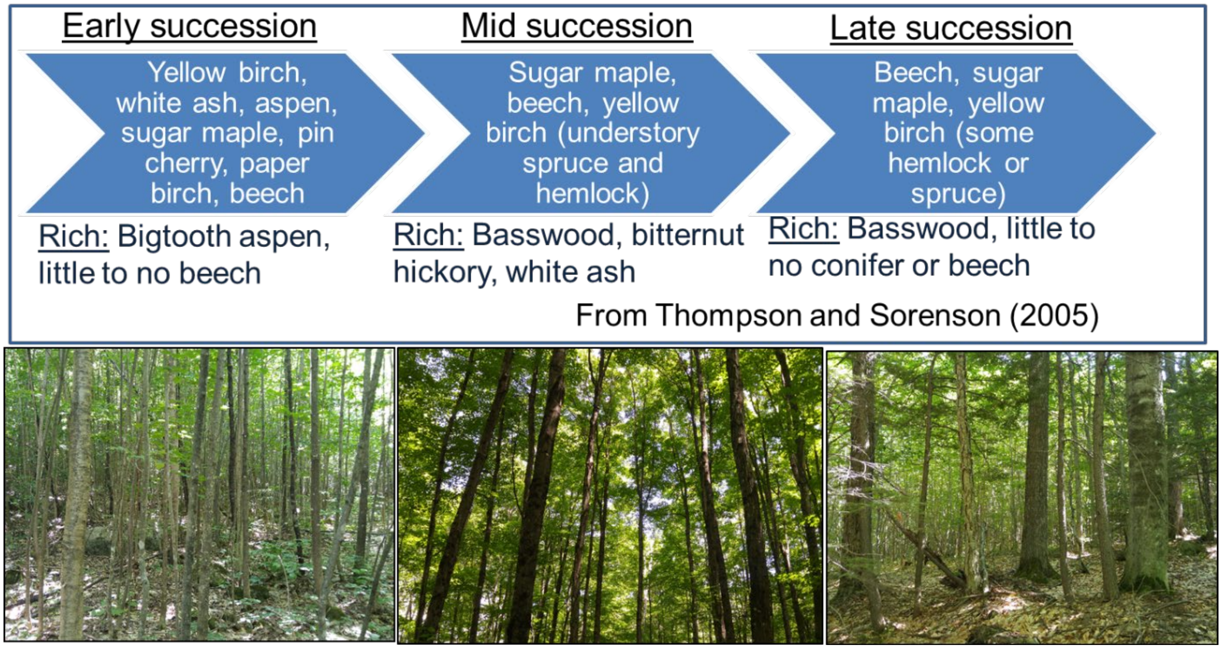


Figure 5: Patterns of succession for northern hardwood forests following stand-replacing disturbance. Blue arrows correspond to patterns observed for sites classified as northern hardwood forests (unenriched), with differences noted for patterns documented for rich sites noted below each arrow.

Anthropogenic disturbances, invasive species, and climate change

In addition to ***natural*** disturbances, those associated with human activities, like agricultural clearing and forest harvesting, have greatly influenced forest composition and health around the globe, including in Vermont. Indigenous peoples in the region influenced patterns of vegetation prior to European settlement through the use of prescribed fire and other practices to maintain open woodlands and fields, particularly in Vermont's fertile valleys and ridgetops. The most profound changes to Vermont's forests began with European settlement in the 1700s and subsequent clearing of large areas of forest for agriculture and timber. By the mid-1800s, more than 75% of the land in Vermont had been cleared and converted to agriculture, mostly for pasture to support sheep for wool production. As settlers moved to the more fertile soils found in the Ohio Valley and other regions of the Midwest, these lands were abandoned and ultimately succeeded back to forests. Today, forests dominate Vermont; however, these forests are far different than those found across the landscape at the time of European settlement. In particular, this period of intensive, historic land use has led to the development of relatively homogenous conditions in terms of age structure and composition, with many areas now containing 70-100 year-old forests with a much higher abundance of maple species than historically documented (Ducey et al. 2013; Thompson et al. 2013).

Beyond the disturbances associated with human land use, one of the biggest human-generated issues facing forests and entire ecosystems across the globe is the spread of ***non-native species*** to new landscapes. These include plant, pathogen, and insect species either deliberately or inadvertently introduced to the region from their native ranges. An early, devastating example was the Chestnut Blight, which is a parasitic fungus introduced to American forests through Japanese chestnut trees brought over from Asia as ornamental trees. Following its introduction, chestnut blight led to the extirpation of American chestnut trees from essentially the entire U.S, causing dramatic changes to hardwood forests, including those found in the Champlain and Connecticut River Valleys of Vermont.

Today, Vermont and New England forests are facing several different ***invasive*** forest pests and diseases. *Beech bark disease*, native to Asia, is resulting in reduction of large overstory American beech and proliferation of beech-dominated understories, which pose a significant management challenge (Figure 7). *Asian longhorn beetle* (ALB) threatens hardwoods throughout the region and are of particular threat to the Vermont maple sugaring industry. *Emerald ash borer* (EAB) has only recently spread to Vermont, but it has already killed tens of *millions* of ash trees around the Great Lakes and throughout central Appalachia. And *hemlock woolly adelgid* (HWA) poses a significant threat to eastern hemlocks which although not an important timber species, are extremely important for many species of wildlife including deer, squirrels, rabbits and hares, rodents, wild turkey and ruffed grouse, and many species of songbirds and raptors.

Figure 6: Beech thicket resulting from beech bark disease impacts in the White Mountains of New Hampshire.

Invasive plants also pose significant threats to Vermont's forests because they often out-compete native species, especially in the case of invasive weeds, which may proliferate after a disturbance. These invasive species can also form dense cover and prevent native plant species from persisting on a site. Examples of invasive plant species impacting Vermont's forests include European buckthorn, garlic mustard, Asiatic bittersweet, and Japanese honeysuckle. All of these can present significant management challenges on a site, so learning to identify these plants is critical to guiding management strategies and minimizing further spread (see Appendix for common invasive plants in Vermont)

One of the biggest issues facing forests today and into the future is ***climate change***. By 2100, Vermont is expected to be significantly warmer year-round with wetter winters, shorter springs and falls, drier summers, and more frequent and severe natural disturbances. These changes are predicted to have substantial effects on Vermont's forests including wide changes in forest canopy composition, increased over-winter survival of forest pests and diseases, more vegetation stress, and increased over-winter survival rates of forest pests and diseases. Thankfully, New England is rich in biodiversity and with this diversity comes resilience. However, this diversity also makes management in the face of climate change significantly more difficult. Management strategies to increase resilience and strength that may be appropriate in a valley bottom will most likely be inappropriate in an alpine forest. Thus, it is important to fully understand the physical, biological, and chemical characteristics of a site to best help it survive and adapt to a changing climate. See Tables 1 & 2 in the Appendix for an in-depth list of expected changes in Vermont's climate through the end of the century and the projected effects from those changes.

Basics of Tree Biology

Parts of a Tree

Trees are complex organisms comprised of several major systems, roots, stems, and leaves, that work together to support survival and growth. Roots typically make up 20-30% of a tree's total biomass (about the same amount as its twigs and branches). Roots serve three main functions – they gather water and nutrients from the soil, pump water and nutrients up to leaves in the canopy, and anchor the tree in soil and provide stability in the face of wind, gravity, and other mechanical stresses. Much of a tree's roots system is concentrated in the first few feet of soil and may spread out over an area equal to or greater than the tree's height. The extent to which a tree's root system extends is a function of its environment. For example, a tree growing on a dry and/or nutrient poor site will typically have more extensive and/or deeper roots, whereas a tree growing on a wet and/or nutrient rich site will have fewer and/or more shallow roots.

There are four main kinds of roots – taproots, anchor roots, transport roots, and feeder roots. When a seed germinates, it sends out a single ***taproot*** – as the tree develops, the taproot grows further into the soil, increases in diameter, and branches out into several large, hardened ***anchor roots*** that mainly help to anchor and stabilize the tree. These anchor roots then expand farther from the central taproot and become thinner and more delicate. These medium-sized roots may collect some water and nutrients from the surrounding soil, but they mostly help to transport fluid and materials to the rest of the tree, thus the name ***transport roots***. At the end of a tree's root system are small, fine roots called ***feeder roots***. These roots are the primary water and nutrient absorbers of the tree and are continuously dying and being replaced.

Feeder roots collect water and nutrients through a combination of root 'hairs' and a symbiotic relationship with soil fungi called ***mycorrhizae***. Fungal hyphae (root-like structures) are much finer and often extend far further into soil, and they are much more efficient at both nutrient and water absorption. In this relationship, the tree gets water and nutrients from the fungus, and the fungus gets carbohydrates (sugars) from the tree, which it often produces in excess. Trees not only utilize these fungi for their own needs, but they also use the fungal 'networks' in the soil to communicate with each other and share resources.

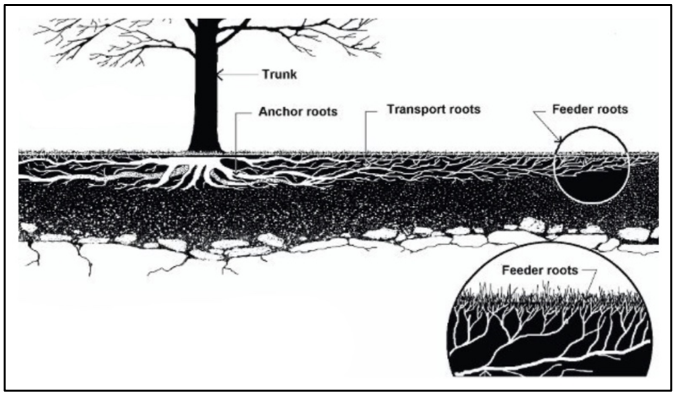
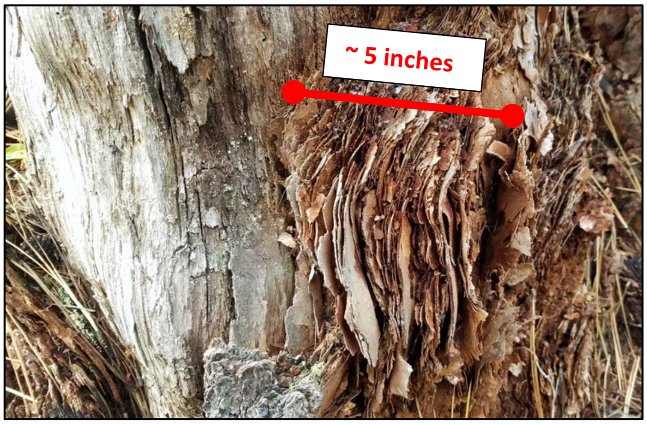


Figure 7: Diagram of tree root system. *Figure 8:* Conifer seedling's roots interacting with soil mycorrhizae.

A tree's ***trunk*** (or stem) serves three main purposes: it positions leaves in the upper canopy where more light is available, provides support and strength, and provides conductive tissue between the roots and leaves to allow for nutrient and water transport between these two locations. The trunk is where most of a tree's merchantable timber and timber products are produced in the form of ***wood***. Not all wood is created equal – there are 5 specific layers of wood that comprise a tree's trunk. The innermost material is the ***heartwood*** and is entirely comprised of dead, hollow cells and waste products of earlier growth. These cells perform no function other than adding structural support to the tree. The next layer of material is the ***sapwood*** – this layer of the tree transports water and dissolved minerals (i.e. sap) between roots and the canopy. As a tree grows and ages, the oldest sapwood dies and becomes heartwood. Together, the heartwood and sapwood comprise most of a tree trunk's volume. The next layer in a tree trunk is the ***cambium***. The cambium layer is thin compared to sapwood and heartwood, but it is where all of the trunk's growth occurs. Inward growth produces sapwood, while outward growth produces phloem and cork. Outside the cambium lies the ***inner bark***, which is comprised of phloem and serves to transport dissolved nutrients absorbed by a tree's roots up to its canopy. Phloem cells do not live long and when they die they turn into cork and become part of the outer bark. The outermost layer of the tree is the ***outer bark*** – this layer serves to protect the inner layers of growing tissue. Bark insulates against extreme cold and heat, keeps out extra moisture in wet conditions and prevents moisture loss in dry conditions, and acts as a barrier against insects, animals, fire, flood, and ice (Figure 10 and Figure 11).



