Afforestation Guide for Southern Ontario

Ontario

AFFORESTATION GUIDE FOR SOUTHERN ONTARIO

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Preface

Ontario has a rich history of afforestation dating back to the late 1800s. Over the years a great deal of knowledge and experience of what works and what doesn't for Ontario sites has been generated. Some of that knowledge has been documented in various technical notes and informal "guides" but much remains only in the minds of practitioners, passed down through mentorship and rules-of-thumb. This afforestation guide attempts to capture those documented and undocumented sources of knowledge into a single practical source.

By design, the *Silvicultural Guide to Managing Southern Ontario Forests* (OMNR 2000) does not address the establishment and management of plantations, particularly those on old field sites. When the southern guide was last reviewed feedback from users placed a high priority on addressing this topic. This afforestation guide serves that purpose and is presented as a companion document to the *Southern Guide*.

This guide presents information and best practices only. In isolation each piece of the guide may be an interesting read but it requires a clear landowner objective (economics, aesthetics, habitat, erosion control, carbon sequestration, etc.) to bring it all together into something meaningful. The first step in applying this guide is deciding what kind of future forest you want. It is highly recommended that you engage a knowledgeable professional in this process.

While the focus of this guide is afforestation on old-field sites, the information within, particularly the plantation management sections, should be useful in the management of plantations in reforested areas as well.

Acknowledgements

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Chapter 1
Introduction and Context

1 Introduction and Context

1.0 Introduction

Afforestation is the establishment of a forest where there previously was not one. The purpose of this guide is to provide information and best practices regarding the establishment and management of afforestation areas. This document is presented as a companion document to *A Silvicultural Guide to Managing Southern Ontario Forests* (MNR 2000) and as such does not represent a policy position of the Ministry of Natural Resources and Forestry (MNRF) or carry any inherent legal or regulatory weight.

This guide was developed through the collaborative efforts of many individuals and organizations with experience in afforestation. This includes both the practitioners engaged in the development of this guide but also those that came before them. The development of this guide was in part an exercise in collecting and aggregating existing sources of information under a common cover. While existing sources provided a good foundation this document also presents new information developed from both empirical information and the experiential knowledge of practitioners.

This guide is organized into 6 chapters. Chapter 1 provides an introduction and brief context for afforestation in Ontario. Chapter 2 covers the establishment and early growth of afforestation areas including site suitability, stock selection, planting methods, and early monitoring. Chapter 3 is dedicated to competition control and covers topics such as site preparation, cover crops, tending, herbicides, and the unique aspects of working on former agricultural land. Chapter 4 addresses management of plantations including predicting growth, spacing and thinning strategies, generating value, and end stage options including transitioning to native forest cover types and establishing the next plantation. Chapter 5 covers forest health including insects and diseases, biotic and abiotic damage, and climate change. Chapter 6 includes eight case studies presented as both a demonstration of the concepts covered in the previous chapters and inspiration to follow or adapt to local circumstances.

While various aspects of this guide may be interesting to a general audience it is largely aimed at a technical forestry audience.

1.1 The forests of Southern Ontario—a brief history

The forests of southern Ontario have undergone significant changes during the 400 years since the arrival of the first European explorers, fur traders, loggers, and settlers. But these same forests had previously undergone many changes since the last retreat of the glaciers. An understanding of the changes to the physiography, the soils and sites, and the vegetation that has developed will help today's forest managers choose the best options for establishing new forests or managing existing ones.

The forests of Ontario became established after the retreat of the Laurentide Ice Sheet of the Wisconsinan Glaciation period, which began about 80 000 years ago. The glaciers finally retreated from southern Ontario 12 000 to 10 000 years ago. At its peak, the ice may have exceeded 3 km in depth. The force exerted on the land by this ice caused erosion and abrasion of the underlying soils and bedrock. When the glacier finally melted, the resulting landscape and soils ranged from deep glaciofluvial deposits (relatively flat deposits of sand and other materials created by outflows of water from glaciers) to moraines (eroded materials deposited at the receding front edge of or underneath a melting glacier), eskers (ridges of gravel and other sediments formed by rivers flowing on or under a glacier), and drumlins (elongated, domed hills created by movement of a glacier), but also including areas of shallow soils (Dyke 2004).

As the glaciers retreated plants, animals, and Indigenous peoples were soon to follow. As the climate grew warmer and wetter early tundra-like forests dominated by spruce and dwarf shrubs gave way to the temperate forest species we see today. Indigenous peoples were not just passive occupants of the forest but an integral part of its development. Indigenous land management activities likely varied over time and between Nations but are believed to include: extensive planting of nut and fruit trees (butternut, black walnut, Kentucky coffee-tree, and Canada plum); the use of fire to improve the habitat for medicine, forage, and game species; and the cultivation of various crops in natural or man-made clearings. By the time European settlers arrived, the forests of southern Ontario were dominated by climax species such as sugar maple, beech, and hemlock, with pines and oaks more prominent in areas that were subject to fire.

Active settlement of Ontario by Europeans began in the 1700s, and usually followed early logging efforts. These early settlers focused on converting the forests into agricultural land, with little regard for the ecological consequences. Trees themselves were seen as obstacles to settlement and were frequently burned and converted into potash. Although much of southern Ontario could be described as “forest” in the early 1800s, clearing of the land was so efficient that by the 1860s, the southern parts of the province were almost devoid of forest cover. These exploitive practices quickly depleted the soil nutrients and organic matter that had built up over millennia causing many ecological and social problems, including topsoil loss, wind and water erosion, a shortage of fuelwood to heat homes, and the decline of most native plants and animals.

1.2 The beginnings of reforestation

The history of reforestation and afforestation in southern Ontario has been well documented (Lambert and Pross 1967, Borczon 1982, Armson 2001, Bacher 2011). Early farmers recognized the need for trees and forests and the benefits they provided in Ontario’s landscape. The government promoted tree planting as one way of preventing further degradation of agricultural lands and watersheds. The provincial government’s first formal response to the challenge of missing forests came in 1871, when they passed An Act to Encourage the Planting of Trees Upon the Highways in the Province, which gave local municipalities the authority to pass by-laws regarding roadside trees. This Act was eventually replaced by the 1883 Ontario Tree Planting Act, which paid landowners a small incentive fee to plant trees. Although this approach was largely unsuccessful in achieving large-scale replanting, some spectacular examples of these plantings can still be seen in southern Ontario (Fig. 1.2). These acts also helped to establish a necessary relationship between the government and landowners as partners in planting programs. This would become the foundation of more successful programs in the following centuries (Armson et al. 2001). A further description of some of these programs can be found in Appendix 6.

Figure 1.2: 120-year-old sugar maples lining a rural concession road near Orangeville, Ontario. [Photo source: Eric Boysen, NewLeaf Forest Services]

For the purposes of this guide, we will use the following definitions:

- "Afforestation" is the direct human-induced conversion of land that has not been forested for a period of at least 50 years into forested land through planting, seeding, promotion of natural regeneration, or a combination of these approaches.
- "Reforestation" is the direct human-induced conversion of non-forested land that was once forested (but is no longer forested) into forested land through planting, seeding, promotion of natural regeneration, or a combination of these approaches.
- "Deforestation" is the direct human-induced conversion of forested land into non-forested land.

1.3 Afforestation and plantation management - the landscape context

Afforestation can deliver a wide range of benefits from economic returns, to habitat, to carbon sequestration. Those benefits often extend beyond the property that is afforested by contributing to a diverse landscape. While it is recognized that afforestation decisions will be based largely on local considerations (soil, species preferences, budget, competing uses, etc.) the goal of this brief section is to provide landowners and forest managers an overview of how the landscape context might be considered in management decisions. Even when decisions are not driven by the landscape context, it may be possible to increase the landscape benefits provided by an afforestation project through small and often low or no cost adjustments.

1.3.1 Landscape context - location

Landscape context is in part knowing how an afforestation project fits within the surrounding landscape. Landowners and forest managers should try to discover any plans or constraints for neighboring properties and understand how those factors may influence decisions on their own property. For example, two adjacent landowners who are both planning a relatively small afforestation project can greatly increase the ecological value of their projects by grouping them at a shared boundary between their properties to increase the size of the new forest's core or to provide a wildlife travel corridor across the boundary. When a boundary is shared with a large landowner, particularly if a public body, a management plan may be available and can be consulted for guidance. Non- government conservation organizations that hold property are becoming increasingly sophisticated in their management and many have developed detailed conservation and restoration plans that an adjacent landowner could consult to evaluate possible synergies.

Managers of larger parcels, or collections of parcels, will have some choice about where an afforestation project will occur. However, even owners of smaller single parcels will have some choice when afforesting only part of their property. Some considerations for location include:

- the potential for connecting two existing natural areas
- the potential for expanding an existing natural area
- opportunities to achieve other objectives (e.g., to protect sensitive sites), and
- the minimum size/configuration to achieve the objective of afforestation (e.g. habitat)

In addition to recognizing the characteristics that define good locations for an afforestation project, it is important to consider factors that may make a given location unsuitable. This includes areas that have:

- high natural heritage value as a non-forest site (e.g., native grasslands)
- high land cost, or future urban or industrial development pressures
- deposits of high-quality aggregates
- prime agricultural land, or
- significant problems due to diseases, pests, or invasive species

The influence of these factors on the location of an afforestation project should be considered on a case by case basis. While these first order questions of location can be a factor, the importance of matching preferred tree species to soil conditions cannot be overstated (see section 2.2).

1.3.2 Landscape context – type of forest

Any landowner will have a wide range of reasons for choosing to establish certain tree species or species mixtures. These include personal preferences (i.e., favorite trees), the desire to attract wildlife, the cost or ease of establishment, and future economic benefits. Establishing a forest of any type where there was no forest before will have a significant ecological impact. Using the landscape context to determine the best type of forest to establish can greatly increase the beneficial impact.

Southern Ontario's forest diversity has declined during centuries of human activity. Forest cover has decreased, forest soils have changed or become degraded, and new soil types have been created (e.g., agricultural soils). Some species have been nearly extirpated in Ontario because of excessive harvesting, competition from invasive alien species, and damage caused by insects or diseases. Examples include cherry birch, American chestnut, American elm, butternut, and white ash. Afforestation projects that incorporate rare or declining species, even in small amounts, will contribute to their conservation. It is recommended that you engage a knowledgeable professional to better understand the location specific challenges and opportunities (e.g. seed source) before incorporating restoration targets.

Chapter 2
Establishment and early growth

2 Establishment and early growth

2.1 Management objectives

Before you begin considering how to establish a new forest, it's necessary to clearly decide on your goals and how you plan to accomplish them. This is commonly known as a "crop plan", and in the rest of this chapter, we'll describe the many characteristics of an afforestation project that you should include in a crop plan. Landowners and forest managers in southern Ontario usually identify several objectives they hope to achieve through their afforestation programs. These include economic goals, such as establishing a hardwood forest to allow harvesting of maple syrup or improve the resale value of land, or ecological goals, such as sequestering carbon to slow climate change or protecting a site from soil erosion by running water. Most plans have both economic and ecological goals.

These objectives may change over time if subsequent owners have different priorities, if economic constraints or opportunities become apparent years after establishment, or if unexpected natural factors such as climatic stresses or invasive pests become significant. You should therefore periodically review your objectives, particularly before each new management action, starting with the decision about what type of forest to establish and continuing with decisions about how to tend the stand to ensure that it remains healthy or to change the composition and structure of the future forest. This review should be based on the most current knowledge of your situation and the forest's condition. Long-term thinking is necessary, since trees take a long time to grow. If your goals are primarily economic, you should think in terms of "crop" planning (i.e., managing the stand to produce a desired crop such as timber or utility poles). This planning requires you to develop prescriptions for various management operations that will take place throughout the life of the plantation. These include how to protect the plantation while the trees are still young and vulnerable, whether to thin or prune the trees, and how and when to begin the forest renewal process as the forest matures. In this chapter, we will describe some of the options available to you and the principles that will guide you throughout the life of your forest.

Management objectives can be characterized as either traditional or ecological. We define *traditional* plantations as those in which:

- single species or perhaps two species, most often coniferous trees, which are planted in defined rows
- larger blocks of land (>4 ha) are preferred to enable the use of larger forestry equipment
- the primary management objectives focus on the cost-effective production of forest products, and
- secondary management objectives include longer-term soil, site, and forest restoration, and carbon sequestration.

We define *ecological* plantations as those in which:

- multiple species of trees (and possibly shrubs) are planted, sometimes in rows, but often in more of a random pattern
- smaller blocks of land are chosen, especially on sensitive sites such as riparian areas

- the primary management objective is an accelerated approach to forest succession through the planting of both shade-tolerant and shade-intolerant species, possibly to create specific habitat for wildlife, and
- the costs of establishment and subsequent management are not usually considered to be limitations

Traditional objectives are similar to the objectives first stated by E.J. Zavitz in 1909, and include possibilities such as ensuring a financial return on investment, producing forest products to supply local mills and create jobs, the protection of streams and watersheds through a forest's ability to improve the landscape's hydrological functions, the creation of wildlife habitat, and the provision of educational opportunities for the general public. More recently, management objectives have expanded to include the consideration of carbon sequestration to support climate change mitigation strategies. Ecological objectives can include economic objectives, and vice versa. But ecological objectives are more likely to include non-timber forest products such as maple syrup, mushrooms, forest herbs, and landscape-level considerations, such as those we described in Section 1.2. Site rehabilitation, biodiversity enhancement, improved wildlife habitat (especially for the species at risk that we discussed in Section 1.2.5), clean air, and aesthetics can also be considered. Some of the Community Forests with a long history of plantation management, dating back to the Agreement Forest Program, are now sufficiently mature that owners are receiving significant revenues because of their early afforestation efforts. These revenues can now be reinvested in further restoration and forest management work.

