Forest Regeneration Assessment Series

1 | Forest Ecology: How a Forest Grows

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Introduction

Understanding how Pennsylvania forests have changed and recognizing the need for careful forest stewardship to ensure their future health and resilience depends on learning to evaluate and address current challenges affecting forests. Among the issues landowners can address as they care for forests is forest regeneration, creating the next forest to replace the current through natural processes or by planting, usually prior to complete or partial removal of the tree canopy. Research conducted by the United States Forest Service finds that forests across the Northeastern United States are not regenerating or will likely fail to regenerate following canopy disturbance.

Pennsylvania's Forests

In Pennsylvania, 70% of the state's 16.7 million acres of forest is held by 750,000 private ownerships.

Across Pennsylvania, forests are the dominant land cover, accounting for 56% of the state's surface area (16.7 million acres). Interestingly, fully 70% of this forest is held in nearly 750,000 private ownerships. These ownerships range from an acre to thousands of acres. Whether you own, manage, or hope to own woodlands, through this and other publications in this series the intent is to help you understand how your stewardship of the land will help you derive what you value from forests and how your decisions affect those of your neighbors and future Pennsylvanians. The goal is a healthy, productive forest spanning generations – both its and ours.

Forest History

Pennsylvania has a rich history involving people and events. Its forest is equally rich in history, and, as is often the case, history shapes what we see and expect. Prior to European settlement, Native Americans influenced forest development as they lived on the land. Evidence suggests they farmed and hunted along major river systems; they used fire to spur food-mast production (e.g., acorns, chestnuts, berries) and to open forests for travel and hunting. Understanding and reading the history of our land use provides first insights into today's forested landscapes.

Major changes came to Pennsylvania in the late 1600s when William Penn received a land grant to settle the state. With this event, the wilderness dominated by forests began to yield to new demands for wood, agricultural development, and an eventually burgeoning economy. Pennsylvania was blessed with connecting river systems for transporting people, farm products, and raw materials. As populations grew, agriculture reduced forests on the better sites and demand for wood grew to build mills, houses, barns, equipment, and even roads (plank roads to facilitate land travel were common). Forests were essential for providing wood and energy. Early industries in the state such as iron and leather depended heavily on forests, as furnaces using wood charcoal and tanneries using bark were common. Demand for land and wood drove much of the early land clearing of forests. By the 1860s, Pennsylvania led the nation in wood production, and demand for wood for railroad ties, mining, and development continued to grow. Technology expanded and steam power came to the forest, replacing water transportation, and, by 1920, much of the state was cut over – forests were decimated and the industries dependent on them were moving west. Witness today that there are few remnants of the original forest – the virgin forest was and is gone.

Today, from a low of only 11 million acres of cut, depleted forests, we've seen a comeback, and many of the farms that once struggled on less productive sites have reforested. We find pride in how the state's forests have recovered; however, it is much different from the forest early settlers encountered. Diminished are the extensive pine and hemlock forests. American chestnut, once dominating parts of Pennsylvania's forests and reaching immense sizes, was stricken by the chestnut blight in the 1910s and is now essentially gone. Other tree species now comprise our forested landscape. It is common to find evidence of these earlier times in our forests – foundations, abandoned roads and railroad grades, fences, stonewalls, even apple trees that seem out of place.

Today, a walk in Pennsylvania's forests uncovers modern change mingled with our history. Farms and once large extensive forest blocks are increasingly broken into small ownerships. New fences intersect with old. Timber harvest, insects, diseases, and other disturbances change forests every day. We continue to have tree species threatened and challenged, recalling hemlock woolly adelgid, emerald ash borer, Dutch elm disease, beech bark disease, and others. We continue to write a new history on the land.

Forest History Further Reading:

https://explorepahistory.com/story.php?storyId=1-9-E&chapter=1

https://www.youtube.com/watch?v=p4ohbPMvaxE

https://www.fs.usda.gov/treesearch/pubs/3961

Forest Ecology

Understanding how forests grow and develop depends on gaining a basic understanding of forest ecology. Those who study forest ecology tend to think of how the site and environment influence the dynamics of existing plant communities where individual species interact and effect change.