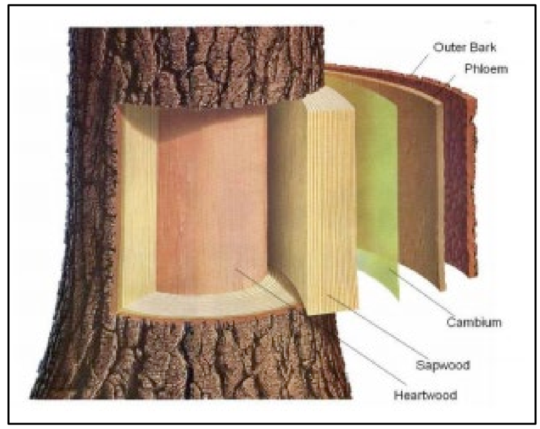


Figure 9: Thickness of ponderosa pine bark on a decaying *Stump. Flathead National Forest, Montana, U.S.A. (2019). Photo by Annie Vance.*

Figure 10: Diagram of wood layers.

The last major system of a tree is the ***crown***. The crown contains all of a tree's photosynthetic tissue and is comprised of branches and twigs, leaves, and reproductive tissues (cones, flowers, and fruits). ***Conifers*** crowns are composed of many needle-like leaves that are only capable of a small amount of photosynthesis each. These species hold onto their leaves year-round allowing for photosynthetic activity whenever conditions are favorable for growth. Retention of this foliage year round makes conifers susceptible to snow and ice loading in the winter, but many conifer species have conical growth forms to reduce the damage caused by these conditions and encourage sloughing-off of precipitation. In contrast, ***deciduous trees*** produce a much smaller amount of larger "*broadleaves"* that are highly efficient and can produce a year's worth of energy in just a few months from late spring to early fall. Most deciduous trees have large, wide, dense crows that expand far outward from the central trunk. As such, these crown forms can be more susceptible to snow and ice loading; however, the abscission and dropping of leaves in the fall not only conserves energy, but also reduces vulnerability to these snow and ice loading events.

Leaves are the powerhouse of the tree – they engage in photosynthesis and use light, water, and carbon dioxide to produce energy in the form of sugars and oxygen (largely as a byproduct). Trees use this energy in combination with minerals and nutrients absorbed by roots to produce growth in *diameter* in the cambium and in *height* in the *apical meristem*. They also use this energy to maintain defenses against harsh weather, insects, and animals, replace lost leaves due to herbivory and high winds, produce next year's buds, and reproduce through sexual and/or asexual means.

All trees produce ***seeds*** and are either ***monoecious***, meaning every tree has both male and female reproductive parts (ex: paper birch and Eastern white pine), or they are ***dioicous***, meaning each tree can only have male flowers or female reproductive parts (ex: white ash and Eastern red cedar). While all species of trees produce seeds through ***sexual reproduction***, the means by which they do so varies between *Gymnosperms* and *Angiosperms*.

Coniferous trees, including pines, spruces, firs, cedars, hemlocks, and many more, were the first 'trees' and are part of the family of plants called ***Gymnosperms***. Gymnosperms do not produce flowers – instead they produce pollen cones (male) toward the base of the tree and seed cones (female) toward the crown. Gymnosperms typically rely on wind for pollination, as updrafts of wind will carry pollen upwards from the base to the female cones in the crown, but they also utilize some insects such as beetles for pollination. Once fertilized, a seed cone will harden into a woody structure (a pinecone) that houses many seeds. These seeds are not protected from the elements or herbivory and are exposed to the air, from which the term Gymnosperms is derived – "Gymnosperm" comes from the Greek words "*gymnos"* and "*sperma,*" which together mean "naked seed." Because these seeds are not protected from the environment, conifers tend to produce large volumes of seeds each year to increase their chances of successful reproduction.

Deciduous trees, including maples, oaks, ashes, hickories, walnuts, and many more, evolved later than their coniferous counterparts and are members of the **Angiosperm** group. Angiosperms are different from Gymnosperms in that they produce *flowers* and *fruits.* When a female flower is fertilized, it will produce a ***fruit*** with either one seed or several seeds encased in an ***ovary***. This ovary often takes the form of a fleshy fruit (ex: apples and walnuts) but can take other forms such as the hard shells that encase nuts (ex: acorns), small, hard skins that extend into wings (ex: maple and ash samaras), and long semi-hard pods (ex: black locust bean pods). The volume of seeds produced varies widely amongst angiosperms and often correlates to the size of the seed and ovary. For example, maples can produce tens of thousands of small, winged seeds in a year, whereas walnut trees will produce significantly less seeds, but the seeds are much larger and are encased in a hard shell within a fleshy fruit.

The Life Cycle of a Tree

Once a seed germinates and begins to grow, this developing tree is called a ***seedling***. In northern forests, we classify seedlings as individuals less than 1 inch in diameter and less than 4.5 feet tall. At this developmental stage, trees are not firmly established on a site and mortality is often quite high from many causes, including lack of moisture and sunlight, and browse by wildlife. When a tree reaches 4.5 feet tall, it is considered a ***sapling***. Saplings are better established than seedlings but still are not big enough to make into a wood product. As such, saplings are generally defined as trees over 4.5' tall, but still under 4 to 5" in diameter.

Once a tree grows to greater than 4-5 inches in diameter, it is considered a ***pole***. Poles are big enough to use for some wood products (like fence posts and pulp), but are not big enough to run through a sawmill. ***Mature*** trees are those whose dbh is greater than 10 inches. The term mature refers to the ability to be milled with a typical sawmill and produce merchantable lumber. Mature trees are classed as either **sawtimber** or **veneer**, the latter reserved for the largest, highest quality stems. At this stage, trees start investing substantial amounts of energy and nutrients in reproduction and less energy is allocated to continued growth. When trees near their ultimate height and girth, they begin to succumb to the accumulated stress of centuries of growth in the forest. At this stage, a tree is considered ***over-mature***, although that is purely from an economic perspective. These trees often have heart-rot and other traits that are undesirable for wood products and have lost most of their financial value, but they are still very much alive and have significant ecological value for habitat and carbon storage (Figure 12).

If a tree dies standing, it becomes a ***snag***. These trees have no financial value and do not photosynthesize, but they provide valuable habitat for a wide variety of wildlife, especially birds and small mammals. Fallen trees, whether they fell when alive or after death, are called **logs**. On the ground, large stems are considered ***downed woody material (DWM)***, and smaller limbs and branches are called ***fine woody debris (FWM)***. DWM and FWM are key components of ecosystems as they help return nutrients to the soil, help retain moisture in dry conditions, store carbon, and serve as habitat for many wildlife. They also often serve as a great medium for tree seedling growth– when seedlings take root on a log, that log is called a ***nurse log***.

Figure 11: Large sugar maple that would classified as “over mature” by economic standards, but that represents many important ecological functions as a source of habitat for cavity-nesting species, as well as a future large deadwood input, such as the log on the right.

Tree Silvics

All tree species have different growth characteristics, habitat preferences, and environmental tolerances that affect how the species behaves and performs, especially amongst other trees. In forestry, these traits are called *silvical characteristics*, or ***silvics*** for short. There are dozens of silvical characteristics that we can use to identify and categorize trees, but we mainly focus on a few key traits including preferred habitat, shade tolerance, means of reproduction, and successional status.

As we discussed in Part 1, environmental factors, both abiotic and biotic, have significant impacts on tree species distribution and how well they grow on a site. While there are many aspects of the environment that affect trees, we tend to focus on a few key ones, including aspect and elevation, soil structure and composition, moisture needs and tolerances, and nutrient requirements. Together, these traits form a brief, yet comprehensive description of ***habitat preferences*** of a certain tree species.

Shade tolerance is the most important silvical characteristics to learn for tree species given it is related to many other traits and is one factor we can manage for (i.e., how much light a tree gets). This characteristic refers to the level of shade a tree species can tolerate before growth and/or reproduction is affected. We typically break shade tolerance down into three groups: *tolerant, intermediate,* and *intolerant* (Figure 13: Shade tolerance rankings of common tree species in Vermont. Diagram from McEvoy (2014)). This characteristic is generally similar across the entire range of a species, but it can vary from site to site and tolerances do tend to vary over the course of a tree’s life. For example, red spruce (*Picea rubens*) is highly shade tolerant as a seedling and too much light can lead to seedling mortality. However, as red spruce grow and reach seedling-pole status, they need full sunlight to reach their maximum growth potential. Shade-tolerant species, like red spruce, often rely on advance regeneration as a general reproductive strategy given their ability to establish and persist in the shade prior to the removal of overstory trees by a disturbance. In contrast, intolerant species, like paper birch, are often strong colonizers of recently disturbed sites given their ability to disperse seeds to these areas and rapid growth under full sunlight conditions.

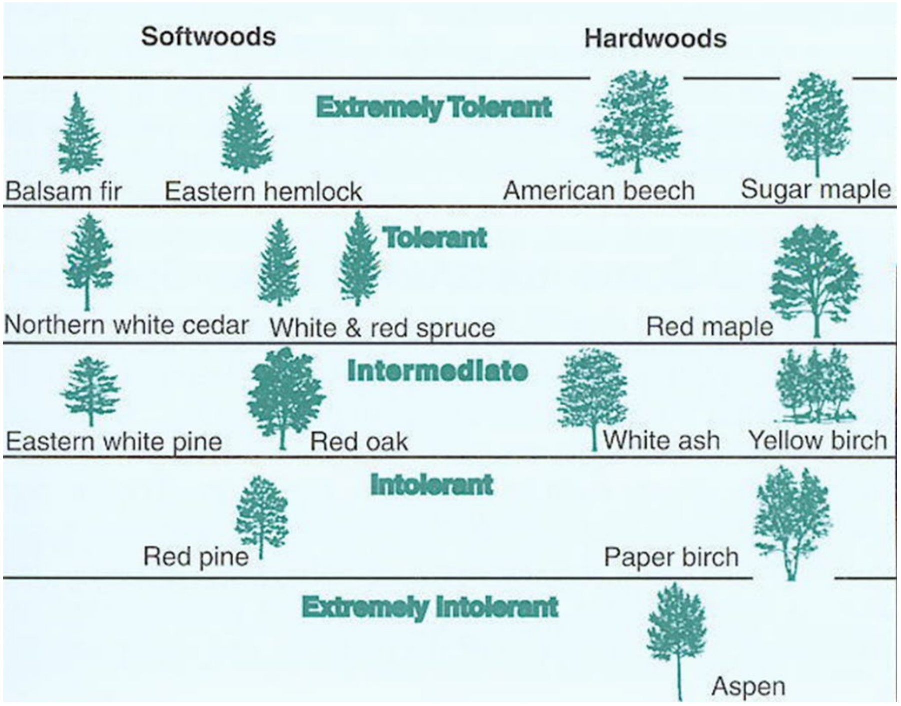


Figure 12: Shade tolerance rankings of common tree species in Vermont. Diagram from McEvoy (2014)

Most tree species have several means of reproduction to ensure that if one method fails, there is still a chance to pass their genes onto the next generation. In order to maximize genetic diversity (which maximizes species persistence in adverse conditions), many tree species prioritize ***sexual reproduction***, which was covered in the previous section. Many species also have the potential for ***asexual reproduction***, also called **vegetative reproduction**, often in times of stress. Trees typically can reproduce asexually at a younger age than they can sexually, and individuals developing from vegetative reproduction often develop more rapidly. As such, it is an excellent adaption for persisting on a given site, particularly when disturbances prevent trees from reaching sexual maturity. The two most common methods of asexual reproduction are ***stump sprouting*** and ***root suckering*** **(sprouts originating from the root system)**. Common species in Vermont that often reproduce via asexual reproduction include American beech (root suckers), red maple (stump sprouts), red oak (stump sprouts), and aspen (root suckers).