During the early years of Ontario's afforestation history, it became apparent that forest managers must first restore the site (particularly the soils, which we'll discuss towards the end of this section) before they can begin to restore the forest. Soils are the foundation of all plantations, and soil amelioration is a critical aspect of restoring a site after years of agricultural use or subsequent abandonment of agriculture. McPherson and Timmer (2002) examined the soil conditions on degraded sandy outwash areas of the Oak Ridges Moraine that had been planted with red pine. They noted several major processes that had begun to improve soils since plantation establishment, including:

- cessation of erosion
- re-development of soil horizons in the soils of non-eroded fallowed sites
- decreased bulk density due to accumulation of soil organic matter and increased root and animal activity, and
- recovery of soil fertility, particularly with fallowed soils

> **Note:** Soil horizons are distinct horizontal layers with different characteristics that develop in soils, such as the surface layer, in which the soil tends to be darker due to an accumulation of organic matter. Bulk density represents the weight of the soil per unit of volume; denser soils are more difficult for roots to penetrate and for oxygen to enter.

McPherson and Timmer also noted that this soil remediation could achieve conditions close to those of natural forest within 75 years after afforestation. The degraded sites where red pine was planted would have initially been unsuitable for the establishment of hardwood species, but over time, these plantations improved soil and site conditions sufficiently to support the natural establishment of a vigorous, shade-tolerant understory of deciduous trees.

> **Note**: Tree species have different light requirements. "Shade tolerant" species are capable of growing in the shade beneath a canopy of mature trees, and may even prefer those conditions. "Shade intolerant" species require large amounts of light, and grow best in the open or below gaps in a forest canopy.

Regardless of the management objective for a site, many factors must be considered before you can develop an afforestation crop plan. These include:

- **Size of the site:** Smaller blocks are more suitable for ecological restoration objectives because the labour requirements and financial investment are more manageable in small areas. Larger blocks are more suitable for traditional objectives because the large size permits operational efficiencies such as the use of heavy equipment.
- **Site conditions:** These conditions constrain what you can initially achieve, and include the soil condition (Table 2.1), the steepness and direction (aspect) of the slope, the vulnerability of the soil to erosion, and the amount of grass or other ground cover that may compete with the trees.
- **Labour and other assistance:** Whether or not you can obtain help doing the work required for tree establishment, the availability of assistance programs (e.g., subsidies or low-interest loans) will constrain the amount of work you can perform.
- **Planting stock and seeds:** The availability of suitable planting stock or seeds may determine what species it is possible to establish at a site.
- **Time:** Decide how quickly you want to achieve your objectives. Forests take a long time to mature, but the more intensive the management you can afford, the faster a new forest will reach key plantation milestones such as the free-to-grow stage (when the control of weeds and other competing vegetation is no longer required), the stage when thinning is required, and the stage when site restoration can be considered complete.
- **Location:** Whether the planting area is close to markets for forest products, or is near other plantations that can be managed cooperatively, will determine what management operations are economically justifiable. Proximity to a nursery that can supply suitable planting stock may also be a consideration.
- **Type of forest products to be produced:** If your goal is primarily traditional, potential products range from small-diameter trees suitable for fuelwood production to larger-diameter trees suitable for producing lumber or utility poles.
- **Financial constraints:** Establishing and tending a plantation will require a considerable up-front investment, and may not begin to provide a financial return for as long as 30 years into the future. Larger blocks that are established using conventional site preparation techniques, planting configurations, and tending techniques tend to be more cost-effective. However, it is difficult to provide sound advice on costs because they tend to be highly variable both between regions of Ontario (e.g., depending on worker availability and local machine costs) and over time (e.g., due to changes in the economy such as inflation). Some of these costs may be subsidized by government programs or local conservation agencies, some may be subsidized by carbon offset credit programs, and some must be borne entirely by the landowner. Once you have the basic outline of your crop plan in place, carefully research the costs associated with each phase of the project and prepare a tentative budget. These costs should include labour, materials (e.g., seedlings), equipment, and permit or licensing costs plus the costs of servicing any loans. You will need to review this budget periodically to ensure that if costs change, you will be able to revise your plan and the associated budget.

It is important to be able to properly identify and describe the characteristics of the planting site because the survival and growth of tree species will be limited by both the soil texture and the soil moisture conditions at the afforestation site. The texture of the soil is determined by the relative proportions of fine particles (clays and silts) and coarser particles (sands and gravels), and this may vary both between sites and within a site. Figure 2.1 and Table 2.1 illustrates the range of compositions for the main texture classes. OCSRE (1993) describes the various tests that you can conduct in the field to determine the soil texture. The simplest test include feeling the moist soil with your hands; sands feel grainy, whereas clays feel sticky. You can also moisten some soil and compress it in your hand; the more strongly the soil holds together, the greater the clay content. A related test is the ribbon test, in which you roll moist soil into a cigarette shape and then squeeze it between your thumb and forefinger to form a ribbon. Soils with a high silt content will form flakes, whereas those with a high clay content will form ribbons and those with a high sand content will fall apart. Last but not least, you can place a pinch of soil on your tongue and move it between your front teeth: sand particles will feel distinctly gritty, silt particles will feel slightly gritty, and clay particles will feel smooth. The soil depth is also important; if the depth to bedrock is ≤50 cm, the soil is shallow.

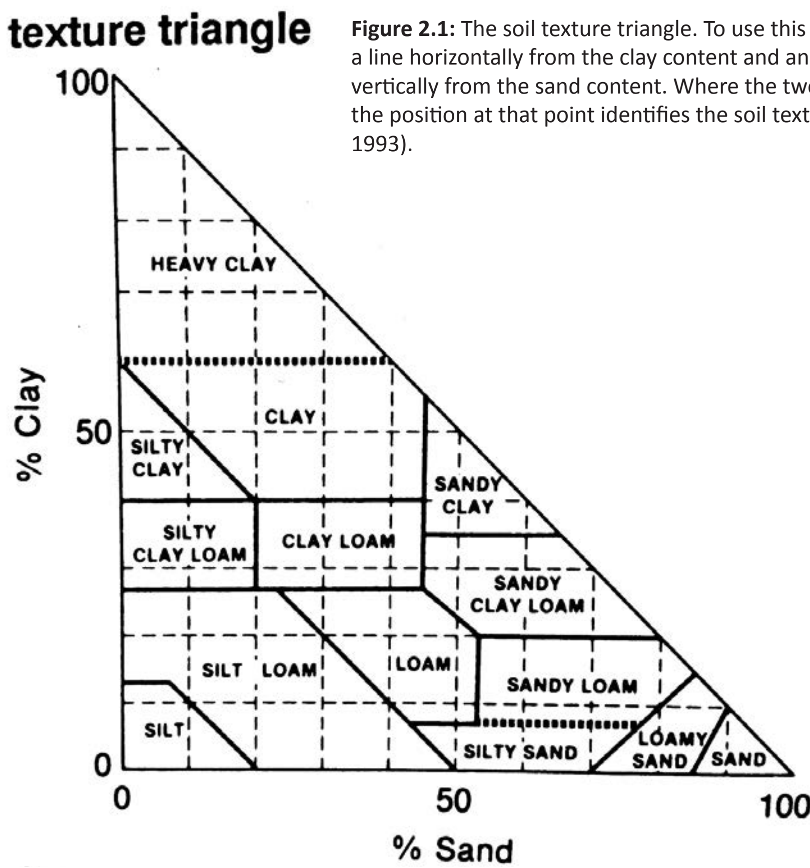


Figure 2.1: The soil texture triangle. To use this figure, draw a line horizontally from the clay content and another line vertically from the sand content. Where the two lines meet, the position at that point identifies the soil texture (OCSRE 1993).

Table 2.1: Typical soil texture classes used to guide selection of the most appropriate species or predict future growth performance (OCSRE 1993).

Soil texture class	Soils
Very gravelly	>50% of the particles are ≥ 2 mm in diameter
Gravelly sandy	Sandy soil with 20 to 50% of the particles ≥ 2 mm in diameter
Sandy	Very coarse, coarse, or medium sand, with few or no gravels. Fine sand, loamy very coarse sand, loamy coarse sand, loamy medium sand, or loamy fine sand. (Loamy soils contain some component of clay or silt.)
Gravelly loamy	All coarse loamy textures with 2 to 50% of the particles ≥2 mm in diameter
Coarse loamy	Very fine sand, loamy very fine sand, sandy loam, or loam
Silty	Silt or silt loam
Fine loamy	Clay loam, silty clay loam, or sandy clay loam
Clayey	Silty clay, sandy clay, clay, or heavy clay

Setting clear objectives is critical for afforestation success. Start by determining the species your site is suitable for. Next, identify what other plants are present that will compete with those species, and the most appropriate way to control this competition and give your trees a better chance to flourish. (We will discuss competition control in Chapter 3.) Based on these considerations, determine the best stock type (the type of seedling) or seed you should use, the optimal ways to handle that stock or seed, and the best planting approach. Define the type of tending (e.g., thinning) you will need to do, including pest management. Each step is important and many newly established forests have failed to thrive because of a lack of timely tending or pest control. In the rest of this chapter, we will summarize information gained from past experience with forest establishment that will increase the likelihood of a successful afforestation program, regardless of your objectives.

2.2 Soil and site considerations

Before you begin an afforestation program, consider the site characteristics so you can make any necessary adjustments to your management approach. For example, von Althen (1990) cautioned that hardwoods will not produce high-quality timber when they are planted on dry, exposed slopes and ridges, or in areas where the topsoil is shallow and the subsoil consists of heavy compacted clay. If those conditions exist at your site, you may need to grow conifers instead. Even if the production of high-quality timber is not your primary objective, the survival, growth, and general health of a hardwood forest may be unsatisfactory on such sites. Site conditions that are unfavourable for certain species can increase the length of time it takes to achieve crown closure and the effort required to maintain trees as the dominant plants. In addition, future tending costs are likely to increase. In the von Althen example, poor survival and growth leads to wider spacing, an extended period in which it's necessary to control competition from other plants, and ultimately poorer tree form and height growth.

Table 2.2 summarizes the species that are likely to perform well on certain soil types. Their performance depends on the soil moisture content, which will be determined by the natural drainage at your site. Sites with poor drainage are easy to detect, as they tend to have standing water for most of the growing season. There may also be no trees present, or only trees such as willows and alders that tolerate or prefer wet soils. Areas with fair (imperfect) drainage will lack surface water, but will reveal damp soil if you dig into the earth. Some will also show blue–grey streaks called "gleying" that indicate a lack of sufficient oxygen. Areas that lack these characteristics will generally have good drainage.

Table 2.2: Summary of the suitability of typical Ontario tree species for different soil types. Adapted from OMAF and AC (1992) and OMNR (1995a).

Soil texture[a]	**Natural drainage**		
	Good	**Fair (imperfect)**	**Poor**
Coarse (very gravelly, gravelly sandy, sandy)	Norway spruce Red pine White pine White spruce European larch Sugar maple Red oak Black locust Eastern white cedar Hybrid poplar Tulip tree [b]	Norway spruce Red pine White pine Eastern white cedar Hybrid poplar Silver maple Black locust Hackberry [b] Eastern cottonwood [b] Big shellbark hickory [b] Sycamore [b]	Norway spruce White spruce Silver maple Eastern white cedar Black spruce Tamarack Willows Swamp white oak [b]
Medium (gravelly loamy, coarse loamy, silty)	Norway spruce Red pine White pine Japanese larch European larch Sugar maple Red oak Bur oak Eastern white cedar Hemlock White spruce Hybrid poplar Black locust Hackberry[b] Sassafras [b] Shagbark hickory [b] Shumard oak [b] Tulip tree [b]	Norway spruce Red pine White pine Eastern white cedar Hybrid poplar Silver maple Bur oak Black locust Black cherry Black walnut American beech Basswood Big shellbark hickory[b] Hackberry[b] Eastern cottonwood[b] Sassafras[b] Shagbark hickory[b] Shumard oak[b] Sycamore [b]	Silver maple Red maple Norway spruce White spruce Tamarack Willows Bur oak Swamp white oak[b]

Soil texture[a]	Natural drainage		
	Good	**Fair (imperfect)**	**Poor**
Fine (fine loamy)	Norway spruce White spruce Japanese larch European larch Eastern white cedar Hemlock Hybrid poplar Black locust Sugar maple Black maple Black gum [b] Eastern cottonwood[b] Hackberry[b] Shagbark hickory[b] Shumard oak[b]	Norway spruce Silver maple White spruce Eastern white cedar Black locust Hybrid poplar Black gum[b] Big shellbark hickory[b] Eastern cottonwood[b] Hackberry[b] Shumard oak[b]	Silver maple Red maple White spruce Black spruce Tamarack Willows Eastern white cedar Swamp white oak[b] Black gum[b]
Very fine (clayey)	Norway spruce White spruce Black locust Eastern white cedar Bur oak Pin oak [b] Hackberry[b]	Silver maple Norway spruce White spruce Hybrid poplar Bur oak Pin oak[b] Hackberry[b]	Silver maple White spruce Willow Tamarack Pin oak[b] Swamp white oak[b]

[a] Table 2.1 defines the soil textures.
[b] This species should only be considered for Site Region 7E (the Carolinean zone).