In Pennsylvania it is easy to observe how site – where forests grow – affects forest growth and development. Simply moving from a valley floor toward the top of a ridge provides a lesson in site as plant species change and the overall mix of species often changes as well. How we use land also changes. On the valley floor, agriculture may be common; wooded areas there may occur in specific locations, for example, along streams or in areas where rock is near the surface. As the slope rises from the farmland, trees become more common, with a diverse mix of hardwood species that, as they mature, attain impressive height, and a rich mix of woody and herbaceous plants in the understory. Further up the slope, plant associations change. The diversity of plants changes as fewer tree species occur in the upper canopy, and understory plants may represent those that grow on drier sites, for example low bush blueberry and mountain laurel. Finally, arriving at the ridge top, there is further species reduction, and trees of species seen at the valley – if they are still in the mix – are noticeably shorter, but otherwise absent. Likely, you can think of other examples of site influencing the plant mix or community – lake shores, swamps, riverbanks locally, or moving from east to west or north to south across the state.

Site interacts with climate, where climate is the longer-term accumulation of seasonal change and weather. Understand that weather changes day to day and season to season; however, climate sets up our anticipations across time – it will get hot or cold, rain or snow. Circling back to site, it is clear to those familiar with Pennsylvania's landscape that the wind, snow, and ice are much different on ridge tops than in the valleys. To the careful observer, site-related climate also changes across the landscape. A site that faces south is hotter and thus often drier than a similar place facing north, east, or west. This relationship is known as aspect. Increasingly, society is considering energy creation based on solar. In this application, south-facing slopes are preferred as they garner more light compared to north-facing aspects. Plants, as solar collectors, exhibit the same preferences; however, they also respond to moisture as the sun's intensity on south-facing slopes can lead to a lack of adequate moisture to efficiently carry on photosynthesis.

Plant Growth

Plants interact directly with their environment and respond to the conditions encountered. It is useful to describe plant interactions as involving two components: 1) non-living (i.e., abiotic), and 2) living (i.e., biotic). The non-living component further defines site conditions and provides information useful in assessing the interaction of plants with site. The living component informs an understanding of how plants interact with each other and other organisms.

Plant growth depends on access to 1) water; 2) nutrients; 3) light; and, 4) space. Arguably, plants also require atmosphere to carry on photosynthesis; however, this is generally available in abundance and difficult to change.

Abiotic (non-living) Considerations

Soils

Scientists with an understanding of soil formation and plant interactions would argue that soils are really a living biome as soils are rich in flora and fauna and represent extremely complex systems. These systems involve organic nutrient recycling through decomposition, along with processes that aid drainage and help build soil structure. While it is easy to overlook the role of soils in the context of tree growth, soils fundamentally provide both water and nutrients. For simplicity, this discussion focuses on these non-living contributions of soil.

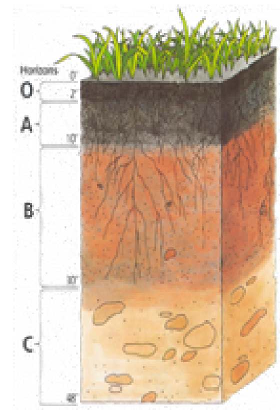
Soil texture describes the mix of sand, silt, and clay, respectively, largest to smallest particle sizes. The relative mix of these mineral components is important in describing a soil's ability to provide both water and oxygen to plants. Soils high in clay are often wet, and, as such, provide water but lack pore space and oxygen to support good root development. On the other hand, soils high in sand have large pore space which is not good for holding water, so they tend to be dry or droughty. There is good space for root development; however, they lack water. Better soils, often referred to as loam, have sand, silt, and clay in nearly equal parts.

Soil development is driven by the parent material or the rocks that decomposed to form the soil. Therefore, understanding the underlying rock formations aids in understanding the nature of the resulting soil. For example, soils formed on the tops of many Pennsylvania ridges, which are often sandstone, have larger amounts of sand. Soils formed in the valleys in central Pennsylvania often derive from limestone and have finer structure and higher nutrients because the parent material, compared to sandstone, creates soils that are less acidic and cycle organic nutrients more efficiently.

Beyond texture, soil depth is another important characteristic affecting tree growth. Several factors influence soil depth, including slope and slope position. Soils move through erosion and gravity. It is logical that soils are deeper near the bottom of slopes, even small shallow slopes. Similarly, soils are shallowest near the top of slopes. A note about water – water is necessary for plant photosynthesis to occur. Pennsylvania is a state rich in water. On average, annual precipitation for the state is around 40 inches. The type of soil and location of the slope determine a plant's access to water, but overall, water is not usually a limiting factor to plant growth, as compared to the more arid west.