Successional status refers to the point in a forest's development after disturbance (***succession***) at which a tree species will most likely establish and predominate. This characteristic is closely linked to shade tolerance and preferred means of reproduction with more tolerant species occurring later in succession relative to intolerant ones (see Figure 6above). We typically classify successional status into three categories: early-successional, mid-successional, and late-successional. These categories also tend to correlate with the average lifespan of a tree species, with early-successional species, like paper birch, tending to live not much longer than 100 years, and late successional species, like eastern hemlock or sugar maple, often living in excess of 300 years.

Together, preferred habitat, shade tolerance, means of reproduction, and successional status form a basic, yet very useful profile of a tree species and help foresters and conservationists determine how best to manage a parcel of land for a desired mix of species. To find in-depth silvicultural information about any tree species found in the U.S., look to *Silvics of North America, Vol. 1&2,* published by the U.S. Forest Service. These references are the culmination of decades of research and observations and are an invaluable resource for making informed decisions regarding what species to manage for on a given site.

Forest Stands, Stand Dynamics, & Stocking

In forestry, we base many of our management decisions upon analysis and understanding of forest **stands**. The definition of a "stand" can vary between fields of study and situations, but it typically refers to a "spatial area where a group of trees is more or less homogenous in regard to species composition, density, and age-class distribution (Ashton & Kelty, 2018)." Stands are typically categorized by their age structure or the number of ***cohorts*** – a group of trees originating or released by a disturbance, commonly composed of trees of similar age. Studying how stands and tree cohorts grow and change over time (***stand dynamics***) enables us to predict what kind of regeneration will follow certain disturbances and what patterns of development should be anticipated as the stand ages. We can then use these predictions and patterns of development to determine what kind of silvicultural treatments to use on a specific forest parcel in order to meet our needs and goals, be it timber production, wildlife habitat, or ecosystem restoration.

Stand Development

As a cohort of trees establishes after a disturbance, it proceeds through a sequence of four main developmental stages (Figure 14: Forest stand developmental stages following disturbance. Letters and textures correspond to different species. Diagram from Oliver and Larson (1996).). The first stage of stand development is called ***stand initiation***; this stage is often dominated by early-successional, shade intolerant species like quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and pin cherry. This stage proceeds until a site is fully occupied by trees. Once fully occupied, new regeneration is prevented from establishing due to lack of space and established trees will start to compete for water, light, and nutrients. This stage is called ***stem exclusion***, as new recruits are excluded and competition ultimately results in weaker, suppressed trees dying off and stronger trees surviving. Many stand tending treatments are applied during this stage to anticipate mortality and concentrate resources on better-formed and higher value individuals. As this cohort of early-successional trees mature and begin to die off, new gaps open in the forest canopy providing opportunities for the next cohort to establish in the understory. This stage is called ***understory reinitiation***; in this stage you will begin to see a greater abundance of shade-tolerant species establishing in the understory. As gap-scale disturbances continue to recruit and release these species, much of the original cohort is ultimately replaced and the forest has now entered what is referred to as the ***old growth*** stage. This classification is related to degree of development a forest stand has experienced and is not to be confused with the use of old growth to describe forests that have developed in the absence of human disturbance. Although the latter condition was the predominant forest condition prior to European settlement, this is now quite rare in the region. The species often dominating the old-growth stage of development are sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga canadensis*).

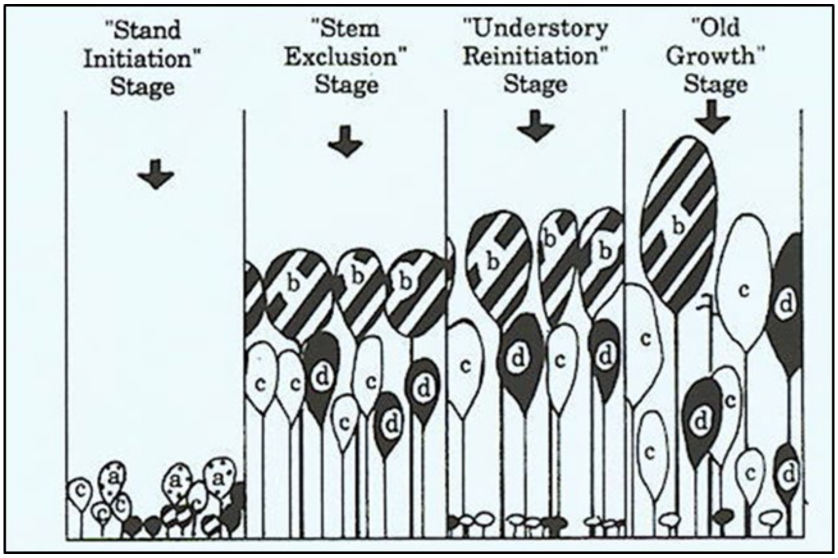


Figure 13: Forest stand developmental stages following disturbance. Letters and textures correspond to different species. Diagram from Oliver and Larson (1996).

Stand Types

When we describe the ***structure*** of a forest stand, we are typically referring to the horizontal and vertical distribution of key components of the forest including tree height and diameter, number of crown layers, and densities of living trees, shrubs, herbs, and dead woody material. When determining what type of stand you are working with, we tend to focus on the distribution of heights and diameters of trees and use those to infer the age structure of the forest. There are three main classes of stand types recognized based on age structure: even-aged, two-aged, and uneven-aged.

Even-aged stands are comprised of only *one* cohort with a narrow range of tree ages that does not exceed 20% of the rotation length. These stands typically form as a result of large, forest-scale disturbances (intense windstorms, clear-cut harvesting, agricultural abandonment.) and have a normal, bell-shaped diameter distribution. Many times, a disturbed site will be colonized by only one or a few species of trees sharing the same silvical characteristics. Nonetheless, in our mixed forests, sites can also be colonized with a variety of tree species, and as they grow and compete, distinct canopy strata will begin to form due to different growth rates of the tree species. In these stands, referred to as a ***stratified even-aged*** stands, there may be the appearance of several different cohorts, but these populations are actually all in the same cohort (Figure 15**:** Diagrams of stand types and their diameter distributions. From Smith et al. (1997).).

Two-aged (double-cohort) stands are created when a new cohort establishes underneath the canopy of an older cohort that is partially or nearly entirely eliminated. These typically result from wildfires or intense storms that severely damage an existing forest stand. The diameter distribution for this stand will look very similar to an even-aged distribution with a normal, bell shaped curve representing the new cohort, with a few larger individuals remaining from the previous cohort.

Uneven-aged stands are typically the result of smaller gap-scale disturbances (windthrow, ice storms, insects and disease) that allow for the recruitment of *multiple* cohorts over time. There are two main types of uneven-aged stands: balanced and irregular. In a ***balanced*** uneven-aged stand, each cohort of trees occupies approximately the same amount of area. This type of stand will typically have a reverse-J shaped diameter distribution curve. An ***irregular*** uneven-aged stand has large differences in age between tree cohorts and will produce a diameter distribution with distinct humps for each cohort.

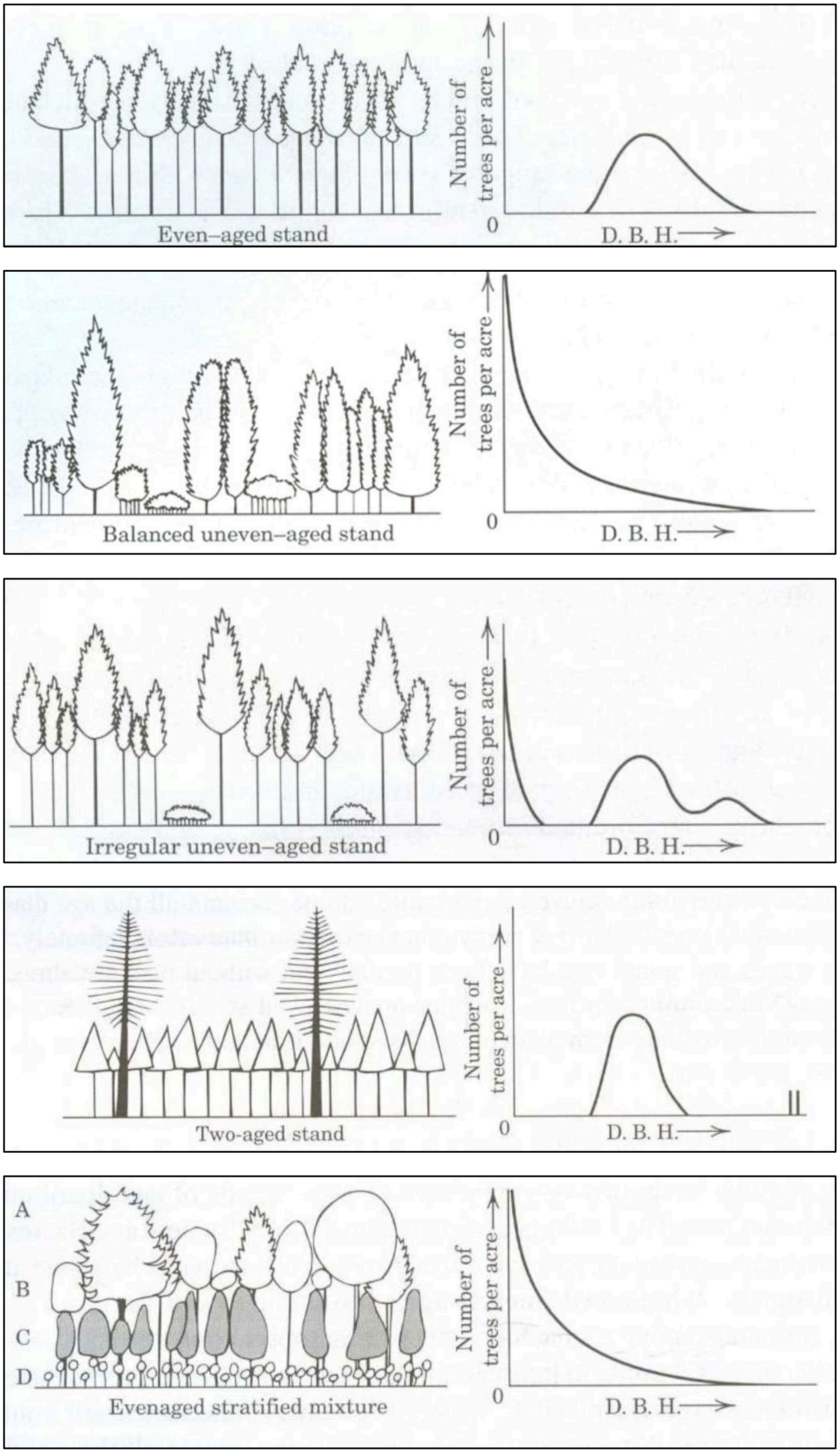


Figure 14: Diagrams of stand types and their diameter distributions. From Smith et al. (1997).

Forest Stocking & Stocking Charts

Competition for resources between trees is a critical process throughout forest development affecting tree growth and mortality rates. Of particular interest when managing forests for wood products is minimizing the amount of self-thinning that occurs. ***Self-thinning*** is mortality that occurs due to resource competition in dense forest stands. This reflects the increasing level of resources and growing space trees require as they grow larger, which is why densities decline as forests age. Self-thinning is a natural process in forests; however, it can take very prolonged periods of time. To meet timber production objectives, we purposely thin forests to speed up this process and encourage trees to reach larger sizes more quickly than they naturally would. In order to know how much we should thin a forest and when we should do it, many foresters utilize *stocking charts*.