Table 2.3 provides additional factors to consider after selecting a species that seems likely to perform well on the soils at your site. Appendix 1 summarizes the study of species suitability and productivity by soil properties in southern Ontario (Taylor and Jones 1986a, 1986b). Together, Tables 2.2 and 2.3 and this appendix will help you choose the best species for your site. If your site has two or more areas with distinctly different conditions, particularly for the soil and drainage, you'll need to choose different species for each area to avoid problems (OMNR 2000). The tables will also help you to group species that have similar survival and growth potential if you are considering a mixed-species planting to (for example) achieve an ecological goal such as increasing biodiversity. However, although the information in these tables is broadly applicable, there are sometimes exceptions. Don't neglect the value of visiting existing plantations on similar sites in your area so you can learn from the experience of other forest managers.

Table 2.3: Special considerations for the most common afforestation species in Ontario. Adapted from Johnson et al. (1996). Chapter 3 provides details on competition control, and Chapter 5 provides details of insect and disease control options.

Species	**Considerations**
White pine	White pine will tolerate a wider range of moisture regimes than the other pines, from moist to moderately dry. However, it should not be planted on dry sites or sites prone to drying. It should also not be planted in areas where white pine blister rust or the white pine weevil are potential problems without considering management techniques to control these pests. This species is also more susceptible to frost damage than other pines, since it begins its annual growth earlier.
Red pine	Red pine is an ideal plantation species when managed properly. It has the potential to provide a higher yield per hectare than any other conifer in Ontario. Red pine requires deep, well-drained, sandy soils. It will not perform well if planted on poorly drained, poorly aerated, or calcareous soils (soils derived from limestone). Although red pine is commonly planted on less productive sites, competition from grasses, raspberry, and shrubs may reduce its survival and growth, and tending is important to prevent this problem. Red pine is relatively free of serious pest and disease problems in Ontario.
White spruce	White spruce has slow initial growth after planting. If it is planted on improper sites, such as deep, well-drained sands, it will not reach its growth potential and will be severely affected by insects and diseases associated with stress. White spruce is prone to frost damage, which kills the terminal bud and leads to the development of multiple leaders (the shoots at the top of a tree that will compete to form the main stem). Choosing larger seedlings may overcome this problem. This species has high genetic variability, which is often expressed soon after germination as differences in seedling height and diameter. Thus, it's important to choose high-quality stock or seed that is well suited to your site.
Eastern white cedar	Eastern white cedar can grow on most sites that are capable of supporting trees in Ontario. Container planting stock and small to medium bareroot stock are adversely affected by competing plants. Larger stock should be used if you anticipate moderate to severe competition. Cedar seedlings are sensitive to drought during the first 3 years after planting. Cedar is usually planted on fresh mineral soils with a high calcium content.
Eastern hemlock	Eastern hemlock is found in the Great Lakes–St. Lawrence Forest Region, where it is able to survive for long periods under deep shade (as low as 5% of full sunlight). Establishment is negatively affected by high temperatures and sites that are prone to drought, so plant hemlock under a partial canopy. Hemlock prefers medium-textured mineral soils (such as sandy loams, loamy sands, and silty loams) that are deeper than 50 cm. Hemlock is intolerant of salt and should not be planted close to roads or other areas that may be salted in the winter.
Norway spruce	Norway spruce is an introduced species that has become naturalized (i.e., it now grows naturally in Ontario). It is predominantly used for shelterbelts and windbreaks, but also performs well in traditional plantations. It prefers well-drained loam to clay soils in a range of moisture regimes from fresh (slightly moist) to moist, or fresh sandy sites, but does not do well on dry or extremely wet sites.
Tamarack	The native tamarack can be established throughout Ontario on sites with a wide range of moisture levels, from sands to heavy clays. Tamarack is an opportunist that grows where other species have difficulty becoming established. However, it performs best on deep, well-drained loams to sandy-loam soils. Tamarack should not be planted where water collects for prolonged periods during the period of active growth. It is very intolerant of shade.

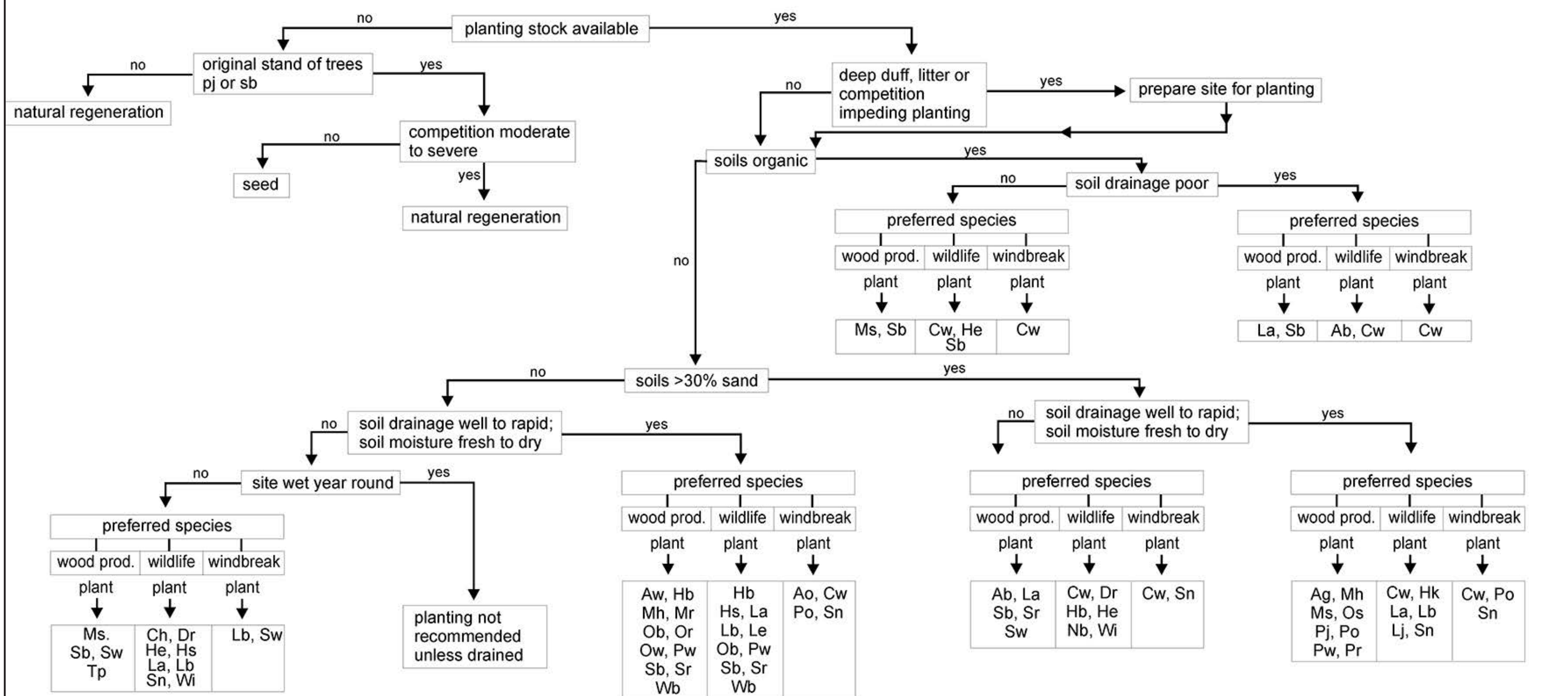
Species	Considerations
Japanese larch and European larch	Japanese larch and European larch are introduced species with soil requirements and growth characteristics similar to those of the native tamarack. In recent years, European larch seed has been in very short supply, necessitating the production of Japanese larch as an alternative species to fill the demands for planting stock. These species differ from tamarack in that they require well-drained loams and sandy loams. They should not be planted in shady areas, frost pockets, on poorly drained sites, or in pure stands. They are not tolerant of frost.
Red oak	Red oak grows on a variety of sites, but grows best on the lower slopes that face north to east and on deep, well-drained sandy loam and loam soils. Avoid sites with heavy clay, shallow soils, and shady, wet, or exposed sites. Red oak is moderately tolerant of drought and therefore tends to compete well with other species on dry sites.
Maples	Maples (sugar, red, and silver) have a wide range of genetic variation, so seed source selection is important. Sugar maple grows on a variety of sites from sands to silt loams, but shallow, dry sites should be avoided. Red maple thrives on a wider range of sites, and can out-perform other species on sites that are either too wet or too dry for those species. Silver maple grows best on rich, moist bottomlands near bodies of water, and prefers well-drained soils that may be subject to temporary flooding.
Black walnut	Black walnut has a limited range in southwestern Ontario. It is found on deep, moist, fertile, well-drained sandy loams, loams, and silt loams. Interplanting with other species should be avoided, because black walnut produces a toxic substance (juglone) that can kill or impede the growth of other plants that are growing within its rooting zone.

The Ecological Land Classification for southern Ontario is another important tool. The classification provides a standardized language and framework for describing ecological and forest management knowledge for Ontario's land (OMNR 2010a).

2.3 Choosing the right species for the site

Site suitability is the major factor that determines which species you can select. In addition to constraints imposed by the biology of a species, site characteristics such as soil and climate, and other factors (e.g., the abundance of certain insects or diseases), your choice of species depends on your goals for establishing a new forest, your budget, and how much time you can devote to the work. Figure 2.2 is an example of a decision key that will help you select suitable species for artificial regeneration in Ontario. Local managers may want to develop their own key for their most common sites and species choices.

KEY FOR SPECIES SELECTION



Once you have keyed out alternatives, the following should be considered:

-not all species are found throughout Ontario: see information on seed zones
*Carolinean species are only found in a small portion of southwestern Ontario
-more competetive sites are better suited to medium or large size classes while less competetive sites are better suited to smaller size classes
-susceptability of species to damage by frost, insects or diseases

Shrub species:
Ch - highbush cranberry
Dr - red-osier dogwood
Nb - nannyberry

Tree species:
Ab - black ash
Ag - green ash
Aw - white ash
Cw - white cedar
Hb - bitternut hickory
He - eastern hemlock
Hk - hackberry*
Hs - shagbark hickory
La - tamarack
Lb - black locust
Le - European larch
Lj - Japanese larch
Mh - sugar maple
Mr - red maple
Ms - silver maple
Ob - black oak
Or - red oak
Os - shumard oak*
Ow - white oak
Pj - jack pine
Po - poplar
Pr - red pine
Pw - white pine
Sb - black spruce
Sn - Norway spruce
Sr - red spruce
Sw - white spruce
Tp - tulip tree*
Wb - black walnut
Wi - willow

Figure 2.2: A sample decision key for identifying preferred species in relation to soil and site characteristics. Johnson et al. (1996).

Planting sites are typically divided into groups according to soil texture, depth, moisture regime, and drainage. Usually, one or two of the coniferous species most suited to the area will account for the bulk of the planting, sometimes with an additional two to four species added as a minor component of the forest. Both hardwood and coniferous species are included in traditional afforestation programs, but for a variety of reasons, conifers are usually emphasized.

Many of the sites available for afforestation have been degraded by past agricultural activity and are characterized by reduced fertility, simplified soil structure, and sometimes topsoil loss (McPherson and Timmer 2002). Where these factors are present, they typically limit the site's productivity, and coniferous species are typically the best option. Thus, species such as red pine (particularly on infertile, well-drained soils), white pine, and white spruce have been most commonly used.

Succession is the process by which a forest's composition and structure evolve over time, leading to the replacement of old plant communities with new ones. Most species that appear during the late phases of succession and some that appear during the middle phases are adapted to survival and growth under a forest canopy. Traditional plantations of conifers create forest conditions relatively quickly due to the uniform spacing of the planted trees and rapid achievement of crown closure, and thus, can eventually provide an overstory condition suitable for the natural establishment of many native shade-tolerant hardwood species. Species such as beech, sugar maple, and hemlock that could grow under these conditions face many challenges in open fields, particularly in terms of the unsuitable microclimate (the climate immediately around the tree) and are therefore not usually recommended for open fields.

In addition to demanding more soil nutrients and moisture than conifers, hardwoods are highly susceptible to competition from herbaceous (non-woody) plant species and to rodent damage. von Althen (1990) listed several requirements for successful hardwood plantation establishment, including:

- **Site:** a deep, moist, but well-drained planting soil
- **Site preparation:** ploughing and disking the whole area to minimize competition
- **Tending:** effective weed control for the first 2 or 3 years after planting
- **Protection:** rodent control to prevent girdling of young trees (gnawing around the circumference of the stem, leading to death), if necessary

Some planting programs restrict the proportion of hardwoods because of the problems caused by competition and predation (Glen McLeod, Forests Ontario, personal communication). Ecoregion 7E is an exception because suitable sites for hardwood establishment are available and landowners are often willing to accept responsibility for the additional costs of site preparation (i.e., preparing the site for planting, typically by harrowing or other measures to create suitable planting spots or seedbeds and to control competing plants) and several years of follow-up tending. Because there is little market demand for forest products in the southwestern portions of Ecoregion 7E, planning must be done based on the assumption that commercial thinning (which produces a saleable product) or non-commercial thinning (which does not) may not occur. Although most hardwoods can still be planted, we caution you against planting of any species of ash due to the risk posed by the emerald ash borer. Certain other species, such as butternut, are species-at-risk and may be subject to regulations under the *Endangered Species Act*. See Section 1.2.5 for additional details.