Soil depth, texture, and drainage are important to tree anchorage as well as growth. Trees on good sites develop extensive root systems that will extend beyond individual tree crown widths, forming a mat of overlapping and sometimes interconnecting roots. Surprisingly, root depth is not always deep. Some roots will reach deep; however, much of the tree root development is the upper 12 to 18 inches of the soil profile. On poorly drained or droughty soils, root development is more restricted and tree anchorage is compromised.

In reality, soil scientists describe soil profiles that provide interpretations across the depth of the soil and how soil particles change and accumulate across the profile. To learn more about soils, it is useful to consult local soil surveys to understand your soils and their ability to grow trees.



Most soils have three major layers: the surface layer (A), the subsoil (B), and the substratum (C). Some soils have an organic layer (O) on the surface. The depth of these layers typically decreases as you move up a slope.

Adapted from the USDA Natural Resources Conservation Service: **www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054308**

Soils Further Reading:

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/forest-soil

https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=PA

Light's Role

Photosynthesis is at the heart of plant and tree growth, and light drives the process. Light provides the energy that allows green plants the ability to convert water and carbon into sugars; therefore, developing an understanding of light intensity, quality, and solar insolence (a measure of how sunlight intensity affects temperature) is another part of interpreting site.

Light intensity and quality are not consistent throughout a forest. For example, moving from full sunlight to the shade of a single tree in summer demonstrates intensity changes and, along with that, heat gain. More subtle is how light intensity changes from the top of a forest canopy to the ground level beneath. The first thing noticeable is that the shadow cast by the canopy is seldom complete. There are "sun flecks" that move across the forest floor. These patches of sunlight are sometimes critical to keeping understory plants alive and functioning even at a diminished level.

Interpret shade as meaning reduced light intensity. Shade is not consistent. The farther something is from the ground, the less shade it casts. This happens because the sun is so large (a non-point light source), and, as a result, individual leaves in the forest canopy block some light. However, some light is capable of going around individual leaves. Hold a single leaf above the ground and it

Above: A closed canopy with minimal light coming through to the forest floor.
Below: Openings in the canopy allow light to break through to the forest floor.

casts two shadows. The one near the center is darker and is called the umbra, and the second shadow, which is smallest when the leaf is near the ground and enlarges as it moves away, is the penumbra. The high canopy, therefore, shows the accumulated penumbra. By extension, as a sun-blocking object is closer to the ground, it casts deeper shade, which in turn reduces light intensity and results in less efficient photosynthesis in plants. These are important concepts because some forest sites have multiple layers, and those layers closest to the ground affect plant growth more.

A second factor enters into the process described above, and that is light quality. A rainbow or a prism demonstrates that white light has different wavelengths or colors. Plants use all the wavelengths of light; however, they use almost none of the green light. This wavelength is the color of chlorophyll, which plants reflect away as they absorb and use most of the others to some degree. So, a plant creating a shadow near the ground is gathering all the useful light and reflecting away green light. This interaction represents a reduction in light quality.

The increased temperature (solar insolence) associated with light intensity is another important light consideration, which interacts with soil moisture as it affects tree growth. The rate of photosynthesis links to both light intensity and temperature. In the northern hemisphere, light intensity is highest on south-facing objects, and, in a forest, south-facing slopes experience this best. At the same time, if soil moisture is low, trees on south-facing slopes may experience a water deficit and suspend photosynthesis through a complex process involving stomata, which are cell structures on leaves that control gas exchange. When this happens, trees have to consume products of photosynthesis to remain alive. Some of the best forest sites with the best tree growth and species diversity are often on the north slope, where light intensity is the least and temperature relatively lower. East slopes are better than west slopes because the air temperature is lower in the morning than in the afternoon, which again affects photosynthetic rates.

Biotic (living) Competition

Competition brings many of these introduced concepts together as trees compete for resources to carry on growth. Trees compete for moisture and nutrients supplied through forest soils. Individual sites vary in their ability to meet these two basic needs as soil texture and depth influence tree development. Further, slope position implies information about soil depth and moisture. Slope and aspect affect light intensity and temperature (i.e., solar insolence). Finally, light intensity, or the inverse, shade, is influenced by vegetation layers as the sun is a non-point light source. In many ways, light becomes the most limited resource in tree growth and forest development in the eastern US. Foresters often discuss shade tolerance when describing interactions between tree plant species.