Forest ***stocking*** is a *relative* measure of the number of trees in a stand compared to the *desirable* number that will produce the best tree and forest-level growth. Stocking charts are based upon decades of research on how much growth and timber yield to expect at various stocking levels for a particular species (Figure 16: Stocking chart for even-aged northern hardwood forests. The quality line is the density necessary for minimizing branch diameter and maximizing branch shedding in early stages of development. Diagram from Leak et al. (1987).). These charts allow us to approximate a starting point for how much to reduce the density of a stand throw thinning so as to let the remaining trees fully utilize site resources to produce optimal wood volumes. Stocking charts are species- or forest-type-specific and will vary within species over different regions, so it is important when using a stocking chart to be sure that the chart you are using is appropriate for your forest. To use a stocking chart, you simply plot your stand on the chart according to its values of Trees Per Acre (TPA) and Basal Area Per Acre (square feet/acre). In order to interpret where your stand falls on a stocking chart, you need to understand the three major lines found on most charts: the A-line, B-line, and C-line.

The ***A-line*** is the top line and represents the upper limit of average density for that species. Stands that fall around the A-line are often considered ***fully-stocked***; any stocking above the A-line is considered ***over-stocked*** and thinning should be conducted to free growing space and resources for the strongest trees. The ***B-line*** represents the lower limit of crown closure and corresponds to the threshold of inter-tree competition. At this level of stocking, trees will begin to grow at a rapid rate in order to out-compete surrounding trees. Stands that fall around the B-line are typically considered ***adequately-stocked***. We typically use the B-line as a target residual density for thinning overstocked stands. The ***C-line*** is not always included on stocking charts, but it represents an estimate of the lowest amount of stocking that will grow to the B-line within approximately 10 years. If a stand falls below the C-line it is considered ***under-stocked*** and thinning should not be conducted.

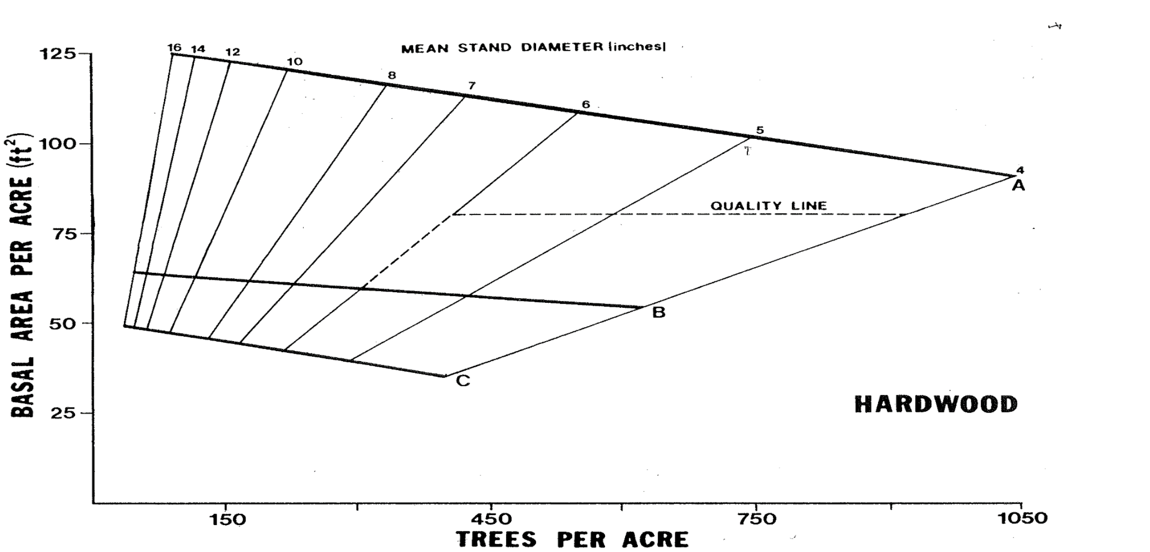


Figure 15: Stocking chart for even-aged northern hardwood forests. The quality line is the density necessary for minimizing branch diameter and maximizing branch shedding in early stages of development. Diagram from Leak et al. (1987).

Module 4 – Tree Quality and Products

Objectives

- Define a quality tree
- Products that come from trees
- Identify characteristics of a quality tree
- Recount factors that affect quality tree development
- Identify quality trees in the field
- Identify the products that a quality tree produces

Introduction

For timber stand improvement, a **quality tree** is "healthy, vigorous, well-formed tree of desired species on the right site that meets landowner goals and objectives." (Jim Frohn 2020). A quality tree meets economic, ecological and societal benefits. Increasing value in the woods provides greater economic returns for public and private forest landowners. It supports the forest products supply chain and diverse employment opportunities, often in rural communities.

A quality tree is desirable. Many quality trees across the landscape, in aggregate, enhance the economic and ecological benefits that our forests provide. The attributes that make a quality tree – that is being healthy, well-formed, having minimal defects, and representing **acceptable growing stock** growing on the right site are also the attributes that support social, ecological and economic goals for our forests.

The attributes that increase value of trees reflect a number of non-monetary benefits. Most quality trees have large crowns that support fast growth and surplus energy that provides resilience to environmental stressors. Large crowns, while not the sole determinant, are a factor in greater mast production, nuts and fruits that provide food for wildlife. Fast growth allows quality trees to sequester more carbon and their resulting large diameter reflect ample carbon stores.

While the focus of this curriculum is to improve the quality and value of the timber resource and the vitality of the forest-based economy in New England by growing better quality trees through early stand tending, there are many types of trees that contribute to the health and well-being of the region's forests. For example, a large, poorly-formed tree, full of decay, is a host for insects, provides denning opportunities, retains high levels of moisture, and is important long-term structure as standing dead or when it falls to the forest floor. While these, and other, trees are not included in our definition of a quality tree, some of these other trees provide immense benefit to the ecosystem.

While all of these benefits are valuable, the monetary value of a tree sold on the stump, its **stumpage value**, is the easiest and most immediate way to calculate a tree's direct value to the forestland owner.

Higher stumpage prices are paid for trees that can produce high value products. Most of a forest's timber value is concentrated in a few quality trees. In fact, 45% of stumpage value can reside in only 10 trees per acre (2% of the trees). 99% percent of the stumpage value is in 16% of the trees (70 trees/acre) according to some research (Miller et al. 2007).

Timber stand improvement (TSI), or stand improvement is defined as "an intermediate treatment made to improve the composition, structure, condition, health, and growth of even- or uneven-aged stands" (Helms 1998).

A TSI prescription usually recommends releasing the crown of a **crop tree** on at least 3 sides. The crop tree is a preferred species that is healthy, has a well-formed stem, and a larger crown relative to other trees of the same cohort. Based on the average tree diameter of a stand, a certain number of crop trees will be identified and thinned. The stand of trees is reduced to a certain density that optimizes growth while maintaining tree form – a straight, defect free quality tree. By removing poorer quality trees adjacent to well-formed crop trees, growth is concentrated on the best trees in a stand. Growing more quality trees per acre and maximizing the value of the existing quality trees is a central tenant of timber stand improvement.

Forest products

Standing trees are processed into different products based on their attributes and the markets that are available (Figure 17). A standing tree is felled and then has the limbs and top cut off, i.e., "limbed" and cut into 8-16' logs. The logs are sorted into piles based on their attributes, i.e., species, size, quality, and sent to different markets. The residual limbs and branches are either left in the woods or processed into a product such as biomass chips that are sent to market.

Figure 16: Logs sorted on the log landing. The pile on the left is going to a pulp mill, the other is going to a sawmill

In general, the following factors determine the type of product that can be produced:

- Species – certain species are valued for characteristics that lend themselves to specific products.
- Diameter – Some markets, e.g., sawmills, require logs of a minimum (and/or maximum) diameter to efficiently process products.
- Defects – Trees that have more *clear faces*, i.e., sides of the tree that do not have dead or live branches (which are called knots in lumber), are often more valuable because clear faces can be processed into higher value clear lumber. Similarly, smaller and fewer branches or knots on a tree tend to result in more valuable lumber.

The products from a tree fall into a number of categories though the specific products and markets can vary. Broadly, there is roundwood (logs) that are sawn into higher value products. Some roundwood is used for lower value products such as pulp or firewood, and then there are the lowest value products which tend to get processed into biomass chips (Figure 18):

- Veneer
- Sawlogs
- Pallet – Tie logs
- Pulpwood
- Firewood (fuelwood)
- Biomass

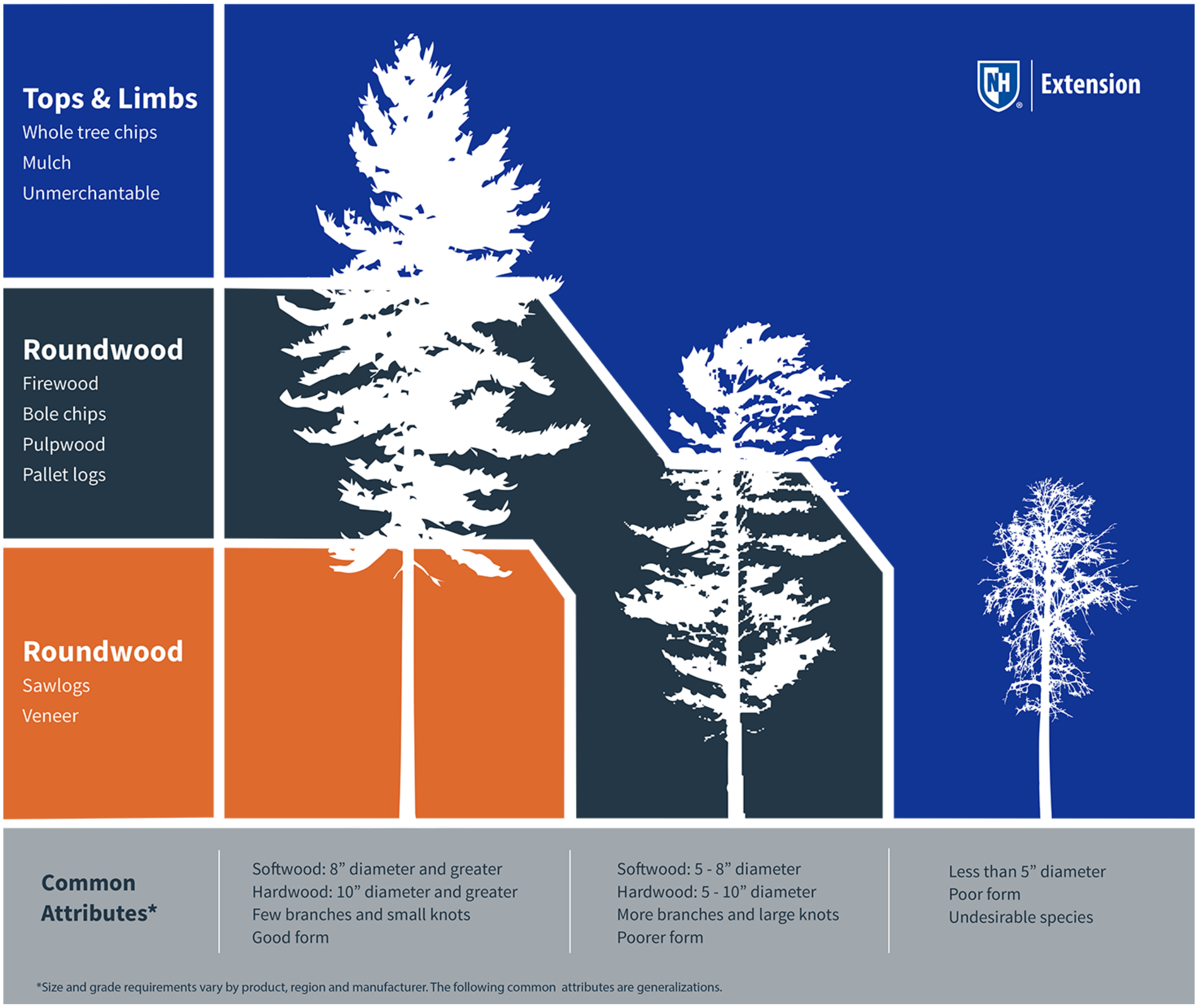


Figure 17: Products derived from trees based on common attributes.