2.3.1 Seed and genetic resource management

Ontario's tree species have evolved for thousands of years to become adapted to their local environment. To take advantage of the superior performance of adapted seeds and avoid the drawbacks of poorly adapted seeds, it's important to understand the basic principles of genetic resource management, starting with the need to obtain high-quality seed from a known source. Genetic quality is ensured by using seed collected in a good seed year and from many individual trees within a healthy population (Fig 2.3). Because of the importance of genetic adaptation to local climate conditions, most forest jurisdictions set standards that limit seed and stock movement; moving even high-quality seed to areas where climate conditions differ from those at the seed's geographic origin can result in poor adaptation, including greatly decreased growth and increased risk of damage by insects and diseases.

Figure 2.3: A red oak seed crop. Left: Acorns developing in early summer. [Photo source: Melissa Spearing, Forest Gene Conservation Association] Right: Acorns maturing in September. [Photo source: Sean Fox, University of Guelph]

OMNRF's Tree Seed Zone Directive defines seed movement guidelines by establishing 38 tree seed zones (Fig. 2.4). These guidelines (OMNR 2010d) govern the seed used on Crown land (land owned by the government) and trees planted with government funds. This directive provides good basic advice on the movement of any seed and planting stock within Ontario. The guidelines are not specific to any species (i.e., they apply to all species), as the zones are based primarily on a difference of 12 to 14 days in the length of the growing season. For some species, such as red oak, this division may be too broad whereas for other species, such as white pine, it may be too restrictive. Though we know too little about the critical thresholds for growing season length (and other climate variables) for most species, the seed zones provide a reasonable approximation. Seed or stock that originates within a given zone can be planted anywhere in the same zone, should generally be adapted to current climate conditions, and when matched to soil types (see section 2.2), should generally perform well.

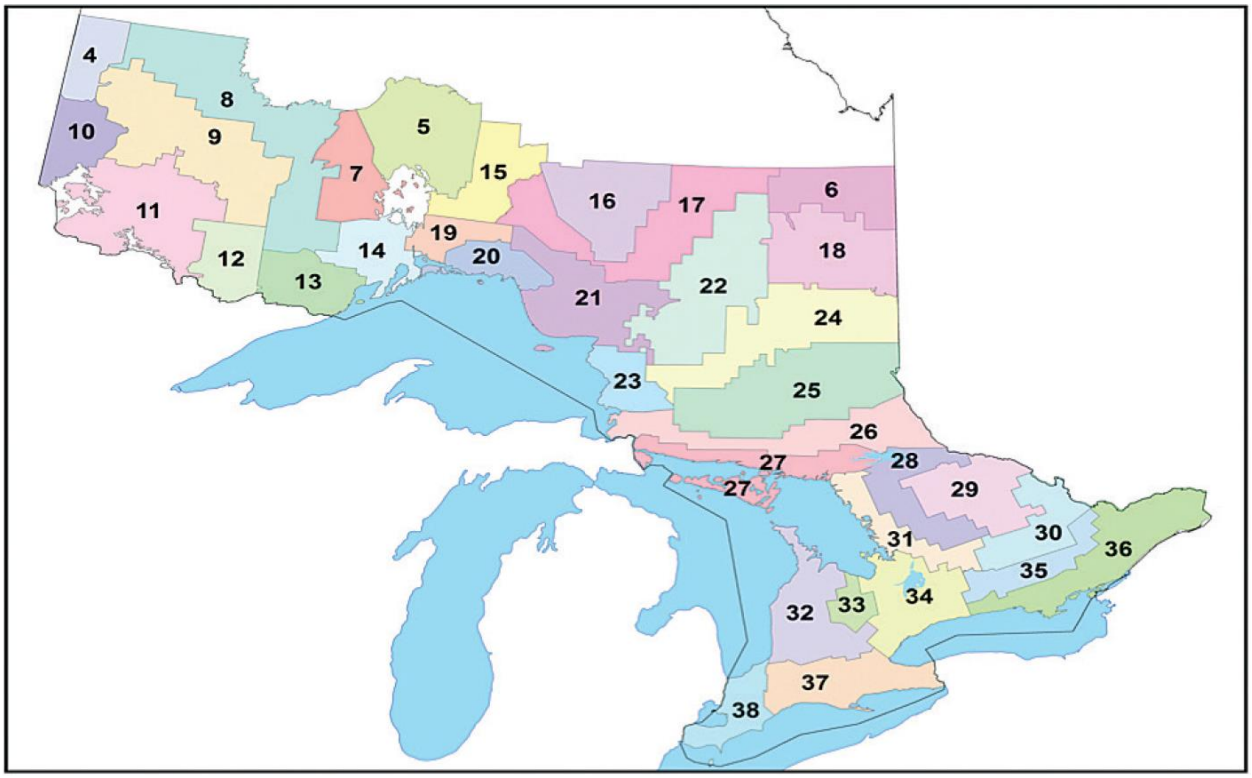


Figure 2.4: Tree seed zones of Ontario.

The 2010 Seed Zone Policy is currently being reviewed by OMNRF, including consideration of projected changes in climate. Any approach to seed transfer guidelines relies on the documentation of its source. This allows for strategic decisions to deploy seed to areas where it can be expected to survive and thrive, potentially far from where it was produced.

It's essential for successful afforestation that accurate information be available about the source of seed, so it can be compared to potential planting sites. McKenney et al. (1999) developed the SeedWhere software, which can answer several types of questions related to selection of an appropriate seed source:

- How similar is the climate at a seed collection site to the climate in potential regeneration areas?
- How similar is the climate in a regeneration area to the climate at potential seed collection sites?
- How similar is the climate at a regeneration area to that of the source area for seed already in storage?

The Forest Gene Conservation Association (FGCA) and Natural Resources Canada are using SeedWhere, with current climate and climate change projections to perform these analyses (FGCA 2017). The tool is particularly helpful in years with limited seed and planting stock.

It is recommended that you follow seed movement standards and maintain chain-of-custody documentation for all tree planting, whether you plant one tree or thousands. For most landowners and forest managers this will mean working with their grower to understand the suitability of available stock and acquire these records. For landowners and forest managers that wish to collect their own seed it is highly recommended that you engage a knowledgeable professional.

The Forest Gene Conservation Association (FGCA) has been working to spread knowledge of the importance of genetic diversity and seed source control under the Ontario's Natural Selections voluntary seed source certification program (www.ontariosnaturalselections.org). Under this program Certified Seed Collector workshops (www.forestsontario.ca) have been designed to promote control of seed sources by identifying their geographic and genetic origins and promoting the collection of high-quality seed. See Appendix 2 and OTSP (2014) for more details.

The Seed Collection Area Network (SCAN) developed by FGCA identifies good collection areas for each species within each seed zone. Sites in this network range from high-quality natural stands to productive plantations and the untested white pine seed orchards that were established across south-central Ontario in the 1980s and 1990s. Gaps in the network exist, but efforts are underway by the FGCA and partners to address them. In some cases, this may mean establishing planting areas specifically so the resulting forests will become future seed production areas. This represents an opportunity for landowners who want to contribute to gene conservation and to improve seed availability in southern Ontario.

> **High-quality seed can lead to good results:** Whether seeds are used to establish hedges of woody shrub species or plantations of conifers and hardwoods, it is critical to use the best-quality seed—seed that is genetically diverse and well adapted to local conditions so that the plants can adapt to site conditions that fluctuate between years and in the long term.

2.4 Choosing the planting stock type used to establish the plantation

Many factors will influence your selection of a planting stock type. Some are pragmatic considerations, such as cost, availability, and suitability of the seed source. Others relate to details of the afforestation project, such as the soil type, expected amount of competition from other plants, planting method, desired species, and planting season. In an ideal world, you would be able to order from a menu of all possibilities and select precisely the best stock for your project. In reality, however, trade-offs are required, since you must select from the stock that is currently available and that is within your budget.

The discussion in the rest of this section provides an overview of the factors that will influence your stock selection. This discussion is based on both recent consultations with experts in the field and the work of Johnson et al. (1996), which remains a valuable reference.

To simplify the discussion, we have proposed stock type selection categories that group species with broadly similar characteristics, stock types with similar properties, and two size classes. Tables 2.4, 2.5, and 2.6 summarize these groups. Information has not been compiled for all of the species in Tables 2.2 and 2.3, so you will need to rely on your own judgment or ask experts in your region for advice about the best stock types for local conditions.

> **Note:** Our description of stock type selection assumes that a species is well suited to the planting site, and that stock from a suitable seed source has already been selected. For more information on species selection and seed sources, refer to Tables 2.2 and 2.3 and Sections 2.1 and 2.2.

Table 2.4: Description of species groupings based on similar characteristics related to site suitability, stock type recommendations, and subsequent field performance.

Group	Primary species included
Hardwood A	Hardwoods with a taproot (a dominant main root): oaks, black walnut, butternut, and hickories.
Hardwood B	Hardwoods with a fibrous root system (a finely branching root system): birches, poplars, maples, black cherry, sycamore, tulip tree, hybrid poplar.
Pines and Norway spruce	white pine, red pine, Norway spruce
Tamarack and larch	tamarack, European larch, Japanese larch
Cedar and spruce	eastern white cedar, white spruce

Table 2.5: Description of stock type groupings based on similar characteristics and expected field performance.

Group	Description	Example[a]
Container (i.e., plugs)	All stock grown in small containers, including both rigid-walled containers (e.g., plastic multipots) and soft-sided containers (e.g., jiffy pots). This category includes hot-grown seedlings (with a single growth season, not hardened off), overwintered stock, and cold-stored stock.	Container 1+0
Bareroot seedling	All stock sown directly in a nursery bed and that has not been moved since germination.	BR 2+0
Bareroot transplant	All stock grown in a nursery bed that was transplanted from a seedbed or greenhouse.	BR G+2

[a] Planting stock is described using numbers that represent the number of years in the greenhouse (G) or the original nursery bed (the first number) + the number of years in a transplant bed (the second number). Transplanting prunes some of the seedling roots, and therefore stimulates the seedling to produce more and denser roots.

Table 2.6: Description of the classification used to differentiate small and large stock types.[a] Adapted from Johnson et al. (1996) and the 50 Million Tree program guidelines.

Parameter	Size 1	Size 2
Caliper (diameter at the base)	4 mm	5 mm
Height (conifers)	15 to 25 cm	>25 cm
Height (hardwoods)	25 to 60 cm	>60 cm
Height:caliper ratio	balanced (e.g., 70:1)	balanced (e.g., 70:1)

[a] These size classes are provided as a matter of convenience, and do not represent mandatory standards for any planting program, funding agency, or regulatory body.

Because it is not possible to discuss all factors that would affect your stock selection, we have limited our discussion to the most important factors. The following text (sections 2.4.1 to 2.4.10) and figures (2.6 to 2.10) provide advice on selecting stock type. The text sections are presented first to provide context and definitions of the terms used in the figures.

2.4.1 Availability

Given that it can take one or more years to produce planting stock, seedlings are not normally grown to order unless clients are willing to pay in advance. The majority of stock production in southern Ontario is done speculatively. Growers do their best to predict the needs of their clients, trends in the industry, and overall supply and demand, and plan accordingly. This means that if you have specific needs, you should contact a suitable grower one or more years in advance to order the special stock that will meet those needs

When the ideal stock type is not available, compromises will be necessary: either select the next-best stock type, or if site conditions permit (e.g., a low level of competition from other plants), it may be possible to wait until the desired stock is available. In some cases the trade-off might include a consideration of alternative species for which the desired stock type (and seed source) is available.

This substitution should not be done lightly; you should apply the same rigor that went into selecting the original species.

When you're forced to compromise, carefully review all components of the establishment plan (e.g., the expected tending frequency) to ensure that you understand and have accounted for the consequences of the compromise. Update your plans, if necessary.

2.4.2 Cost

Although the cost of acquiring various stock types is an important consideration, it is only one element of the overall cost of establishing the plantation. It is also important to understand that the cost of the stock cannot be considered in isolation, but must be considered as a part of the overall project cost, since it affects all other costs. For example, larger stock may cost more initially, yet it has the potential to save money later by reducing the number or intensity of tendings required or the need for refill planting. The ideal stock type should minimize the overall establishment cost while maximizing the probability of success. Consulting a knowledgeable and experienced professional will help you understand how the different elements of your establishment plan will interact to determine the overall cost.

A project-level approach to budgeting your time and money assumes that you are committed to the project and willing to devote the resources required to succeed. This means that you will need to stick to your establishment plan, monitor conditions subsequently, and respond appropriately (i.e., modify your plan). When you're not certain you will have the resources to undertake follow-up actions like tending and refill planting, it may be wise to invest in a species and stock type with the greatest likelihood of success for your specific planting site.

2.4.3 Competition

Larger stock will generally perform better, and is therefore recommended, particularly for sites with a high level of competition from other plants. This is because larger seedlings compete more strongly for the available resources (e.g., light, water, nutrients) and are physically stronger (e.g., resist damage better). The extent to which competition should be a factor in selecting a stock type depends on the both the competitiveness of the local plants (e.g., the type of competitors already present and how large and vigorous they are), constraints imposed by the site (e.g., limited soil nutrients), and any treatments (e.g., site preparation, tending) that you have planned to control the competition. If you are willing to undertake aggressive control of the competition throughout the establishment period, you may be able to use smaller stock. Refer to Chapter 3 of this guide for information on competition from other plants and methods of control.