Shade tolerance describes light requirements for individual tree species to germinate and respond to varying light levels. Shade tolerant species have the ability to germinate in relatively dense shade common under a fully-closed forest canopy and to persist in this condition. As well, shade tolerant species then have the ability to respond to increased light when it becomes available by increasing their height growth. Intermediate species are similar to shade tolerant species; however, while they may germinate in the same amount of shade, they will not persist. As well, they will not respond by reinitiating height growth as readily as tolerant species if they are held in shade too long. Ideally, intermediate shade tolerant species demonstrate their best growth with 50% or more light for germination and their best height growth. Finally, shade intolerant tree species require more light, up to full sunlight to germinate, will not persist in low light levels, and must have nearly full sunlight to demonstrate their best height growth. Given full sunlight, shade intolerant tree species on a given site will grow taller faster than intermediate species, which will grow faster than shade tolerant species. See Table 1 for a listing of common Eastern tree species by shade tolerance. One additional issue with shade tolerance relates to relative life expectancy, which is the inverse of height growth rates. That is, shade tolerant species tend to live longer and grow slower than trees in the other tolerance groups, while shade intolerant trees tend to have shorter life spans.

Table 1. Shade Tolerance of Some Common Eastern Trees

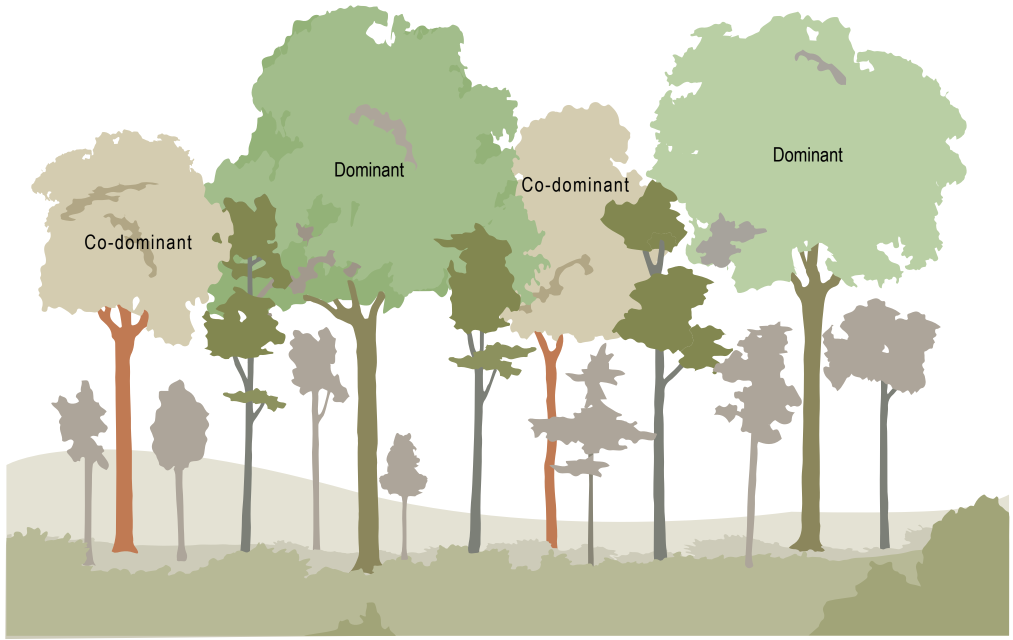
Shade-tolerant	**Intermediate**	**Shade-intolerant**
Beech, American	Ash, white	Aspen
Blackgum	Bald Cypress	Basswood
Dogwood, flowering	Birch, black and yellow	Birch, gray and paper
Hemlock, eastern	Boxelder	Cedar, eastern red
Maple, sugar	Cedar, Atlantic white	Cherry, fire and black
Sourwood	Hackberry	Cottonwood, eastern
Pawpaw	Hickories	Larch
Yellow buckeye	Magnolia, cucumber	Oak, pin
	Maple, red	Oak, scarlet
	Maple, silver	Pine, red
	Oak, black	Pine, shortleaf and loblolly
	Oak, chestnut	Pine, Virginia
	Oak, northern red	Poplar, yellow
	Oak, southern red	Sycamore, American
	Oak, white	Sweetgum
	Pine, eastern white	Willow, black
		Walnut, black

Source: Kays, J., Downing, A.K., Finley, J. et al. 2015. *The Woods in your Backyard,* 2nd Edition. Plant and Life Sciences Publishing, New York.

Shade tolerance is an important concept in forest management and guides decisions on how individual tree species will respond to competition. If tree species from all three tolerance levels germinate together, the forest may have multiple crown levels where shade tolerant trees are in the lower canopy level (e.g., hemlock, sugar maple, beech), intermediate species compete at the fringes of the upper canopy (e.g., red maple, red and white oak), and shade intolerant species are in and extend beyond the main canopy (e.g., yellow poplar, aspen, black cherry, white pine).