Veneer Logs – Veneer logs are the rarest, highest value logs. Straight, large diameter, defect free logs that are capable of producing thin defect free sheets of wood at a veneer mill (Figure 18). These thin sheets are typically glued to panels or lumber to improve the appearance of wood products such as doors, cabinets, furniture components and more.

Figure 19: Veneer - standing timber and finished sheet

Sawlogs – Sawlogs are logs that are of sufficient size - usually a minimum 8” or 10” diameter depending on the species, measured inside the bark at the small end of the log - and quality to produce hardwood or softwood lumber (Figure 21). There is a lot of variation in the type, quality, and value of lumber produced from sawlogs. **Boards** are less than 2 inch **nominal** thickness and two inches or greater in width. **Dimension lumber** is 2 inches to 5 inches in thickness and **timbers** are lumber 5 inches nominal and greater in thickness. Despite the variation, the principle holds that the higher the quality of the log, the higher quality of the lumber.

Figure 20: Sawlogs – standing timber and rough sawn, green lumber

Pallet – tie Logs – Pallet and tie logs are the lowest grades of sawlogs (Figure 22). A large percentage of the log is sawn into industrial lumber and timbers. The low-grade lumber produced from pallet logs can have lots of knots, and may not be aesthetically pleasing. Nonetheless, the wood is functional for the use, and appropriate for producing pallets. Tie logs show similar characteristics. They are often squared off into **cants**, treated to reduce rot, and used for railroad ties.

Figure 21: Pallet-Tie Logs – standing timber and finished pallets

Firewood – Hardwood logs that are too small or not of sufficient quality to saw into lumber can be used to make firewood (Figure 23). There are different firewood log markets depending on the quality of firewood (straight and easy to process or full of knots and crooked) and how it is sold.

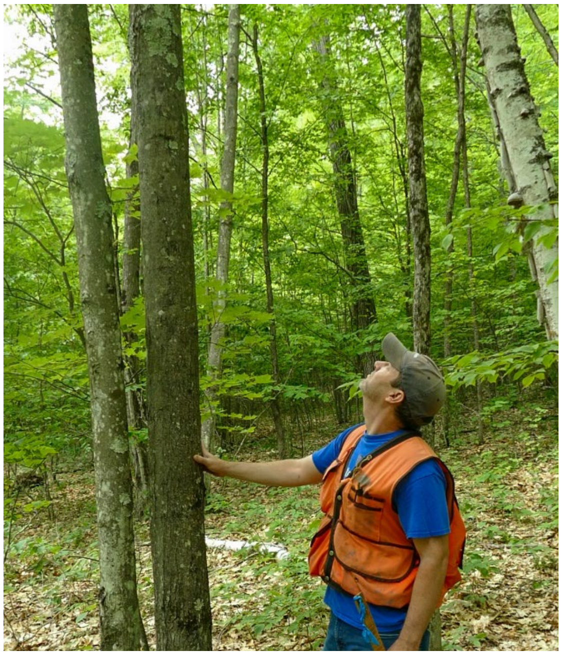


Figure 22: Firewood – standing timber and firewood being processed on the log landing

Pulpwood – Hardwood and softwood logs not suitable for lumber production because of their size or quality are also sold into pulp and paper markets (Figure 24).

Figure 23: Pulpwood – hemlock pulpwood and paper

Biomass Chips – A product of whole tree harvesting systems where low grade or small diameter roundwood or tops are chipped for biomass plants or thermal chip markets (Figure 25). Chips that are made from whole trees, including leaves, sticks, and bark are used for electrical power generation. There are bole chips made from debarked, chipped logs. These types of chips tend to be screened for uniform consistency, do not have the mix of leaves, bark and wood, and are used for paper production, pellets and larger scale, and specialty heating systems.

Figure 24: Biomass Chips – semi-dry wood chips for heating and sapling that can be processed for biomass electricity.

Scale and Grade

Usually, high-grade products are measured, or **scaled**, and sold by the thousand board foot (MBF). A board foot is a piece of lumber equivalent to 12”x12”x1”. Low-grade products are mostly sold by the cord or ton (Table 1).

Table 1: Representative values and units of measure for forest products.

Products	Representative Values	Unit of Measure
Veneer Logs	$1000	MBF
Sawlogs	$350	MBF
Pallet Logs	$50	MBF
Firewood	$8	Ton
Pulpwood	$4	Ton
Biomass Chips	$0	Ton

To calculate volume in a standing tree, the diameter of the trunk, or bole, is measured at breast height (4.5 feet). For cut logs, the small end diameter inside the bark (Figure 26) is measured at the mill or market where the product is delivered.

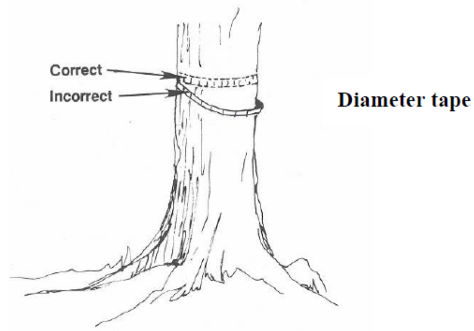



Figure 25: Tree and log measurement

There are **log rules**, typically formulas, and associated tables that predict the board foot volume in a given size log. These log rules were developed as a uniform way to measure the volume in a log and create consistency in trade for buyers and sellers. The international ¼" log rule is the most common log rule used in New England and is represented in Figure 27(Wenger 1984)

Top Diameter of Log in Inches	Contents in Board Feet						
	Length of Log in Feet						
	8	10	12	14	16	18	20
6	10	10	15	15	20	25	25
7	10	15	20	25	30	35	40
8	15	20	25	35	40	45	50
9	20	30	35	45	50	60	70
10	30	35	45	55	65	75	85
11	35	45	55	70	80	95	105
12	45	55	70	85	95	110	125
13	55	70	85	100	115	135	150
14	65	80	100	115	135	155	170
15	75	95	115	135	160	180	205
16	85	110	130	155	180	205	235
17	95	125	150	180	205	235	265
18	110	140	170	200	230	265	300
19	125	155	190	225	260	300	335
20	135	175	210	250	290	330	370
21	155	195	235	280	320	365	410
22	170	215	260	305	355	405	455
23	185	235	285	335	390	445	495
24	205	255	310	370	425	485	545
25	220	280	340	400	460	525	590
26	240	305	370	435	500	570	640
27	260	330	400	470	540	615	690
28	280	355	430	510	585	665	745
29	305	385	465	545	630	715	800
30	325	410	495	585	675	765	860
31	350	440	530	625	720	820	915
32	375	470	570	570	770	875	980
33	400	500	605	715	820	930	1045
34	425	535	645	760	876	990	1110
35	450	565	685	805	925	1050	1175
36	475	600	725	855	980	1115	1245

Figure 26: International ¼" log rule

GRADE

Log grading is a process for rapidly evaluating the quality of a log – and it reflects the number of **clear faces** of the log and may also reflect log diameter (Figure 28). Certain grades of logs are expected to yield different percentages of lumber grades. High grade logs yield a greater percentage of high-grade lumber. Because higher grades of lumber sell for more money, sawmills pay more for these logs. Conversely, low grade logs yield considerably less high-grade lumber and are less valuable. Grades vary by species group and products, and in some cases, logs can be sold on a weight or "straight through" price where there is a price per unit volume (e.g., $ per 1,000 board feet) regardless of grade.

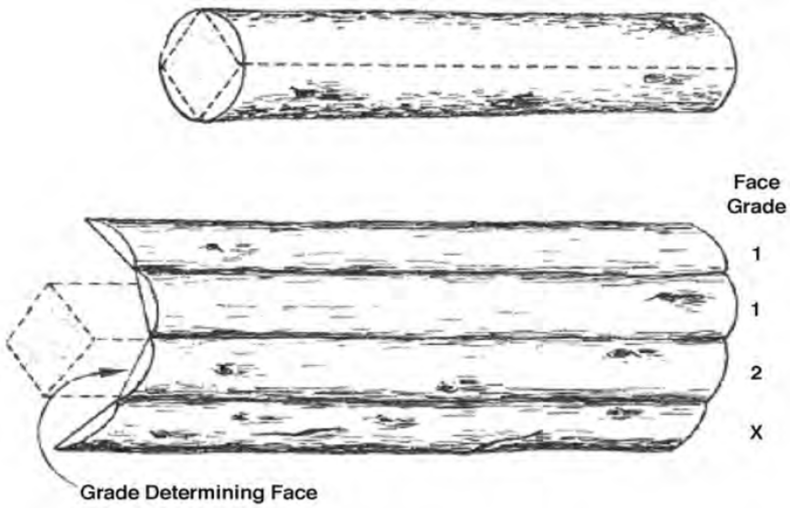


Figure 27: Grading faces (Reproduced from: Rast et al. 1973)

Timber stand improvement increases the growth rate, and ultimately scale, in the highest grade trees thereby increasing the value growth of timber per acre. Table X demonstrates a significant increase in value as a tree graduates through product classes (e.g., pulp to sawlog). This value increase in grade is further compounded by the increased growth resulting from TSI (i.e., scale). The difference between a 12" sawlog and a 20" veneer log could be in excess of 700%.

Defects[1]

As noted above, grade indicates quality of wood, while scale indicates volume of wood. The following defects result in a loss of scale: rot, rotten knots, fire scars, logging damage, pitch pockets, shake, sweep, crook (severe sidebend), insect holes, crotch, severe checks, seams, breakage, shatter, stump pull (fiber pulled from butt log during felling), cracks, split, spider heart, and white pine weevil damage.

Defects can inform what tree should be removed or retained when doing TSI.

Spider Heart: Spider Heart are decay infected cracks that occur in some standing trees, and are of particular concern in oak. While not always visible in the standing tree, spider heart will result in a loss of lumber volume recovered in the butt log.

Shake: Shake is a separation of wood fiber along the growth rings. As the log is sawn into lumber the boards tend to fall apart. Obviously, shake is a serious defect. It is often seen in hemlock logs. It is not readily visible in standing trees, but there are some indicators. These include large dead limbs and seams on the outside of the bark.

Butt Rot: Rot is a common defect in logs, often identified once the tree is cut. The estimated volume of the rot is calculated when it is encountered and reduced from the gross scale.

[1] Much of the language about defects is taken directly from NH Best Log Scaling Practices Guide (Smith 2001).

Red Rot: Red rot is a serious defect in white pine logs. It is found in scattered pockets in the wood and severely degrades the lumber or causes it to be culled. Trees infected with red rot can be difficult to determine on the stump. One telltale sign is the presence of fruiting bodies of the fungus at the base of a dead branch stub's junction with the bole of the tree.

Sweep: Sweep or sidebend is a curve in the log. Since sawmill blades do not account for curved stems, a curve reduced the overall yield of a log. Even relatively defect free logs will have little to no value if there is significant sweep.

White Pine Weevil Damage: The white pine weevil is an insect that attacks and kills the top of the main stem (leader) of the white pine. The result is that a side branch replaces the leader and causes a major deviation in the growth form. Many sawmills will cull (reject) weeviled logs, or the scale deduction will severely reduce the net volume. It is important to check with the mill to understand the treatment of weevil damage.

Cracks, seams, splits: Surface defects only affect scale if they penetrate enough to reduce the lumber yield of a sawlog. The orientation of a crack is critical. As an example, if a crack follows the grain of the sawlog the scaling volume may not be reduced. Conversely, a spiral seam or a crack that wanders around a sawlog may substantially reduce the scaling volume.

Module 5 – Implementation and Equipment

Objectives

To become familiar with basic equipment and tools used in TSI

- Felling tools
- Girdling tools
- Pruning tools

Implementation of TSI

- Pre-commercial thinning
- Crop tree release
- Low-density pine management

Equipment

In general, use the lightest, most ergonomic equipment available. Using ergonomic techniques saves energy and allows you to work safely and efficiently for longer periods. Training in proper use of the equipment, such as Game of Logging, is essential to safe and efficient operation.