2.4.4 Planting method and equipment

Smaller seedlings are generally easier to plant than larger stock, whether by machine or by hand. For machine planting, the capacity and production capabilities of the available machinery must be considered when selecting a stock type. This may preclude using some of the largest stock. For hand planting, the planter's experience should be considered. Novice planters will find it easier to plant container stock or small bareroot stock.

2.4.5 Handling

Section 2.6 provides a comprehensive discussion of the handling requirements for different stock types. In summary, bareroot stock must be shipped, delivered, stored, and handled more carefully than container stock—but both types require care. Even when you do everything else right, poor handling of stock can lead to failure.

2.4.6 Heavy clay soil

In addition to being prone to drought, heavy clay soils tend to be at risk of frost-heaving (in which expansion of water in the soil during freezing ejects seedlings from the soil). This is particularly true for container seedlings before new roots establish a strong connection between the seedling and the surrounding soil. The relatively smooth wall of the container offers little mechanical resistance, making it vulnerable to being partially or entirely expelled. Bareroot seedlings, when planted properly, offer better resistance to frost heaving because their roots immediately establish a stronger contact with the soil.

2.4.7 Shallow or stony soil

Shallow soils and soils with significant stoniness can be difficult to plant because of the difficulty of penetrating the soil. It is generally easier to fit smaller trees into plantable spots than larger trees, and easier to plant container stock than bareroot stock. Transplanted bareroot seedlings are also more likely to succeed than bareroot seedlings.

2.4.8 Drought-prone sites

Drought-prone sites can be identified by the soil texture: sands and gravels are risky because water drains too freely, and heavy clay is risky because dry clays hold water tightly, and the density of clays makes it difficult for roots to reach water. The landforms at a site also provide important clues. For example, outwash plains show clear signs of rapid drainage, beaches and dune complexes represent fast-draining sands, and ridges lie higher above the water table than the surrounding lowlands. Although species selection is probably the most important success factor on these sites, stock type will also play a role. It is difficult to recommend the optimal stock type for drought-prone sites, as species differ (Fig. 2.6 to 2.10). In general, transplant stock will survive drought better than bareroot seedlings and larger containers will do better than smaller containers, as they have more robust root systems. But smaller bareroot stock will likely do better than larger stock, particularly for hardwoods, because they have a higher root:shoot ratio, which allows the seedling to immediately access the water needed to support the eventual growth of the shoot.

2.4.9 Nursery practices

Many nursery practices will interact with the stock type selection factors described earlier in this section. For example, root wrenching or pruning, modifying the nutrient loading, and mycorrhizal inoculation can improve the suitability of most stock types. We encourage you to speak with your grower or a knowledgeable forest manager to learn the implications and possibilities.

2.4.10 Recommended stock types

Given the many possible combinations of species, stock type, and stock size, it is impractical to propose a perfect stock type for every situation. However, we have provided some general recommendations for combinations of species and site factors, and you can apply them to judge the best solution for unique site conditions.

Figures 2.6 to 2.10 provide a visual representation of the relative suitabilities of the different stock types for different species under different site characteristics. To use these graphs, consider each of the five site properties (e.g., the presence of heavy clay) in turn. The more important that factor is at your planting site, the closer the graph for a stock type should come to the outside of the graph; lines close to the center of the graph indicate the lowest suitability. For example, in Figure 2.6, which depicts the suitability for Hardwood A species, bareroot seedlings of size 1 and bareroot transplants of sizes 1 and 2 are the best options for a heavy clay soil, and both container sizes are far less suitable. Since stock types will have different suitabilities for different site conditions, balancing the different suitabilities can be tricky. Start by ranking the site conditions in order of importance (i.e., based on how strongly they constrain seedling establishment at your site), then choose the two or three most suitable stock types for the most serious constraint. For the second-most serious constraint, retain only the stock types that are still suitable. Continue this process until you have narrowed the remaining options to one or two stock types.

Some additional explanation is necessary to interpret the figures:

- The competition axis represents the net result of the predicted intensity of competition at a site and the effectiveness of any treatments applied to reduce that competition. The placement of the lines is based on an assumption of a high-competition environment.
- The equipment and handling axis combines both aspects. A low score on this axis may result from difficult handling requirements, limited flexibility in the planting method, or a combination of both.

It is important to re-iterate that the use of these diagrams assumes that you have already selected an appropriate species. For example, Figure 2.8 shows moderately high suitability for several red pine stock types on a site with a heavy clay soil. This does not mean that you should plant red pine on clay soils, but rather, that if you plan to do that, certain stock types would perform best for that species.

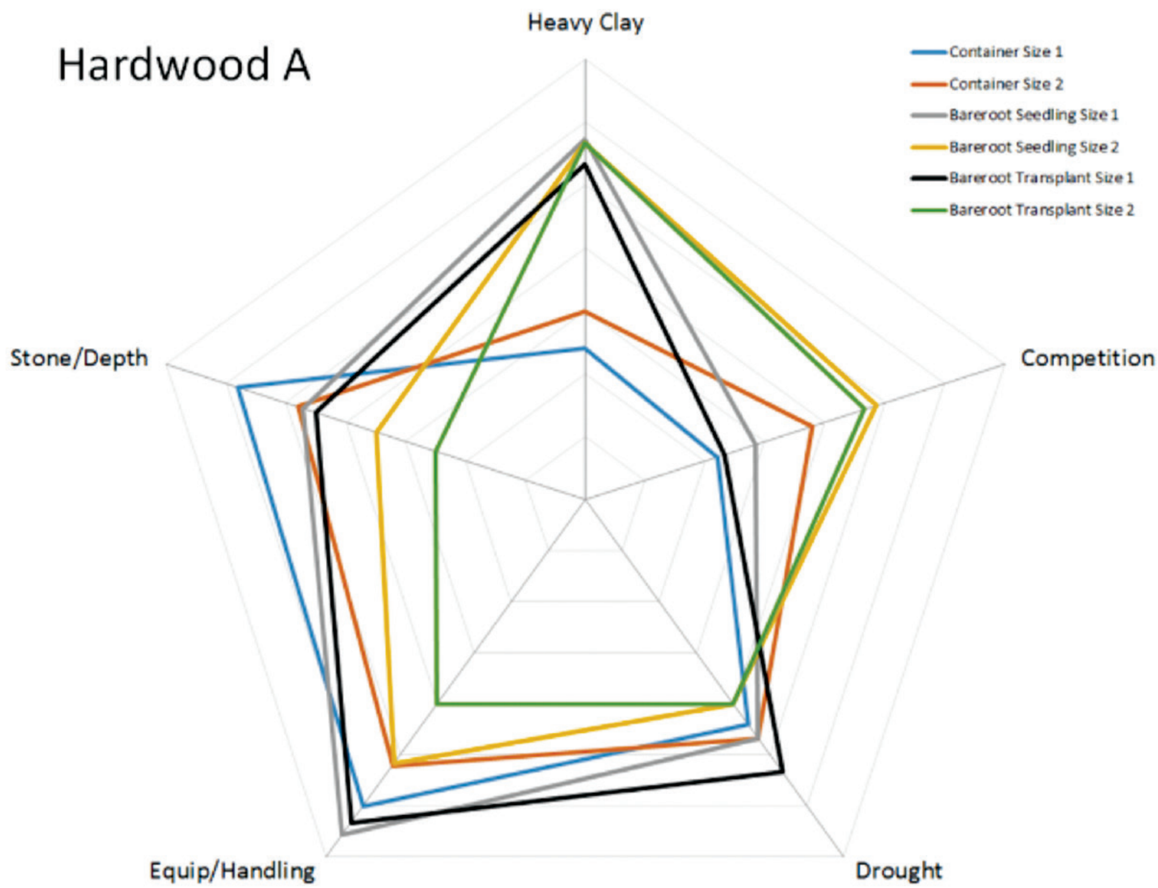


Figure 2.6: Illustration of the relative suitability of each stock type for the Hardwood A species group (hardwoods with a taproot; Table 2.4). Lines closest to the center of the diagram have the lowest suitability. Refer to sections 2.4.3 to 2.4.8 for a description of the terms.

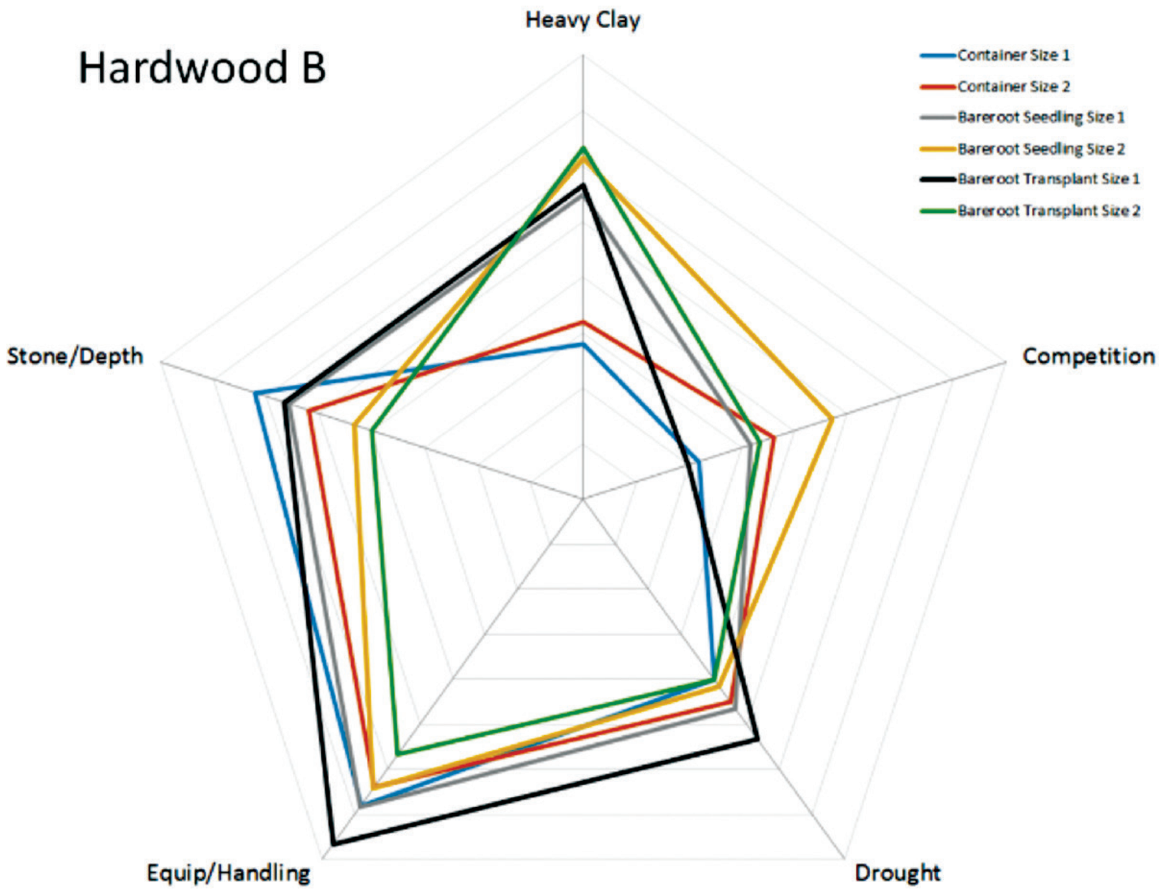


Figure 2.7: Illustration of the relative suitability of each stock type for the Hardwood B species group (hardwoods with a fibrous root system; Table 2.4). Lines closest to the center of the diagram have the lowest suitability. Refer to sections 2.4.3 to 2.4.8 for a description of the terms.

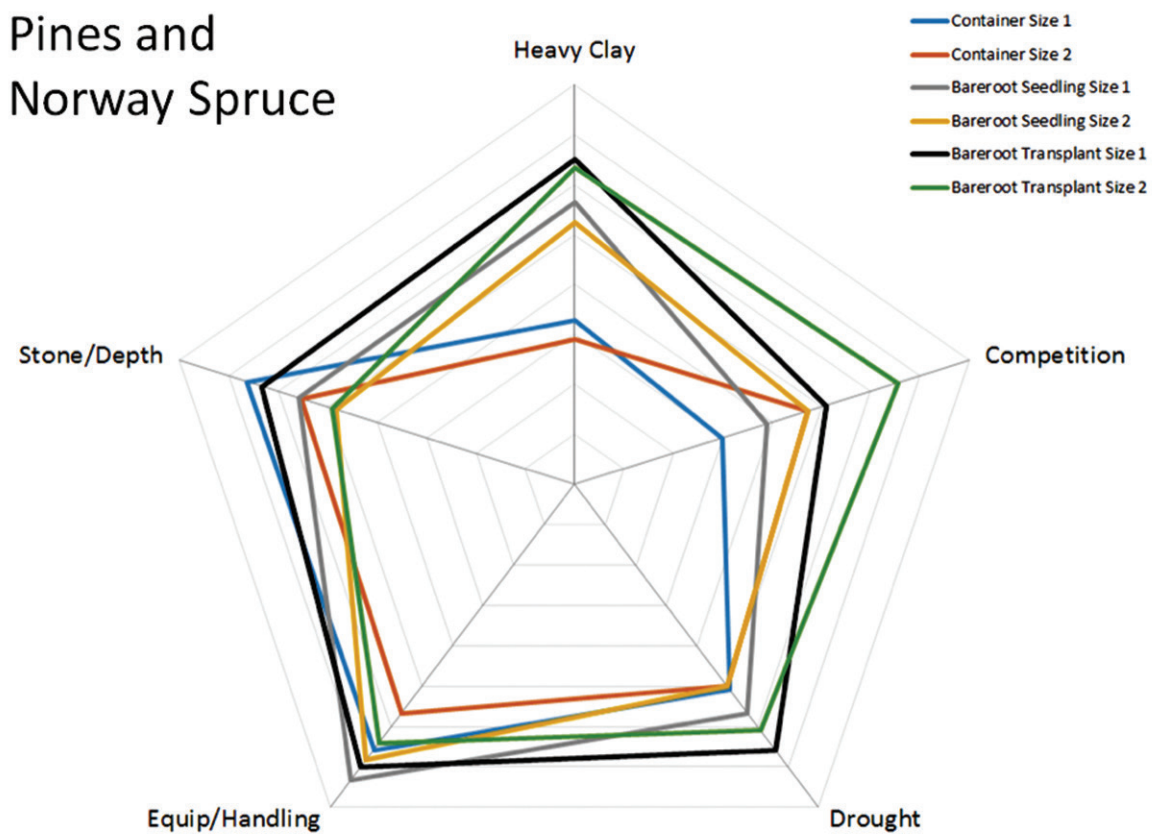


Figure 2.8: Illustration of the relative suitability of each stock type for white pine, red pine, and Norway spruce. Lines closest to the center of the diagram have the lowest suitability. Refer to sections 2.4.3 to 2.4.8 for a description of the terms.