The above process describes how many of the forest stands in Pennsylvania developed following the heavy harvesting in the late 1800s and early 1900s. As the state's forests regrew with a mix of shade intolerant to tolerant tree species, individual trees garnered more site resources, especially light. As the stand developed and individual trees increased in height, they competed for space in the canopy, and the stand tended to stratify by stem height and diameter class. Shade intolerant trees captured the upper, or dominant, positions (see Figure 1), and because they captured site resources most efficiently, they developed larger diameters. While it might not always be apparent, undisturbed stands often differentiate by tolerance into height and stem size classes.

Foresters typically describe four crown classes: dominant, co-dominant, intermediate, and shade-tolerant. As shown in Figure 1, dominant trees comprise



Because shade intolerant trees require much sunlight, they typically become the dominant and co-dominant trees in a forest with trees of similar age.

Adapted from: Kays, J., Downing, A.K., Finley, J. et al. 2015. *The Woods in your Backyard,* 2nd Edition. Plant and Life Sciences Publishing, New York.

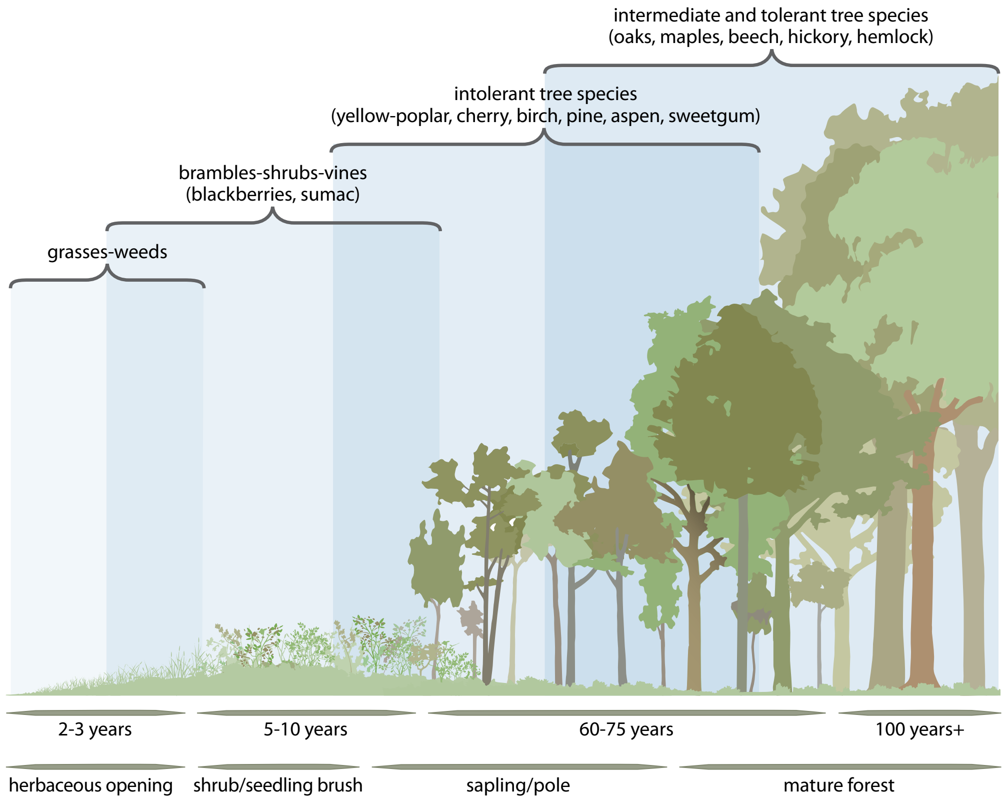
Figure 1. Shade Tolerance and the Four Crown Classes

the uppermost layer of the forest canopy, and because they emerge above the general canopy level, receive light from above and the crown sides. From below, these individual tree crowns appear round as they are above competition from lower trees. Co-dominant trees represent the general canopy and receive light from above and some from the side. From the ground, these crowns often have irregular crowns as they compete with others in the same crown position as wind moves the crowns and they abrade or fight with each other. Intermediate tree crowns are struggling or have lost the contest to reach the co-dominant layer and only receive light from above. Finally, the overtopped or suppressed crowns receive no direct sunlight from above. Shade-tolerant trees can linger in the understory, waiting to take advantage of light when an opening occurs in the overstory.