Forest stand improvement involves cutting and killing undesirable trees. The most common tools for this are a chainsaw and a brush saw. Trees are often felled in tending operations, but don't necessarily need to be. Girdling is also an effective method of eliminating competing trees. Girdling can be done with a chainsaw or other manual tools such as a hatchet.

Pruning is another activity used to improve forest stands. There are a variety of manual tools used for pruning, depending on species and objectives.

Felling Tools

Chainsaw – smaller saws are lighter, easier to handle, and less tiring for the operator. Trees removed in stand improvement are generally sapling to poletimber size, so large saws are not necessary. 50cc and smaller are good choices; arborist saws are especially lightweight but may be too small for many TSI applications. A 12” to 16” bar and chain is a good choice because shorter bars are lighter and easier to maneuver and less tiring over the course of a day. Shorter chains take less time to sharpen.

Figure 28: Small, light chainsaw with 15” bar

Brush saw – A gas powered saw that resembles a weed whacker, with a circular saw on the end. Use an appropriate size saw for the material you will most often be cutting. A brush saw is an excellent tool for cutting sapling size trees, and small poles up to 4-5” at the base. Brush saws are designed to be ergonomic, using a harness to hold the weight of the saw on the operator’s shoulders and waist. The saw’s design allows the user to stand upright, unlike a chainsaw. This is far less tiring, and therefore safer, than bending over with a chainsaw. It’s much easier on the back too.

Figure 29: Brush saw with brush blade for small diameter material (<1”)

Larger diameter trees are cut with a circular saw blade

The choice of chainsaw or brush saw depends on the average size of the material to be cut. While a brush saw can handle trees up to 4 or 5" at the base, a chainsaw is more efficient if this is the average size tree encountered on a site. The brush saw is best when the majority of trees are seedling and sapling size, and less than an inch or two in diameter.

Girdling Tools

Girdling is the practice of killing a tree by cutting through the cambium around the circumference. This disrupts the flow of water, nutrients, and sugars through the xylem and phloem. To be effective, girdling cuts must completely sever the xylem and phloem around the tree. Double girdling, where two parallel girdling cuts are made, ensures the disruption, especially when combined with peeling the bark between the cuts. Girdling can be a fast, effective way to kill a tree without the need to fell it. It is particularly useful for larger trees that will damage crop trees if felled. Girdling can, however, create hazards once the tree dies.

A chainsaw is the most common tool used for girdling. Care must be taken not to cut too far into the tree, weakening it and becoming an immediate hazard for those working in the area.

Figure 30: Elm was girdled to release apple tree

Hand tools such as a hatchet or a draw shave can also be used for girdling. Any tool that can cut through the bark and sever the cambium layer will work.

Pruning Tools

The purpose of pruning in growing quality trees is to create knot-free wood. Pruning should be done when the tree is tall enough to create clear future logs and still have plenty of height to support a minimum live crown ratio of 30%.

Common Pruning Tools

- Hand pruners – for small diameter live branches within easy reach

- Pruning saw – for live and dead branches from ground to about 8 ft up the trunk (depending on the operator's height)
- Pole pruning saw – For live and dead branches from 8 ft. to 20 ft. or so
- Loppers (used in conjunction with a ladder) – Though the ladder can be somewhat cumbersome, loppers can be a very fast and efficient way to prune. Professional pruning crews in New Zealand and elsewhere use this method

Figure 31: Pruning Tools top to bottom: Pole saw, hand saw with scabbard, bypass pruners, loppers

A new pruning tool, designed for fast pruning of small branches (1 inch or less in diameter) was developed in Finland and will be available in the US. Instead of sawing off the branch, it works by hooking a pair of blades over the branch and pulling down. The two blades close together, shearing off the limb. A clean cut results with no bark tearing.

Figure 32: A new type of pruning tool – the "Limb Zipper"

Implementation

Timber stand improvement work, whether using power equipment or not, carries considerable risk and should not be done without proper training and sound understanding of the obvious and less visible dangers in the work environment. Chainsaw work should only be conducted after participating in an established and reputable chainsaw training program. There are hidden risks such as unseen rot and decay in live trees, sudden release of bound trees and limbs, overhead hazards such as standing dead trees and dead branches, among others. When conducting TSI, it is important to always wear appropriate safety equipment to minimize risk. Personal protection equipment (PPE) for chainsaw and brush saw operation includes hard hat, eye and ear protection, leg protection (i.e., cut resistant chaps or pants), safety toe boots, and gloves.

Forest stand improvement can be accomplished in a number of ways, and the methods have different names. The methods depend on the species, the uniformity of the stand, and the goal of the improvement work. Regardless of method or goal, forest stand improvement involves choosing crop trees (those trees that meet landowner goals) and cutting/killing trees that are competing with the crop trees.

Pre-commercial thinning, or PCT, is a generic term for thinning stands that are not ready for commercial harvest due to tree size. Thinning, whether pre-commercial or commercial, is done to reduce crowding and improve growth. The treatment is done uniformly across the stand, but can be modified to enhance species composition. PCT is typically done to a prescribed spacing. It is best used in stands with low species diversity and relatively uniform quality. A classic example of PCT is in young spruce-fir stands, where the trees are spaced to 8 ft x 8 ft or 10 ft x 10 ft spacing. Balsam fir typically far outnumbers red spruce in a stand and grows faster, so strictly following spacing can inadvertently discriminate against spruce. Spacing can be modified to favor spruce or other desired crop tree species when found. This helps improve species diversity, and reduces that stand's susceptibility to spruce budworm, which actually favors balsam fir.

Crop tree release is a focused method of forest stand improvement. The crop trees in a stand are identified and each is given a crown-touching release to remove competition. Pre-determined spacing or uniform treatment across the stand are not necessarily considerations in crop tree management, but spacing can be used as a guide. The key is improving each crop tree's growing space by removing trees directly competing with them. There may be as few as five or six crop trees per acre or as many as one hundred. Areas with no crop tree candidates can be skipped, making the labor more efficient and focused. Crop tree management works well in hardwood stands and mixed stands with a variety of species and quality. It also works well in white pine stands. Crop tree management in white pine stands is somewhat different than in hardwood and mixed stands. It will be addressed separately later. The next section pertains to crop tree management for hardwood and mixed stands with a primary purpose of developing quality timber.

Use what you learned about valuable species, form, health, vigor, and site to select the crop trees on a given site. A timber crop tree will meet the following criteria (From Hardwoods Perkey, A.W., and B.L. Wilkins. 1993. Crop Tree Management in Eastern Hardwoods. USDA For. Serv. NA—State and Private Forestry. NA-TP-19-93).

- A vigorous, dominant or co-dominant tree with good form, relatively straight trunk with few knots in the first 20 feet or so. Two ten-foot logs of high quality are the goal for timber trees when possible.

- Minimum of 30% live crown ratio. Same rule applies when pruning crop trees - Don't reduce live crown ratio to less than 30%.

- No epicormic branches, live or dead. Even very small epicormic branches are a sign of stress, and releasing the tree will encourage rapid development of these branches, which reduce log quality.

- Crotches with U-shaped connections are okay; try to avoid V-shaped crotches, which have higher risk of splitting

- No dead branches in upper crown – the tree grows from the upper branch tips; die-back in these branches indicate serious health problems

- Avoid high-risk trees such as leaners, splitting forks, seams in bole

- High-value tree species. The top-tier hardwood species in New England are red oak, sugar maple, and yellow birch. Second-tier hardwoods in terms of timber value are red maple, white ash, black birch, white birch, and black cherry. Valuable softwoods are white pine and red spruce. Balsam fir and white spruce are also valuable softwoods.

- While promoting high value species is a traditional approach to TSI, there is some benefit to thinning around the highest quality trees regardless of species, i.e., the best formed, healthiest, defect free trees that have a large crown. Because markets and product prices change over time, the species that are high value currently may not be the high value species of the future. Relatively defect free trees have historically been at the higher end of the price range for sawlog size logs. Ultimately, we can't predict future markets so a crop tree can be any species with good form and vigor.

Some additional considerations when conducting TSI (Bennet 2010):

- Fully releasing the crown of a crop tree increases the possibility for epicormic branching, which lowers its timber quality.
- Conducting TSI on good growing sites on dominant and codominant trees limits epicormic branching. Tendencies:
    - Black cherry and red oak have strong epicormic branching tendencies
    - red maple has moderate tendencies
    - white ash and yellow birch low tendencies
    - sugar maple has low tendencies on good sites.
- When two crop trees grow in close proximity, treat them as one tree and remove all trees whose crowns touch those of the two crop trees.

As shown in module 3, stand density affects tree growth and branching so it is an important determinant in tree value. Lower density provides more growing space and crown expansion that increases growth rates. However, if there are too few trees per acre, trees can become more branchy (epicormic sprouting) or there can be lower yields per acre. Higher density encourages trees to grow straight but may limit crown expansion and the tree's ability to generate more energy to allocate to growth.

Trees that add clear wood quickly are quality trees – these tend to be trees in the dominant / codominant classes. From a timber stand improvement standpoint, we want to encourage desirable pole-sized trees to occupy the dominant or codominant positions in the canopy.

Figure 33: Red maple crown released on four sides. The V-shaped branch connection is not ideal, but it's necessary to work with the existing trees

Low density pine management – many of the same principles of crop tree selection and management apply to white pine, with a few key differences. Low density pine management works best in pure or nearly pure pine stands. Pine as a component of a mixed stand can be approached as another crop tree. Low density pine management relies on spacing guidelines as well as crop tree criteria. In addition to choosing trees with good form, and healthy crowns with a minimum 30% live crown ratio, white pine crop trees should have the following:

- Minor or no pine weevil damage
- Small diameter (less than ½ inch) dead limbs – these translate into black knots in the lumber
- No or minimal spike knots – dead branches that enter the stem at a sharp angle
- DBH from 5" to 10" - it takes five inches of growth beyond the pruning wound to overcome the influence of the knot on lumber

White pine log quality is determined by clear wood (lack of knots) or the presence of small red knots (from live branches). The key to valuable pine logs, and the aim of low-density pine thinning, is to maximize the amount of clear and red-knotted lumber and minimizing or eliminating black-knotted lumber. This is done by pruning the lower bole and maximizing live branches in the rest of the tree. Wide spacing between crop trees is essential to minimizing death of lower branches that form black knots.

Principles of Low-Density Pine Management (from Robert Seymour, University of Maine Professor of Silviculture Emeritus):

- Select crop trees early (no larger than 30 – 40 feet tall, live crown base at 17 – 25 ft)
- Release heavily to prevent further crown recession (death of lower branches)
- Prune to 17 – 25 feet (for one 16 ft log or two 12 ft logs)
- Space trees at 50% of total height – a stand of 30 ft tall trees will be spaced to 15 ft

Figure 34: Crowded (left) and fully released (right) white pine crowns

Planning and Implementation

Regardless of method or species, the following procedures are helpful for planning and implementing TSI work.

Identify crop trees and mark them with flagging or paint, at least at first so you get the feel of what the crop trees look like and, when appropriate, what a good spacing will be. The marking will also make the trees easily visible so you know to avoid them during cutting operations.

Approach the crop tree and look at the crown, and identify trees that are competing with it. Remember that neighboring trees whose crowns are completely below the live crown of the crop tree are not competitors. Once the competing trees are identified, fell them or girdle them. Aim for a crown-touching release on at least three sides, ideally four. In white pine, release the crown on four sides and use the 50% of tree height spacing guide (see Low Density Pine Thinning). By focusing on the crop trees, we can avoid expending energy in areas that won't get a lot of benefit. We can spend our energy where it matters – giving the crop trees the best chance to flourish. We can skip over areas without crop trees, or cut everything to create an opening for regeneration, if that fits with the landowner's goals.