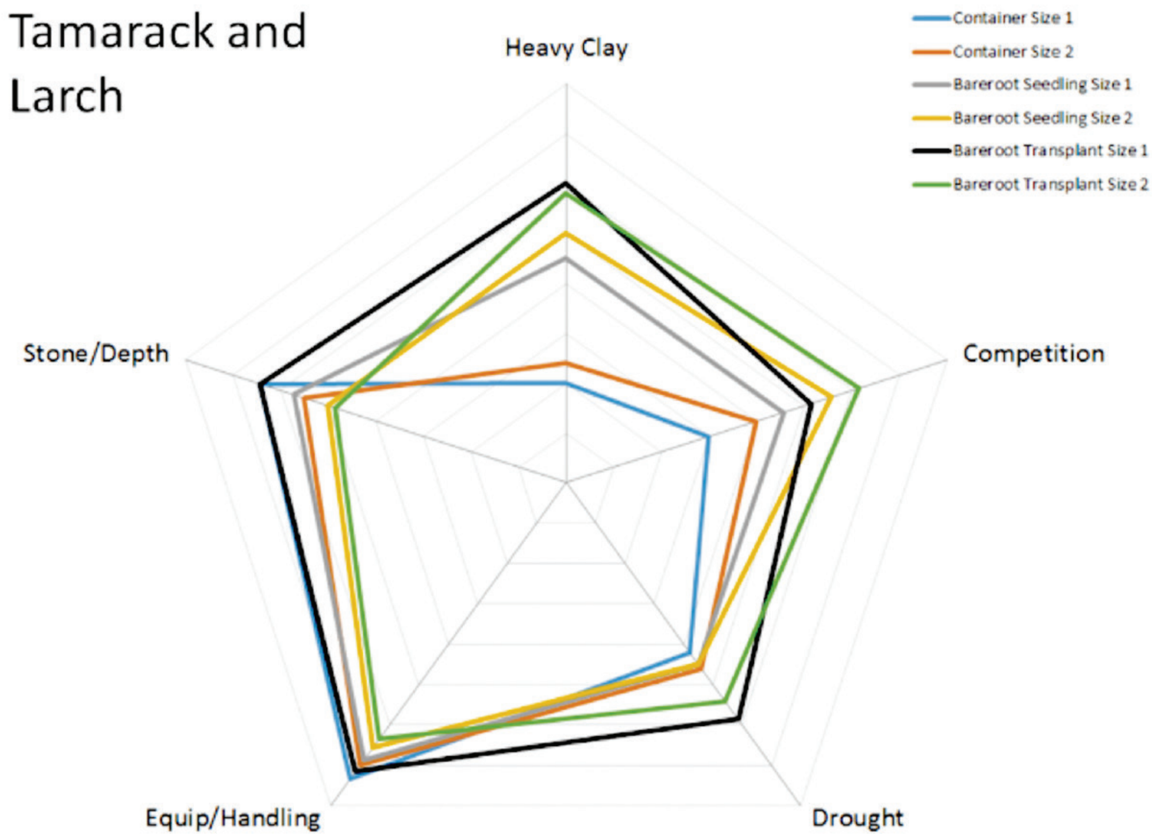


Figure 2.9: Illustration of the relative suitability of each stock type for tamarack, European larch, and Japanese larch. Lines closest to the center of the diagram have the lowest suitability. Refer to sections 2.4.3 to 2.4.8 for a description of the terms.

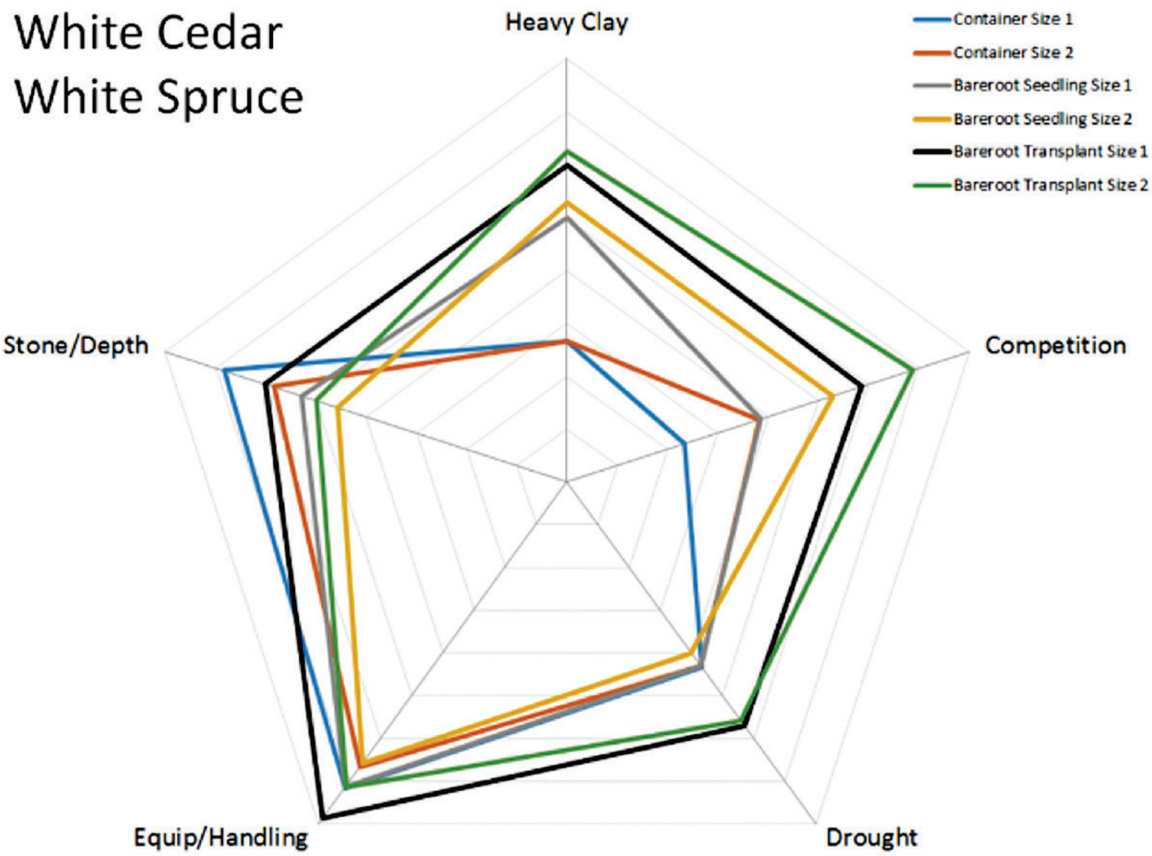


Figure 2.10: Illustration of the relative suitability of each stock type for eastern white cedar and white spruce. Lines closest to the center of the diagram have the lowest suitability. Refer to sections 2.4.3 to 2.4.8 for a description of the terms.

2.5 Special considerations for hardwood establishment

Efforts to establish hardwood plantations have often been disappointing because managers had insufficient knowledge of the site requirements of the various species, and the planting techniques developed for conifers proved to be unsuitable for hardwoods. Successful hardwood establishment requires intensive site preparation and tending for at least 3 years to maintain a relatively weed-free site, whereas coniferous species require less intense management, usually for only 1 to 2 years (White et al. 2005).

Many potential planting sites in southern Ontario cannot be cultivated prior to planting because the soil is either too rocky or too shallow, and this limits the type of site preparation equipment that can be used. Cultivation is usually considered essential in hardwood planting programs. Where cultivation and competition control were inadequate, survival, growth, and form of the trees were unacceptable. Where sites were suitable, the cost of cultivation and subsequent weed control were sometimes too high for the landowner or the planting agency over the long-term, leading to unsatisfactory results.

Inappropriate or misapplied competition control has led to difficulties with plantation establishment, particularly when dealing with cool-season grasses that respond aggressively to treatments such as mowing.

Good growth has been achieved in plantations established from bareroot stock where proper site selection, high-quality planting stock, adequate site preparation, and the necessary tending operations have been part of the program.

The use of high-quality seedlings is critical. Red oak has been studied extensively, and research has shown that oak ecosystems are associated with repeated ground fires. To survive on sites that are treated to emulate those conditions, seedlings must have the following attributes (Dey and Buchanan 1995):

- A well-developed root system with large carbohydrate reserves, a balanced root:shoot length ratio of 1:1 or 2:1, and a well-branched root system with a framework of permanent lateral roots offers an increased likelihood of success. First-order lateral roots (the ones that attach directly to the main root) are strongly related to survival and early growth performance.
- A larger stem diameter near the root collar will increase success. Many authors recommend a root collar diameter of at least 7.4 mm, and a minimum diameter of 4.6 to 6 mm at 2 cm above the root collar. Smaller trees should be culled.
- A taller main shoot is recommended, since these seedlings perform best after outplanting. Some authors recommend a shoot length of 50 cm, and set 30 cm as the minimum.
- Stock age is less important than the size of the nursery stock. For example, 2-year-old seedlings outperform 1+0 seedlings because they are larger and have better developed root systems. Very young but fast-growing hardwood container stock show promise for the same reason.

These criteria are relevant to a greater or lesser degree for other hardwood species as well.

2.6 Stock handling

A successful afforestation program requires a commitment from everyone involved in the process from the nursery to the planting site. How nursery staff manage the growth and shipping processes will have a major effect on the growth potential of the trees. Tree planters likewise have a critical role in ensuring that high-quality stock is handled and planted properly. Tree seedlings are living organisms that require oxygen, water, and nutrients to survive and grow. They have a limited amount of stored energy to survive the stresses that occur before planting and to support growth in the season after planting. These reserves can be reduced during the various stages of handling after a seedling leaves the nursery. The stress that a seedling undergoes from seed to seedling to planting cannot be eliminated, but can and should be minimized through careful handling and storage practices. These stresses include, but are not limited to, moisture imbalances (desiccation to excessive moisture), temperature fluctuations, physical abuse (e.g., crushing), and the storage duration between lifting at the nursery and planting at the final location. Seedlings respond to these stresses by shifting nutrient allocation away from maintenance and growth to adjustment and repair. Stock types have different characteristics that interact with the species to determine the vulnerability of their root systems and shoots. As a result, you must take measures to protect the condition of your planting stock, and take responsibility for your role within the chain from nursery to planting site. Following safe handling procedures, and understanding the signs of stress (mold development, sour odours, high temperatures, poor physical condition) are both necessary components of a successful planting.

2.6.1 Bareroot versus container stock

Unlike container stock, bareroot stock lacks a container filled with soil that protects its roots from the surrounding environment. In addition, bareroot stock tends to be grown in nursery beds (an uncontrolled environment) and is subject to more handling stages, such as lifting and root-pruning (Section 2.6.2). Preparing bareroot stock for shipment begins at the nursery either in the fall, if the stock will be frozen for over-winter storage, or in the spring, if the stock will be planted immediately. The nursery will grade, sort, and bundle trees in accordance with their stock standards and client needs. Nursery crews should be well trained, all equipment should be kept in proper condition, and the trees themselves must be in optimal condition to reduce the effects of potential stresses.

In contrast, container stock is generally grown in the controlled environment of a greenhouse, and is less subject to the stresses imposed by lifting and storage. Once the container stock has reached the desired size, dormancy is induced by artificially creating conditions that mimic the seasonal change in light and temperature, and the stock can be safely over-wintered. It can be stored outside if there will be sufficient snow cover to protect it, or stored in covered hoop houses. Container stock may be graded and packaged at the nursery before cold storage, left in their original containers, or re-packaged into other containers. Stock that has been frozen must be thawed following guidelines similar to those for bareroot stock. Once thawed, they can be shipped to a local cooler facility to keep them cool until they are used or shipped directly to the planting site.

Stock that is shipped in the container should be spread out on the ground at the planting site. A cool, shady location is ideal, close to a water source; if shade is not available, use a reflective tarpaulin. The stock must be watered regularly if it is not used immediately, since warm weather and wind will dry out the plugs. Stock that has been packaged and cold-stored must be kept in a refrigerated environment until it's ready to plant. Delivery of stock to the planting site should be as close as possible to the planting time. Unplanted container stock should be returned to a central storage area each night for watering or refrigerated storage.