These oak tree crowns in the uppermost layer of the forest canopy illustrate the round appearance of a dominant tree (left) and the irregular shape of a co-dominant tree (right).

Because light and competition drive crown stratification, it is relatively easy to appreciate the role tolerance plays in this process. Interestingly, those trees comprising the upper canopy are more often impacted by disturbance events caused by wind, ice, or harvesting. A harvest focused on the largest trees invariably takes the winners and retains less competitive individuals, and shifts stand composition toward more shade tolerant individuals or trees of a given species that grew slower or hung in despite a lack of access to light and other resources. This has major ramifications to future forest conditions as the disturbed stand moves toward regeneration or older structure.

Light and competition set the stage for appreciating the need to evaluate and create light conditions to foster tree regeneration or to retain some tree species. They also set the stage for thinking about how light drives competition as a forest grows and develops.



Adapted from: Kays, J., Downing, A.K., Finley, J. et al. 2015. *The Woods in your Backyard,* 2nd Edition. Plant and Life Sciences Publishing, New York.

Figure 2. Old-field Succession Timeline

Succession

On a given site, ecologists suggest there is a natural and predictable replacement of plant communities over time. This is known as succession and describes the process and expected outcomes. Old-field succession, shown in Figure 2, is a classic example that describes how an abandoned old field slowly becomes a forest-dominated plant community. Competition for resources, tolerance for light, and other conditions allow each successive plant community to modify growing conditions to benefit the next wave of plants.

In old-field succession, the process begins with exposed bare soil. The first plants to appear are annual herbaceous. These plants tolerate rather harsh conditions of perhaps full light, high heat, and water stress. Their passing each year adds organic material to the surface, which modifies the site by cooling the surface and decreasing surface water loss. They are creating a cooler microclimate for other species less tolerant to heat and full sun. Biennial and perennial herbaceous plants replace the annuals, and grasses eventually become part of the evolving plant community. Next are woody shrubs that emerge above the herbaceous plants. These taller, longer-living woody plants create shade that suppresses the herbaceous component; this sets the stage for trees to emerge and overtop shrubs. Shade intolerant trees in theory are first to appear and the shade tolerance slowly shifts to more tolerant species.

There are variations in this process. For example, if the soils are too wet, species composition will vary and the process may stop or arrest when high-bush blueberries capture the site. Alternatively, on a dry site, succession might slow or stop if mountain laurel dominates. Available seed sources also modify the progression of species. In another example, perhaps the old field has abundant sugar maple upwind from the site. In that case, the field might quickly move to sugar maple, skipping the earlier herbaceous and shrub communities.

Succession also occurs in the forest. As individual or small groups of trees die from wind or storm events, insects, or management activities, light conditions below the canopy change. Depending on the size of the opening, site conditions, and seed sources, or already established understory plants or trees (called advance regeneration), some plants will have an advantage and others will lose in the competition for site resources.

Forest Development

Obviously, forests or woodlands are dynamic and complex places. In even small woodlots, there are differences in vegetation composition, size, arrangement, and spacing. One of the first steps toward managing a woodland is to recognize these differences.

In forestry, information-gathering and decision-making occur at the stand level. A stand is a contiguous, distinguishable group of trees of similar age distribution, species, structure, site, and history such that it is recognized as a unit. A landowner might even recognize and name these areas as the hemlocks, the old orchard, the oak ridge.

Each stand has gone through a separate or unique development as competition occurs both within and between species for light, moisture, nutrients, and space. As described earlier, individual tree species have specific needs and tolerances (e.g., shade tolerance). Imagine a carpet of tree seedlings growing under an existing forest canopy. Even with unlimited resources, most of these trees must die for a few to reach the forest canopy.

Disturbance plays a big role in stand development. Forest ecologists (e.g., Oliver and Larson 1996) describe how disturbance affects stand development and identify four stages of stand development:

> **Stand Initiation:** This stage occurs immediately after a major event that removes the existing stand. When this happens, trees, herbaceous plants, grass, and shrubs respond to increased access to resources and “capture” the site. The type of disturbance, soils, adjacent landscapes, and climate provide advantages to some species. Eventually, after several years, some plants occupy the site continuously. Ideally, these plants are desirable trees; however, in some landscapes invasive or competitive plants might capture the site. All of the plants (trees) that develop from this disturbance are the “cohort.”
>
> **Stem exclusion:** This stage begins when continuously growing plants occupy all the space and there is a lack of resources for plants to regenerate. In a forest stand, the plants will appear as a single layer, sometimes called the “brush stage.” In some cases, depending on stand conditions prior to the disturbance, invasive plants could quickly create this condition and “arrest” or stop stand development. For example, it is common to see invasive multiflora rose, bush honeysuckle, Japanese barberry, among other plants, take over a disturbed stand. In a single species stand, individual trees will begin to differentiate into crown classes, as individual trees gain dominance and subsequently suppress others in their cohort. Eventually, this within-species competition leads to tree mortality, which has to happen if individual trees are to continue to expand their crowns to capture light resources and their need for an increasing share of water and nutrients from the site. In the case where mixed tree species

develop, faster growing species and individuals within the species group and the cohort will overtop slower ones and lead to shifting composition. This is often the case in Pennsylvania, where, for example, faster growing black cherry and yellow poplar might overtop red and sugar maple. When this happens, it is easy to assume that these layers represent different age classes, which is not the case. This condition might persist for years, decades, or even centuries.

Understory reinitiation: At this stage, a stand is fairly far along in its development and trees from the stand initiation cohort have fully occupied the growing space. Canopy trees may have died, but those slower growing trees in the cohort have moved up to fill in gaps. Eventually, though, the cohort lacks to the capacity to hold the site and regeneration reappears on the forest floor. The amount of light available to this regeneration remains low as the overstory shade restricts its further development.

A shelterwood harvest is a two-step harvest with the first cut reinitiating an understory of regeneration to become the next forest. 10-20 years later, the second step removes the remaining large trees.

Complex/Mature: Development of complex/mature stands evolves over time and can come about without a significant disturbance event; rather, the disturbance can occur at the individual tree or small group level. The resulting stand has two structural components: 1) spatial in both vertical and horizontal dimensions and, 2) age as there are multiple cohorts in the stand. At some point in the stand's development there was an initiation event (e.g., fire, wind, ice, insects, disease, harvest) followed by multiple reinitiation occurrences. Over time, repeated reintiation events lead to the development of multiple cohorts, which represent different species and tolerances, depending on the spatial arrangement of individual and small group losses. Complex/mature stands may have high or low species diversity, but will have trees of all diameters and heights, which truly represent different ages/cohorts. Eventually, time, individual tree loss, and small reinitiation events will replace all individuals from the original cohort.

Stand Development Further Reading:

Oliver, C.D. and Larson, B.A. 1996. "Forest Stand Dynamics, Update Edition." *Yale School of Forestry & Environmental Studies Other Publications*. **https://elischolar.library.yale.edu/fes_pubs/1/**

Stand Development and Succession

The stand development process described above assumes that succession from stand initiation to complex structure proceeds without disturbance. This is seldom the case because either natural events (e.g., wind, ice, insects, diseases, herbivory (i.e., rabbits, voles, deer)) or human-driven events (e.g., firewood cutting, forest thinning, large tree harvests) affect stand development. Such disturbances can reset forest stand succession.

As shown in Figure 3, human decisions can advance succession. The first dotted line connects a mown lawn condition with the sapling/shrub stand condition. Left to natural development to attain a condition synonymous with the stem exclusion stage might require 30 or more years; however, a decision and action to plant sufficient plants might shorten this time period significantly. In the same way, natural development to complex/mature depending on site, species composition, and competition might involve 125 or more years, perhaps centuries. Careful interventions that remove competition among trees that reach or have the capacity to reach into the canopy can increase their stem and crown diameter