Determining space between crop trees

To determine how much space is needed between crop trees, there are a couple of ways to go about it. According to *Crop Tree Management in Eastern Hardwoods* by Perkey, et al, a healthy crown on an immature hardwood expands at about one foot per year. This means that the growing space between two crop trees decreases by approximately two feet per year. A 15-foot spacing between crown edges (not the trunk) will close in seven to eight years. Using this method, a crown-touching release means cutting any trees whose crown edge is 7.5 feet or less from the edge of the crop tree's crown.

Another method is to determine the number of trees per acre to release, and convert this to spacing. Younger stands tend to have more potential crop trees than older stands. A young stand might have 100 to 200 potential crop trees. Ultimately, a mature hardwood stand isn't going to support more than 100 crop trees per acre, so releasing more than that can be counterproductive. To convert to spacing, first divide 43,560 square feet (area of one acre) by the number of crop trees to be released. This gives the square feet needed per tree. Taking the square root of this number gives the spacing.

For 100 crop trees, the spacing is: 43,560 sq. Ft/100 = 435.6. The square root is 20.87. Twenty-one feet between crop trees is the target spacing.

It is common to have far fewer than 100 crop trees per acre on a given site. In these cases, the best approach is to identify the crop trees and give the crown a four-sided release with adequate space for the crown to grow for several years before the next release cut is needed.

Pruning

When pruning, use proper technique to minimize damage. Pruning cuts should be flush with the branch collar, not flush with the bole of the tree. Cuts that are flush with the branch collar will heal quickly; cuts flush with the bole essentially create a large wound and a pathway for disease.

It's also important to take care to avoid damage to the bole of the tree when pruning. This can occur when sawn branches fall before being completely severed, resulting in bark tearing. It can also occur when the pruning saw blade is accidentally raked down the side of the tree, damaging the bark. Young pine, with their thin bark, are especially susceptible.

Working safely and efficiently

When conducting crop tree release and TSI, plan your work in such a way that you are felling trees away from your work area. Avoid putting tops and branches where you'll be working next. Depending on the landowner, you may not even need to get the tree to the ground.

There are many techniques for working efficiently with a chainsaw and brush saw. Training in their safe and efficient use is essential and will help get you started in the right direction, but there is no substitute for experience.

Because the goal is to produce quality trees, TSI should be focused on the best sites and soils that can support well-formed, rapidly growing desired species. Conversely, poor sites, e.g., poorly drained or shallow soils receive less benefit from TSI.

TSI Recommendations from Good Forestry in the Granite state (Bennett 2010).

- TSI should focus on better growing sites, preferably on sites with site index of 60 or higher for the desired species;
- start releasing the crop trees when they reach 5 to 8 inches DBH.
- Weeding is usually most needed in mixed stands of conifers and hardwoods when conifers are the crop trees. Release conifers by weeding out overtopping hardwood in sapling stands (1 to 4 inches DBH and 10 to 20 feet tall). Bring the upper crowns of valuable stems into full sunlight. After treatment, stands should be dense enough to assure self-pruning of lower limbs, straightness of stem, and protection against snow and ice damage (except in cases of low-density pine thinning).
- Release 100-200 tree per acre in young in young stands and 50-75 trees per acre in older stands.
- To maximize financial benefits, consider releasing fewer crop trees per acre and having a commercial harvest as soon as possible.
- Protect crop trees susceptible to epicormic sprouting (most hardwoods) from receiving too much light on their trunks. For those trees not prone to epicormic sprouting and growing on good sites, release on at least three sides of its crown to increase diameter growth.

- Follow the following guidelines when pruning:
    - Prune pole-sized crop trees (4 to 6 inches in DBH and no larger than 10 inches).
    - Limit the number of crop trees pruned per acre to those that can be carried to full maturity and add enough growth of clear, knot-free wood to justify the pruning investment. It takes at least 5 inches of wood growth to overcome the influence of the pruned branch on wood quality.
    - Prune no more than 100 softwood and no more than 50 to 75 hardwood crop trees per acre.
    - Pruning can be done prior to non-commercial thinning treatments. A pruned crop tree is easily seen when conducting release work, and the person doing the pruning doesn't have to walk through the dense debris created by felling. If the thinning is done commercially, pruning should follow, rather than precede, thinning. Keep damage to crop trees at an absolute minimum during harvests.
    - Document when and where pruning occurred.

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Glossary

Acceptable growing stock: tress growing in a forest or in a specific part of it meeting acceptable standards of size, quality and vigor.

Adequately-stocked: an indication of adequate growing space occupancy relative to a prescribed standard.

A-line: pertains to the upper limit of stocking on a stocking chart. Stands above the A-line are considered overstocked.

Anchor roots: Large roots whose main function is to hold a plant in place in the soil

Angiosperm: The group of vascular flowering plants that produce seeds enclosed in an ovary.

Asexual reproduction: The process of fertilization without fertilization.

Aspect: a position facing a particular direction.

Atmosphere: air

Balanced (uneven-aged stand): An uneven aged stand that have three or more age classes occupying approximately equal areas.

Biosphere: organic life

B-line: pertaining to a stocking chart or guide, the B-line is the lower limit of stocking that will allow the stand to develop naturally; stands below the B-line are considered understocked.

Board: A piece of lumber less than 2 inches in nominal thickness and one inch or more in width.

Cambium: a layer of living meristematic cells between the wood (secondary xylem) and the inner bark (secondary phloem) of a tree.

Cant: A partially sawn log with at least one flat side. There can be cants with one to four flat sides.

Clear faces: The side of a piece of wood (log) that is without blemish.

Climate change: The long-term fluctuations or trends in temperature, precipitation, wind, and all other aspects of the earth's climate.

C-line: pertains to the lower limit of stocking on a stocking chart. Stands below the C-line are considered understocked.

Cohort(s): a distinct aggregation of trees originating from a single natural event or regeneration activity, or a grouping of trees, e.g., 10-year age class, as used in inventory or management.

Colloids: any substance consisting of particles substantially larger than atoms or ordinary molecules but too small to be visible to the unaided eye

Compaction: The process by which the soil grains are rearranged, resulting in a decrease in void space and causing closer contact with one another, thereby increasing bulk density.

Conifers: a cone bearing tree.

Crop tree: a term to describe a tree that is commercially desirable, with the potential to grow straight, tall, and vigorously. Any tree selected to become or forming a component of the final crop. A crop tree can also be one selected for non-timber objectives, such as mast production or habitat potential.

Crown: The part of a tree or woody plant bearing live branches and foliage.

Deciduous trees: Trees that are normally more or less leafless for some time during the year.

Dimension lumber: Timber cut to specific widths, thicknesses, and lengths.

Dioecious: Pertaining to a species having male and female flowers (or strobili) produced on separate plants.

Disturbance: Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

Down woody material (DWM): Any piece(s) of dead woody material, e.g. dead boles, limbs, and large root masses, on the ground in forest stands or in streams.

Ecological classification systems: A multifactor approach to categorizing and delineating, at different levels of resolution, areas of land and water having similar characteristic combinations of physical environment (such as topography, climate, geomorphic processes, geology, soil, and hydrology), biological communities (such as plants, animals, microorganisms, and potential natural communities), and human factors (such as social, economic, cultural, and infrastructure).

Even-aged: of a forest, stand, or forest type in which relatively small age differences exist between individual trees. The differences in age permitted are usually 10 to 20 years; if the stand will not be harvested until it is 100 to 200 years old, larger differences up to 25 percent of the rotation age may be allowed.

Feeder roots: Roots whose primary function is to absorb water and nutrients.

Fine woody debris (FWM): see down woody material. The type and size of material designated as fine woody debris varies among classification systems.

Forest cover type: a category of forest usually defined by its vegetation, particularly its dominant vegetation as based on percentage cover of trees.

Forest ecology:

Fruit: the seed-bearing organ of a flowering plant.

Fully-stocked: stand density that fully meets a management objective.

Gymnosperms: the group of vascular flowing plants that produce seeds not enclosed in an ovary (naked seeds).

Habitat preferences: a preferred area where an animal lives.

Heartwood: the inner, nonliving part of a tree stem that is altered to a protective state as a result of normal, genetically controlled aging processes as cells die, and that provides mechanical support.
Hydrosphere: water

Improvement [cutting]: a cutting made in a stand past the sapling stage, primarily to improve composition and quality through the removal of less desirable trees of any species.

Inner bark: the inner bark, or "phloem" is a pipeline through which food is passed to the rest of the tree. It lives for only a short time, then dies and turns to cork to become part of the protective outer bark.

Invasive: an invasive organism is one that has arrived in a place from somewhere else and has a harmful effect on that place.

Lithosphere: earth's crust

Logs: The stem of a tree after it has been felled.

Log rules: Any one of various methods of determining the net yield of a log, usually expressed in terms of board feet of finished lumber.

Macronutrients: A chemical element (not including carbon, hydrogen, or oxygen) needed in relatively large amounts by organisms.

Mature: a tree that has attained most of its height growth or has reached merchantability standards.

Metamorphism: The ontology of some animals encompassing the series of changes in shape, structure and habits undergone from egg or embryonic stage into adult stage.

Micronutrients: a chemical element needed in relatively small amounts by organisms.

Monoecious: a population or species having functional male and female flowers.

Mycorrhizae: the symbiotic association between certain fungi and plant roots which enhances the uptake of water and nutrients.

Natural communities: Groups of plants and associated animals classified and described by their dominant biological and physical features.

Non-native species: a species that originated somewhere other than its current location and has been introduced to the area where it now lives.

Nurse log: a fallen tree which, as it decays, provides ecological facilitation to seedlings.

Old growth: late successional stage of forest development.

Outer bark: mostly dead tissue, cork and old dead phloem, on the surface of the stems.

Ovary: The enlarged basal portion of the pistil, the female organ of the flower. The ovary will mature into a fruit, dry or fleshy, enclosing the seeds.

Over-mature: 1) a tree or even-aged stand that has reached that stage of development when it is declining in vigor and health and reaching the end of its natural life span, or 2) a tree or even-aged stand that has begun to lessen in commercial value because of size, age, decay, or other factors.

Over-stocked: Conditions in which the growing space is so completely utilized that growth has slowed down.

Parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of the soil is developed.

Physiography: Landform, including surface geometry and underlying geologic material.

Pole: a tree between a sapling and small sawtimber size. Size varies by region, e.g., for boreal and eastern forests (Canadian) 12–20 cm.

Quality tree: A healthy, vigorous, well-formed tree of desired species on the right site that meets landowner goals and objectives.

Root suckering: Vegetative formation of a new stem and root from an adventitious bud of a stem or root.

Sapling: young tree larger than a seedling but smaller than a pole.

Sapwood: the outer layers of a stem, which in a live tree are composed of living cells and conduct water up the tree.

Sawtimber: trees that will yield logs suitable in size and quality for the production of lumber.

Scaling: to measure the weight or volume of a log, load of logs or stacked fuelwood.

Seedling: A tree, usually less than an inch in diameter.

Seeds: the ripened ovule of a plant containing an embryo, seed coat and nutritive tissue.

Self-thinning: tree mortality from the effect of the competition arising between trees on the same site.

Sexual reproduction: in flowering plants involves the production of male and female gametes, the transfer of male gametes to the female ovules in a process called pollination.

Shade tolerance: a plant's ability to tolerate low light levels.

Silvics: the study of the life history and general characteristics of forest trees and stands.

Site factors: factors related to the area in which a plant or stand grows.

Site index: a species-specific measure of actual or potential forest productivity (site quality, usually for even-aged stands), expressed in terms of the average heigh of trees included in a specified stand component (defined as a certain number of dominants, codominants, or the largest and tallest trees per unit area) at a specified index or base age.

Slope: a measurement of change in surface value over distance, expressed in degrees or as a percentage.

Snag: a standing, generally unmerchantable dead tree from which the leaves and most of the branches have fallen.