2.6.2 Lifting at the nursery

In the fall, lifting (removal of seedlings from the soil for storage) must occur only after the seedlings have reached an acceptable level of dormancy, but before the ground freezes. Generally, dormancy occurs naturally in the fall in response to the shortened daylength and below-freezing night temperatures. Dormancy may need to be induced for greenhouse-grown stock by artificially creating conditions which mimic this seasonal change in light and temperature. The seedlings are held in frozen storage until they're ready for shipment in the spring. Spruces, larches, and pines should be lifted in the fall. Fall stock can be thawed before delivery, and is therefore available throughout the planting season.

When hardwoods are lifted in the fall, they are sometimes "heeled in" using temporary beds located closer to the nursery shipping and packing facilities for easier access in the spring. Heel-in beds should be a well-drained sandy loam, be located in a sheltered location to protect the seedlings from wind and to retain snow cover, and should be tilled prior to receiving the stock. The trench should be big enough to accommodate the root system. The roots are then covered with soil to ensure that the root collar is buried 2.5 cm below the soil surface, and the soil is then packed around the roots to remove air pockets. If there may not be sufficient winter snow cover, the seedlings should be protected by completely covering them with straw or other clean mulch.

The following lifting and packaging guidelines should be followed by the nursery:

- Keep the foliage dry (conifers) or wait until the leaves have dropped (hardwoods).
- Sharpen the blade of the mechanical lifter and keep the machine in good repair.
- Lift, sort, bundle, and root-prune the stock (generally at a depth of 20 cm), and then move it to storage within 45 minutes after lifting.
- Handle the seedlings gently throughout all stages and reduce their exposure to sun and wind. Avoid stripping the roots and avoid getting soil on the foliage.
- Package the seedlings in bundles less than 25 kg in weight. Gently compress the bags to push out excess air, but don't compact the seedlings.
- Keep the bags cool during processing and transport to storage.

In the spring, lifting can occur as soon as the nursery bed thaws and surface water drains. Spring-lifted stock should be cooled to 3 to 5°C before delivery to the field. The length of time that seedlings can remain in cool storage is influenced by the species, lifting date, weather and soil conditions at the time of lifting, physiological state of the trees at the time of lifting, and the time required to reduce the temperature in the packaging below 5°C. Follow the same guidelines for fall lifting. Spring-lifted stock should be planted as soon as possible after lifting

2.6.3 Storage at the nursery

After fall lifting, the stock is over-wintered in frozen storage. The following guidelines should be followed by the nursery:

- Cool and freeze the stock as soon as possible after lifting.
- Maintain its temperature between –2 and –4°C, with minimal fluctuation. Use a 24/7 recording thermograph to monitor storage temperatures.
- Because the stock is brittle in this state, handle it very carefully.
- Place the frozen stock on pallets and move it with a forklift.
- Condition (thaw) the frozen stock at 2 to 3°C for 2 to 3 weeks before shipping it to cool storage, unless the stock is to be shipped frozen and will be thawed at the local facility. Spread the bags out for better air circulation.

After spring lifting, the stock should be held in cool storage until shipping. The following guidelines should be followed by the nursery:

- Cool the stock to between 1 and 4°C within 24 hours.
- Maintain the cooler at 1 to 2°C, with minimal fluctuation. Use a 24/7 recording thermograph to monitor storage temperatures.
- Stand the bags upright on pallets—do not stack or pile them, as this may crush the seedlings. Handle them as little as possible.
- Check the stock every 3 or 4 days for signs of stress (e.g., mold, smell, excessively wet or dry).
- Don't ship stressed stock to the field.

The maximum storage time for trees in cool storage (either fresh-lifted or thawed frozen stock) is 2 weeks for cedar and larches, 3 weeks for red pine and white pine, and 5 weeks for all other species. These storage times decrease dramatically with increasing storage temperatures. The nursery will often perform out-planting trials of various stock lots, species, and storage methods to ensure quality control of their products.

2.6.4 Transport to the local storage facility

Stock is sometimes moved to an interim local storage facility, depending on the complexity of the planting program. This complexity depends on the relative locations of the nursery and planting sites, whether seedlings are obtained from multiple nurseries, and the length of the planting season. Local apple orchards sometimes have ideal facilities for short-term spring storage. If a local storage facility is used, the same storage and conditioning guidelines outlined in the previous section should be followed. Refrigerated trucks should be used to transport the stock, and all stock should be treated with care to avoid physical injuries. Be careful to not throw, drop, or compress the bags of seedlings.

2.6.5 Transport to the planting site

Ideally, stock should be transported to the planting site in refrigerated vans. Air temperature should be maintained between 1 and 4°C. Sometimes, these vans can be left at the site until the trees are planted. However, this is uncommon in southern Ontario due to the wide dispersal of the typically small planting sites. In these cases, stock is transported in non-refrigerated trucks, and the transport duration should be less than 3 hours. This is a critical time, since the stock will be growing warm and will be increasingly vulnerable to environmental stresses such as heat, wind, and physical abuse. Drivers should obey the following guidelines while transporting stock to the planting site:

- If possible, transport the stock in a covered vehicle that can be insulated using Styrofoam or another type of insulating material.
- If not, cover the stock with a reflective tarpaulin with the white side facing up.
- Schedule the transport for a cool part of the day (early morning, evening).
- Handle the bags with care. Don't throw or drop them, and if it's necessary to stack them, don't stack them more than two layers high.
- Secure the load, but allow air circulation around the bags.
- Maintain the bag temperature below 5°C during transport.
- Don't ship frozen stock to the planting site unless arrangements have been made to condition the stock at the planting site.

2.6.6 Storage at the planting site

This is the most critical stage of stock handling, because it is harder to control the environmental factors that can stress the seedlings, and there are few options to cool the stock. The best way to avoid excessive stress is to only deliver as many seedlings as can be planted in 1 day. The following guidelines should be followed by the manager of the planting crew:

- Select an on-site storage location that is cool and shaded. Storage under an adjacent canopy of conifers is ideal. If no suitable location is available, build a temporary tent to protect the seedlings from sun and rain.
- Handle the bags carefully—do not stack, throw, or drop them. Measure and record the internal temperatures of the bags. Keep bag temperatures below 10°C.
- Cover the bags with a reflective tarpaulin, white side up, even when seedlings are stored under a temporary tent.
- If bags must be left overnight at the site, secure the tarpaulin on all sides. Re-seal any partially used bags.
- If temperatures in the bag exceed 10°C, plant the stock immediately. Stock that has been subjected to temperatures higher than this level may not survive due to heat stress and should not be planted.

2.6.7 Handling by planters

The manager of the planting crew should ensure that all planters understand their role in the planting process and receive sufficient training and appropriate feedback on the quality of their work. Seedling survival after planting depends upon proper handling by the planters. The planting manager should ensure good organisation—including keeping track of the stock (quantity and quality), delivering trees to the planters on larger sites, and keeping track of the planter's handling procedures. The following guidelines should be followed (for both hand planting and mechanical planting):

- Wait until the soil temperature is above 5°C.
- Check the stock for signs of stress (e.g., mold, dryness, smell). If significant stress is apparent, the stock should not be planted, and should be returned to the nursery.
- Provide planters with planting bags made with reflective materials and closable skirts.
- Fill the planting bags in the shade and out of the wind. Dip the roots into clean, cool water before putting the seedlings in the planting bag, and keep the seedlings upright (i.e., with the roots at the bottom of the bag).
- Keep the roots moist by placing a small quantity of water in the bottom of the bag.
- Carefully remove one seedling at a time for planting. Instruct planters to avoid holding bundles of trees in their hands (where they can easily dry out) as they plant.
- Cut off the elastics that hold the bundles together (don't pull them off) to avoid stripping off the roots.
- Don't prune roots in the field. This is a nursery function. If roots are too long according to the stock specifications, ask the nursery to immediately correct the problem or seek their advice on how to deal with the situation in the field.
- Mechanical planters should have a protective overhead canopy to protect both the seedlings and the planter.

2.6.8 Summary

Proper stock handling is everyone's responsibility. There is a long chain of custody from the nursery to the planting site. Proper care and handling will reduce seedling stress and help to ensure survival and growth. Using the proper equipment will help—thermometers to determine temperatures, digital thermographs to record them, refrigerated vans, reflective tarpaulins, and insulated planting bags. But even with the best of care, things can sometimes go wrong. Proper records will help to identify the source of the problem and allow for corrective actions in the future.

OMNR (1992) and Johnson et al. (1996) provide additional information on handling procedures.

2.7 Planting the trees

The nature and accessibility of the site, as well as the resources available to you (workers and equipment), determine whether to plant trees by hand or by machine. Steep, rocky, wet, and small sites that are difficult to reach or navigate are generally better suited to hand planting. Machine planting is best suited to larger, less difficult sites. However, hand planting can also be effective on large, well-drained, level sites. The choice of planting method depends upon:

- **Availability of experienced labour:** Hand planting requires more workers than machine planting. It also requires more logistical support and supervision to control planting quality, distribute the planting stock, and keep records (e.g., the number of trees planted by each planter).
- **Availability of equipment:** Machine planting requires specialized equipment that is usually towed behind a tractor. The operators of both the tractor and the equipment need to be well trained to ensure proper row alignment, spacing within the rows, planting depth, and planting quality.
- **Size of the planting area:** Planting areas smaller than 2 ha, or that are far from other planting sites and that require significant equipment transportation costs, may be better suited to hand planting. Machine planters also require considerable space to turn around at the end of each row.
- **Site physical characteristics:** Steep slopes, irregular topography, rocky soils, and variable soil drainage—in short, anything that will interfere with travel by the machine—all suggest that hand planting will be the best method. Soil texture and drainage are also considerations, as machines can get bogged down more easily on wetter sites with heavier soils during spring plantings.
- **Variety of trees to be planted:** Machine planting is ideal for planting monocultures, or alternating rows of two species. Hand planting is more flexible when several species will be planted.

2.7.1 Hand planting

The wedge method, in which the shovel blade is inserted vertically into the soil and then pulled backwards to create a triangular hole (Fig. 2.11a, b, c & d), is preferred for most open-field planting because it can deal well with a layer of sod or other types of vegetation. When planters use a straight-shank shovel, the hole it creates is usually large enough to accommodate the root system of most common stock types. There are other ways to dig a suitable hole. In the slit method, the shovel is inserted vertically into the soil to create a slit, and the resulting slit is suitable for both large and small stock. In the "T" method, the shovel is inserted vertically into the soil twice, at right angles, to form a T-shaped slit, and seedlings are inserted where the two slits meet. This is suitable for planting in lighter soils with a sod layer. In the "L" method, the shovel is inserted vertically into the soil twice, at right angles, but with the ends of the slits meeting to form an L-shaped slit; again, seedlings are inserted where the slits meet. As alternatives to a straight-shank shovel, a tree planting bar or a dibble (a pointed tool for making a rounded hole) can be effective. Regardless of how the hole is prepared, the hole must be deep enough to accommodate the whole root system, and the side of the hole should be vertical to ensure that the root and shoot are vertically aligned. Refer to OMNR 1973 for more details on other methods of hand planting.

Once the hole has been created, the tree should be placed gently in the hole so that the root collar will be at the soil surface. Soil should then be packed firmly around the roots to eliminate air pockets, which can dry out the roots, by stepping firmly on the soil on each side of the hole, taking care not to step on the seedling.

Most often, tree planters work alone, and are paid for each tree they properly plant. However, planters can work in teams, with one person carrying the trees and placing them in the holes their partner creates. An experienced hand planter should be able to plant up to 1000 bareroot trees per day (Fig 2.12).

Figure 2.11a: Digging the planting hole using the wedge method.

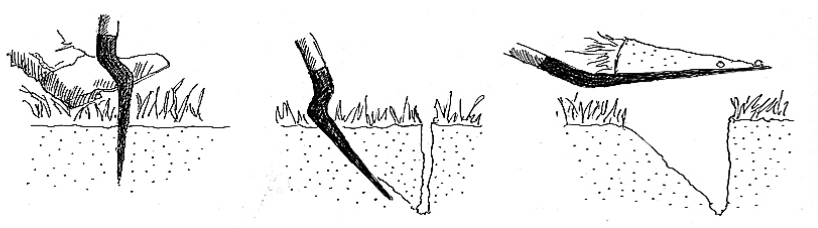


Figure 2.11b: Digging the planting hole using the wedge method (detailed view).

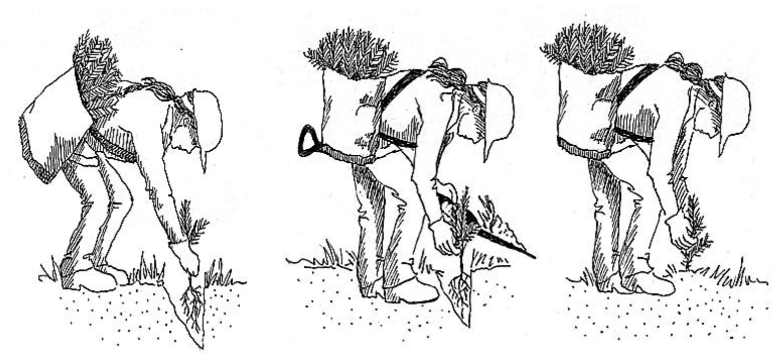


Figure 2.11c: Hand planting the bareroot seedling.