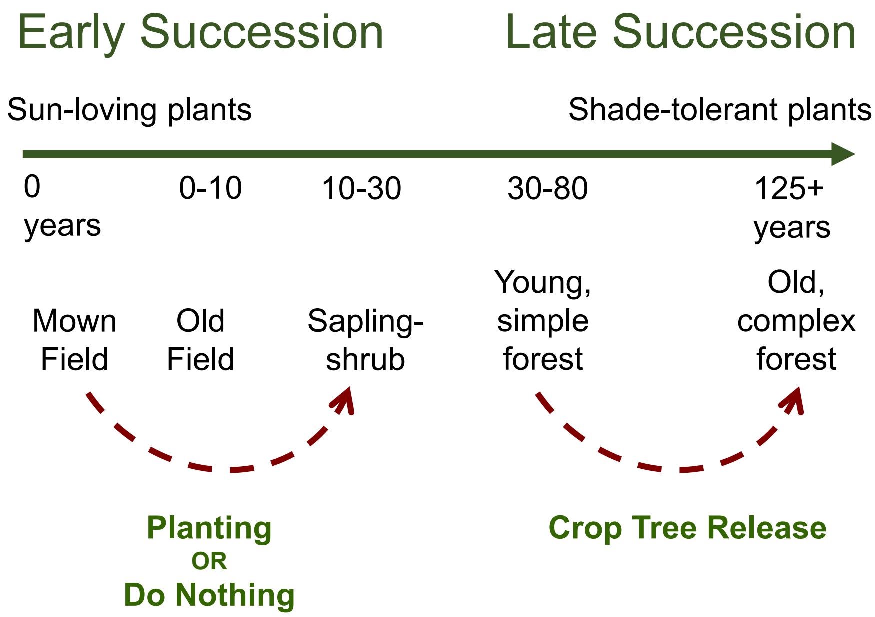


Figure 3. Advancing Succession through Decisive Action

by reallocating light and other resources to their growth. Then, later in stand development, removing some of the previously-released trees could encourage development of understory structure to accelerate the appearance of complex/ mature characteristics.

Figure 4 demonstrates how succession is reset to a previous stage. In each case, the focus is on the complex/mature condition. Depending on the disturbance intensity, the outcome can significantly alter the successional pathway. The least clear reset is moving the stand back to the "young-simple forest." This is not simple and represents a decision made by many forest owners who chose to harvest mature trees – cutting the big ones to allow the little ones to grow. Recalling the history discussed earlier, heavy harvesting across the state in the late 1800s and early 1900s resulted in forests where trees, whether in the canopy or below their taller neighbors, are often the same age. A careful observer might determine that

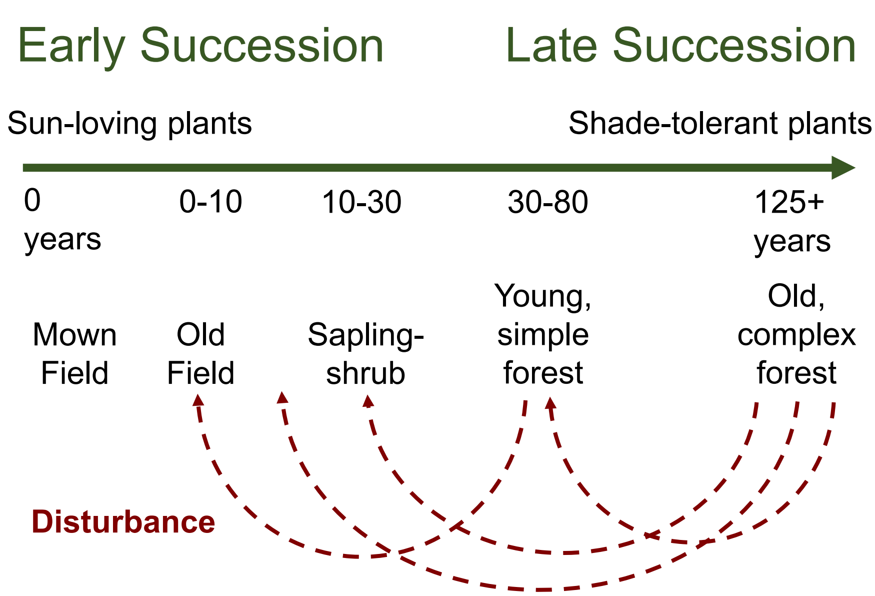


Figure 4. Resetting Succession through Natural Disturbances

the shorter trees are more shade tolerant and smaller in diameter, while the upper canopy trees tend toward shade intolerant species and have larger diameters. Decisions to cut the “big old trees” will shift species composition and result in a less species-diverse forest. More on this later in subsequent publications in this series.

Conclusion

This publication, *Forest Ecology: How a Forest Grows*, has set the stage for taking a series of steps to help ensure that Pennsylvania’s forests remain healthy and resilient. As mentioned at the onset, many of our forests, both public and private, are facing challenges relating to regeneration of the next forest. In subsequent publications in the series, you will learn to assess where forest stands in your woodland are in their development stage. If they are at a stage where regeneration should be present or you are considering specific management activities or anticipate threats to your forest, you will learn to assess the likelihood of successful regeneration. You will also learn how to assess reasons for a lack of regeneration and explore options for moving forward or for seeking assistance.

For many reasons Pennsylvania’s forests are changing. If you want to steward your woodlands well, it is imperative each woodland owner learn to gauge their woodland’s health, evaluate the potential for renewal, and act accordingly.

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