Stand: as defined in classic silviculture, a contiguous group of trees sufficiently uniform in age class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, to be a distinguishable unit. In ecological silviculture, forest areas that incorporate the structure, age, composition, and spatial pattern of trees of natural ecosystems, as determined by an underlying geomorphic, soil, or disturbance templates.

Stand dynamics: The study of change in forest stand structure with time, including stand behavior after disturbance.

Stand initiation: the initial stage of stand structural development, lasting from the time of stand-replacing disturbance until the new cohort forms a continuous canopy and trees begin competing with each other for light and canopy space.

Stem exclusion: A stage of succession where all growing space is occupied, and new plants are excluded from regenerating.

Stocking: an indication of growing-space occupancy relative to a preestablished standard. Common indices of stocking are based on percent occupancy, basal area, relative density, and crown competition factor.

Stratified even-aged: Even aged principle but different crown layers develop as a result of varied height growth due to species, shade tolerance, rooting depth and other factors.

Structure: the horizontal and vertical distribution of components of a forest stand including the height, diameter, crown layers and stems of trees, shrubs, herbaceous understory, snags, and down woody debris.

Stumpage value: The monetary value of standing timber calculated before the tree is cut.

Stump sprouting: sprouts that originate from the stump after a tree is cut or damaged.

Succession: the gradual supplanting of one community of plants by another.

Successional status: the stage of succession that a plant community is in.

Taproot: the main descending root of a plant.

Timbers: A size classification of lumber that includes pieces that are at least five inches in their smallest dimension.

Timber stand improvement: An intermediate treatment made to improve the composition, structure, condition, health, and growth of even or uneven aged stands.

Transport roots: Roots, often with large surface area or roots hairs, whose function is to absorb and transport water and nutrients.

Trunk (stem): the principal axis of a plant form which buds and shoots develop.

Two-aged (double-cohort): methods designed to maintain and regenerate a stand with two age classes. In each case the resulting stand may be two-aged or tend toward an uneven-aged condition as a consequence of both an extended period of regeneration establishment and the retention of reserve trees that may represent one or more age classes.

Under-stocked: Conditions in which the growing space is so completely utilized that growth has slowed down.

Understory reinitiation: disturbance and the creation of gaps at which point stratification develops with layers of canopy, midstory, and understory.

Uneven-aged (selection methods): methods of regenerating a forest stand, and maintaining an uneven-aged structure, by removing some trees in all size classes either singly, in small groups, or in steps.

Vegetative reproduction: reproduction produced by vegetative propagation by asexual means.

Veneer: a thin sheet of wood of uniform thickness, produced by rotary cutting (peeling) or slicing, and sometimes by sawing.

Wood: the material produced in stems and branches of trees and other woody plants.

Appendix

		THREATS	CONTROL AND REMOVAL
	**Japanese Barberry** *Berberis vulgaris (pictured)* **Common Barberry** *B. thunbergii*	Where barberry establishes a dense, shady ground cover, little else is able to sprout or grow. Deer and other browsers avoid it in favor of native plants. Raises soil pH and reduces depth of leaf litter on the forest floor.	The entire plant and roots can be pulled with hand tools or by other mechanical means. Alternatively, the stem can be cut and herbicide applied to the stump.
	**Oriental Bittersweet** *Celastrus orbiculatus*	Twining vines girdle the trees and shrubs they climb. Vine mass can pull trees down and make them more vulnerable to wind, snow, and ice damage. Once an infestation is well-established, a nearly impenetrable mat blankets the area, shading and choking out other vegetation. Unfortunately, it remains popular as an ornamental.	A combination of mechanical removal and herbicide (often triclopyr) is typical. Large infestations are difficult to control, as roots sucker and seeds persist in the soil for several years. In fields, weekly mowing is effective. Infrequent mowing merely stimulates root-sprouting.
	**Common Buckthorn** *Rhamnus cathartica (pictured)* **Glossy Buckthorn** *Frangula alnus*	Dense stands shade out all other shrubs and tree seedlings, as well as wildflowers and other herbaceous plants, reducing habitat for small mammals and birds. Seedlings can wait decades for the canopy to be opened. Laxative properties of fruits can harm wildlife or rob them of energy. Elevates nitrogen content of forest soils, altering insect communities.	In small numbers, seedlings can be pulled by hand and hung in nearby trees to desiccate. In thicker stands, pulling can stimulate growth, as can mowing or burning. Foliar herbicide is sometimes required. Larger trees can be girdled, or cut (with herbicide then applied to the stump).
	**Burning bush** *Euonymus alatus*	In a well-established stand, the thick foliage casts heavy shade, which – combined with a shallow, dense root system – prohibits all other undergrowth species. The numerous seeds are widely spread by birds.	Smaller plants should be pulled by hand or dug out with hand tools. Larger shrubs can be cut and herbicide applied to the stump. For extremely large infestations, herbicide can be sprayed in early summer.
	**Garlic mustard** *Alliaria petiolata*	Shade tolerance, dense growth, and prolific seed production (to 6,000 per plant) make it an aggressive competitor, especially against other spring-blooming species. Kills mycorrhizal fungi, thus threatening hardwood regeneration. Certain native butterfly larvae often die when hatched from eggs laid on garlic mustard.	Infestations are best pulled by hand (with care taken to remove the taproot) or repeatedly cut at ground level before seeds form. Second-year plants are best removed when in full bloom. Fire or herbicides are sometimes used for larger areas. Seeds persist in soil for up to five years.
	**Bush Honeysuckles** *Lonicera maackii, L. morrowii, L. tatarica, L. x bella*	Spreading quickly in disturbed soils, honey-suckles can severely affect forest regeneration after logging. Mature bushes cast heavy shade and suppress growth of native species, resulting in a reduction of plant diversity. Because invasive honeysuckle is rarely eaten by deer, its presence increases browsing pressure on the relatively fewer, nearby native species.	Small plants can be pulled by hand. With mechanical removal techniques, any portion of the root left behind may resprout. Cutting and applying herbicide to the stump can be effective, especially in autumn.
	**Japanese Honeysuckle** *Lonicera japonica*	Competes ferociously for both light and soil resources, spreading by seeds, runners, and underground rhizomes. Can, like bittersweet, topple trees and shrubs.	Very difficult to control, due to its several propagation strategies. Pulling often leaves roots and rhizomes behind. Herbicide (sometimes in tandem with fire) is often applied in fall or winter.
	**Autumn Olive** *Elaeagnus umbellata*	Outcompeting native species, olives can form dense thickets that alter natural succession pat-terns and reduce plant, bird, and other wildlife diversity. Can interfere with the nitrogen cycle of native species dependent on poor soils. Prolific seeds are easily spread by birds. Can flower and set fruit at three to five years old.	Small plants can be hand-pulled. Herbicide is often required, applied to cut stumps or as a foliar spray. Cutting (without herbicide follow-up) and burning merely stimulate sprouting and more vigorous growth.
	**Norway maple** *Acer platanoides*	Outcompetes sugar maple by spreading rapidly to disturbed forest sites. Seedlings sprout vigorously. Mature trees form a denser canopy than sugar maple, shading out wildflowers and other tree seedlings.	Control methods include pulling seedlings, cutting trees, and – when necessary – applying herbicide to prevent re-sprouting.

Figure 35: Vermont forest invasives. Trimmed down from Cerulli (2008).

1. Buds

    a. types

        -terminal
        -pseudoterminal
        -lateral
        -superposed (more than one bud per leaf axil)
        -floral
        -vegetative
        -mixed

    b. covering

        -naked
        -scaly

            -imbricate
            -valvate
            -single, cap-like scale

2. Leaf Scars
3. Vascular Bundle Scars (located inside leaf scars)
4. Stipule Scars (modified leaves next to petiole)
5. Lenticels
6. Pith

    a. solid

        -homogeneous
        -diaphragmed (alternating dark and light layers)

    b. chambered
    c. hollow

7. Thorns, Spines, Prickles

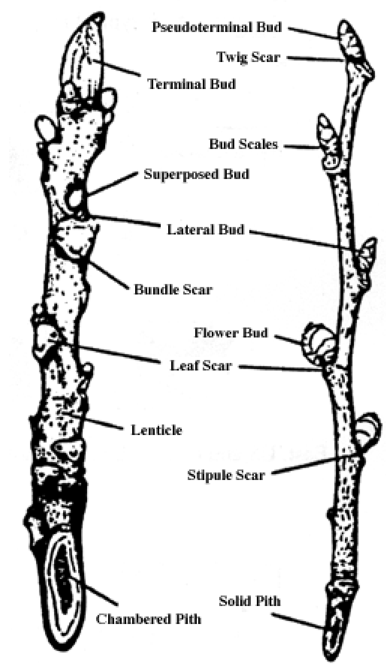

Figure 36: Twig anatomy

Table 2: Summary of Vermont climate projections. Adapted from Horton et al. (2015).

	Parameter	Trend	Projections*
Temperature	Annual Temperature	Increase	By 2050, projected increase in average annual temperature by 3.7-5.8° F; by 2100, increase by 5.0-9.5° F
	Seasonal Temperature	Increase	By 2050, projected increase in average winter temperature by 4.3-6.1° F; average summer temperature by 3.8-6.4° F
	Variability	Increase	Greater variability (i.e. more ups and downs)
Precipitation	Annual Precipitation	Increase	By 2100, projected total increase of 10% (about 4 more inches per year)
	Seasonal Precipitation	Variable	More winter rain, less snow; by 2050, winter precipitation could increase by 11-16% on average; little change expected in summer
	Soil Moisture	Decrease	Reduction in soil moisture and increase in evaporation rates in the summer
	Snow & Ice	Decrease	Fewer days with snow cover (by 2100, could lose ¼ to more than ½ of snow-covered days); increased snow density; less ice cover, reduced ice thickness
Extreme Events	Flood events	Increase	More likely, particularly in winter and particularly under high-emissions scenario
	Number of short-term droughts	Increase	By 2100, under high-emissions scenario, short-term droughts could occur as much as once per year (in some places)
	Storms	Increase	More frequent and intense
	Fire	Increase	More likely
Phenology	Growing Season	Increase	By 2100, projected to be 4-6 weeks longer
	Onset of Spring	Earlier	By 2100, could be 1-3 weeks earlier
	Onset of Fall	Later	By 2100, could arrive 2-3 weeks later

* Range = low-to-high-emission scenario.

Table 3: Expected effects of key climate change factors on Vermont forests. Adapted from Horton et al. (2015).

Key Climate Change Impacts	Expected Effects
Increased Temperatures	Increased evapotranspiration, resulting in a decrease in soil moisture; moisture limitation/stress negatively impacts productivity and survival in many species
	Increased physiological stress, resulting in increased susceptibility to pests and disease, decreased productivity, and increased tree mortality
	Increase in overwinter survival rates of pests like Hemlock Woolly Adelgid and Emerald Ash Borer
	Decrease in winter snowpack, leading to change in deer and moose browsing patterns, thus affecting tree regeneration
	Lengthening of growing season resulting in changes in species competitiveness, especially favoring non-native invasive plants
Increased Fire Risk	Earlier, warmer springs, smaller snow packs, and hotter, drier summers conducive to increased fire risk
	Loss of fire-intolerant and increase in fire-tolerant species, such as red and pitch pines
Increase in Extreme Storm Events (e.g. wind and ice)	Increased physical damage and disturbance, leading to gap formation, which could facilitate the spread of invasive plants
	More gaps lead to more early-successional and edge habitats which are favored by seedling-browsing species like deer and rodents
Increase in Short-Term Droughts	Declines in forest productivity and tree survival associated with water limitation
	More drought stress decreases many tree species' ability to defend itself from forest pests and diseases, especially against defoliators like tent caterpillars (native) and gypsy moths (invasive)
Disrupted Phenology	Loss of cold-adapted species and increase in warm-adapted species
	Increased decomposition rate of organic material may enrich soils and make them more suitable for competitors and invasive plants
	Early spring thaws and late frosts can damage buds, blossoms, and roots, thus affecting regeneration