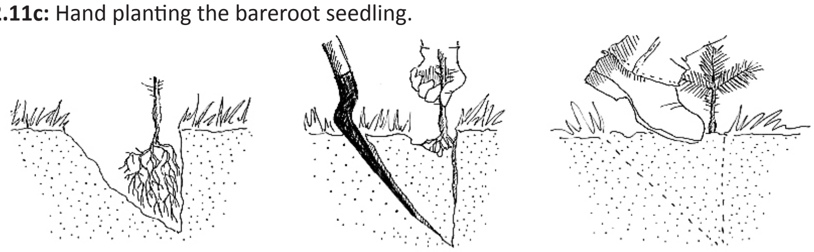


Figure 2.11d: Hand planting the bareroot seedling (detailed view)

Figure 2.12: Hand planting. Left: A planter inserts a bareroot seedling into the planting hole. [Photo source: Wade Knight, Forests Ontario] Right: A planting crew in action [Photo source: Wade Knight, Forests Ontario]

2.7.2 Machine planting

Planting machines are towed by tractors or other equipment large enough to pull a given machine, and your choice of machine is also determined by the characteristics of the site; rougher sites require larger and more powerful machines. During operation, one person sits on or in the planting machine, regulates the tree spacing within the rows, and carries out the actual planting (Fig. 2.13). The tractor operator controls the spacing between rows. A third person usually helps by monitoring the quality and spacing of the planted trees, and keeps the stock sorted and ready for planting. Although machine design varies, most feature a vertical cutting blade (a coulter) that cuts the sod, a scalper that removes the sod and other vegetation to expose the mineral soil, and a trencher that opens a slit to receive the planting stock. Rubber-tired packing wheels pass on either side of the slit to pack the soil around the tree. Sometimes, spraying equipment is attached to or towed behind the planter to apply herbicides for weed control. An experienced machine planting crew can plant up to 8000 trees per day.

Figure 2.13: An example of a planting machine towed behind a small farm tractor. [Photo source: Wade Knight, Forests Ontario]

Regardless of the planting method, the seedlings should be carefully planted to ensure their survival. This means that:

- Each planting hole must be large enough to accommodate the entire root system of the tree. Roots should be spread out in a natural position, similar to their original growth pattern. They should not be tangled, bunched, or doubled-up. If the roots are not primarily vertical, this can produce what is called "hockey stick" roots, which are unstable and render the seedlings more vulnerable to falling over as they mature.
- Each tree needs to be planted sufficiently deep that after filling the hole and compacting the soil around the roots, the seedling's root collar is near the soil surface. No roots should be exposed. With container stock, no portion of the original paper pot or plug should be visible above the soil surface.
- Leaves or needles should not be buried.
- Soil must be compacted around the roots to eliminate air pockets and firmly anchor the tree.
- Each planted tree must be capable of withstanding a reasonable tug by hand without being extracted from the planting hole.

2.7.3 Direct seeding

Our experience with direct seeding of hardwood species in open fields in southern Ontario is limited and the results have been poorly documented, even though seeding has been an important component of many restoration projects. There have been obvious successes, often on sandy sites, but poorer results have been observed in heavier soils (John Enright, Upper Thames River Conservation Authority, personal communication). In general, the stocking levels (the number of trees per unit area) have been highly variable, particularly compared with planting.

Direct seeding of black walnut, red oak, white oak, bur oak, swamp white oak, sugar maple, and shagbark hickory in Wisconsin showed the most consistent stocking for black walnut, with many sites developing more than 1235 stems/ha), whereas red oak germination was more variable (several sites had low germination rates), and direct seeding success rates for white oak were very low (Edge 2004).

The experience with light-seeded species such as ashes, maples, and birches is also limited, and at least one expert suggests treating this approach as experimental until more field research is complete (Edge 2004). Others suggest that relatively small seeds such as those of ashes and birches are simply unsuitable for direct seeding (von Althen 1990). It is worth noting that direct seeding of yellow birch has been successfully carried out using a shelterwood system (i.e., planting of the birch in the understory of a hardwood forest), as this provides a cool, shaded, and somewhat moist environment that can be maintained during germination and the early development stages.

Mechanical or spot seeding is a more efficient use of seed than broadcast methods, as it allows better control over the final stand density and decreases establishment costs (Edge 2004). Seed desiccation at the soil surface after broadcast sowing has resulted in poor germination and regeneration failures for red oak (Dey and Buchanan 1995). Seeding depths for acorns of between 2.5 and 5.0 cm reduce the risk of desiccation and is therefore recommended.

Table 2.7 provides estimated seed to seedling ratios based on Ontario nursery records, assuming that any necessary site preparation and competition control are carried out. This table will help you to estimate the number of seeds required to produce a single 1-year-old seedling.

Table 2.7: Estimated numbers of seeds required to produce a 1-year-old seedling (Brian Swaile, retired manager, Ontario Tree Seed Plant, personal communication). For species from Table 2.2 that are not listed here, there is no estimate available.

Species	Seed:seedling ratio required to produce a shippable bareroot seedling
Ashes	
Green	9:1
White	9:1
Birches	
White	15:1
Yellow	15:1
Cherry (black)	10:1
Hickories	
Bitternut	5:1
Pignut	5:1
Shagbark	5:1
Shellbark	5:1
Maples	
Red	10:1
Silver	5:1
Sugar	12.5:1
Oaks	
Black	5:1
Bur	3:1
Red	3:1
Swamp white	5:1
White	5:1
Walnuts	
Black	2.5:1
Butternut	4.5:1

Direct seeding of some hardwood species, and particularly the large-seeded species, has advantages. Seedlings that arise from the planted seed will develop more natural root systems, and this will avoid the root injuries commonly associated with planted bareroot stock. In addition, it becomes possible to more easily regenerate shallow-soiled sites, and seeds can be less expensive than seedlings. However, competition control is critical, as it is with bareroot stock. Although several reports describe the seeding of black walnut and red oak, information on other oak species and hickories is limited, so it's difficult to predict the severity of problems such as seed predation, and both germination rates and long-term development potential are still unknown. (See Case Study #1 for a description of direct seeding of hardwoods in southwestern Ontario)

2.8 Initial spacing

Where timber production is one of the objectives for a plantation, maintaining regular spacing between trees promotes relatively predictable and uniform development of the crop trees. It also makes early survival assessment and follow-up tending operations easier because it is easier to find the planted seedlings. Tree spacing may vary between blocks, but is usually dictated by the desired density at the time of the first planned thinning; thus, it will vary between species and desired products. Adjustments can be made to meet specific objectives. For example, higher densities will promote early self-pruning (natural loss of lower branches) and the development of clear boles; in contrast, lower densities will promote larger stem diameter, thereby making commercial thinning more profitable, but will increase branch retention and possibly require pruning. In some cases, the use of companion planting may be an option. In this approach, a non-crop species is planted between trees of the crop species to increase the spacing between these trees, thereby improving the quality of their stems. In some ecologically focused plantings on smaller blocks where future thinning is not planned, the trees are not planted in rows at all, but are planted in a more random fashion. Table 2.8 provides some suggestions about suitable spacing for a range of species.

Table 2.8: Spacing configurations for afforestation programs in southern Ontario.

Distance between rows (m)	Distance between trees within a row (m)	Numbers of trees required per ha	Considerations
1.5	1.5	4444	Suitable for white pine sites at risk of damage from the white pine weevil. Costly to establish because of the large number of seedlings.
1.8	1.8	3086	This is a typical coniferous plantation spacing from the 1960s and 1970s. It will require pre-commercial thinning (removal of excess stems before they have significant economic value).
1.8	2.1	2645	not recommended
1.8	2.4	2314	not recommended
2.1	1.8	2645	This is a typical conifer plantation spacing from the 1980s and 1990s.
2.1	2.1	2267	not commonly prescribed
2.1	2.4	1984	not commonly prescribed
2.4	1.8	2314	This is commonly recommended for new plantations with mixed species within the rows, and for white pine where the white pine weevil is not a concern.
2.4	2.1	1984	This is commonly recommended for red pine and spruces.
2.4	2.4	1736	not commonly prescribed
2.4	2.9	1534	not commonly prescribed

Controlling the spacing at the time of plantation establishment and throughout the life of the stand can make stands less susceptible to insects and diseases or to windthrow and stem breakage (Oliver and Larson 1996). For an example, see Case Study #2, which describes the impact that the 1998 ice storm had on plantations in eastern Ontario. The uniform age and spacing of plantations in which all trees were established at the same time (single-cohort plantations) allows control of species composition, creation of more uniform stands, growth of more uniform trees, development of more uniform wood properties, and quicker financial returns on the investment. Although this approach offers more efficient management, forest managers must also plan and implement a thinning regime to avoid stagnation of growth.

The timing of crown closure and eventual slowing of diameter growth is controlled by the initial and early spacing of the trees. Trees with uniform spacing and equal vigour are less likely to differentiate than those planted with an initially irregular spacing. Regular spacing is therefore more likely to yield trees of uniform, predictable size. The genotype and phenotype of the species and the stock selected will also affect growth rates and patterns. See Section 4.3 for more details about managing an older stand's density.

The initial spacing or density sets the stage for stand development, growth, and the long-term need for pruning and thinning. When developing a crop plan, answer the following questions:

- What is the desired stocking level at the free-to-grow stage?
- Will refill planting be required to meet this target?
- What is the minimum average stem diameter expected at the first thinning?
- What is the preferred time (age) that will produce a diameter suitable for the first thinning operation?
- Does the species self-prune well or will pruning to promote the development of knot-free wood be part of the management regime?
- What is the width of the equipment that will be used during the establishment phase and the equipment that will be used for the initial thinning?
- Does the species produce economically valuable small-diameter stems from thinning?
- If the thinned stems are valuable, can site conditions and the establishment or tending operations be designed to accommodate wider initial spacings in order to delay the first thinning and increase their value?
- Alternatively, can companion species be used that will die naturally after promoting natural thinning?
- Are there any health considerations based on the initial density or species combinations?

Where timber production is planned, a common recommendation is that rows be between 2.4 and 2.7 m apart. However, this will depend on:

- the species to be planted (branching pattern, susceptibility to early mortality)
- the topography
- future management objectives (e.g., wood production targets)
- equipment available for planting, tending, and thinning operations (the rows must be far enough apart to accommodate the equipment)
- cost considerations

Similarly, a common recommendation for spacing between trees within the rows is 1.8 to 2.4 m. However, this will depend on the same considerations as the row spacing.

Tighter initial spacings can be considered on difficult sites, such as sites that are susceptible to drought and likely to experience high juvenile mortality, or for species like white pine, where higher initial densities can mitigate damage by pests such as the white pine weevil.

2.9 Encouraging natural regeneration

At many planting sites, you can take advantage of the natural seed-production potential of an adjacent hardwood or coniferous forest. Observations from existing plantations indicate that seeds released from existing forests into recently established sites can both supplement the stocking created by planting and accelerate restoration of a more natural forest. As the plantation matures, thinning operations can be designed to further encourage the recruitment of new seedlings and development of this natural regeneration.

Although there have been no studies on this subject, you can take several steps to encourage natural regeneration at the time of plantation establishment:

- Maintain a minimum distance of 20 m between existing forests and new plantings. This area can be used to simplify future operations (tending, thinning), or to provide access or fire protection around the plantation.
- Disking of the soil in this gap for 2 to 3 years can provide a suitable seedbed for hardwoods until the desired recruitment has been achieved.
- Preserve any existing desirable natural regeneration during the initial site preparation phase. This may be impractical on sites that will be machine-planted unless the seedlings are growing in clumps that the tractor can avoid.
- Adjust the planting density or species choice adjacent to the natural forest. For example, jack pine has been planted on sites with shallow soils adjacent to sugar maple forest to act as a nurse crop for the maple seedlings. Because jack pine foliage is relatively sparse, it allows sufficient sunlight and moisture at the forest floor, and it increases the soil organic content through its litter, thereby encouraging and protecting the developing maple forest. Eventually, the jack pine can be removed.
- Caution is required when implementing any of these techniques, since invasive species (especially the dog-strangling vine) and other competitors such as buckthorn may invade the plantation.

2.10 Species mixtures

Traditional plantations are often established with a single dominant species as the long-term crop, since this makes harvesting more efficient, but it's also possible to incorporate several alternative (companion) species, depending on the site characteristics and your goals for the site. The companion species is usually planted in alternate rows, or in uniform blocks, with the location dictated by local soil characteristics. Block planting of the companion species can increase the establishment efficiency, survival and growth of the main crop, thereby facilitating weed control, providing protection from browsing, and promoting natural thinning to favour the best individuals (von Althen 1988). Where species have compatible growth characteristics or when you have specific management objectives (e.g., using white pine to train red oak), the dominant and companion species can be intermixed as alternating rows of each species.

When properly designed and implemented, mixed-species plantings using alternate rows or block planting, as in the cases of black walnut with white pine and white pine with red oak, have often achieved good results. However, when species selection and distribution is random (sometimes referred to as a "bag mixture"), with little consideration of the different growth requirements and patterns of each species or no consideration of site variability, the results have been disappointing. Subsequent management efforts, especially 25 to 40 years later, become more challenging.

Some researchers and forest managers have expressed concerns related to the practicality of intermixing large numbers of species on a planting site from the perspectives of cost and silvicultural factors. Kelty (1992) reported no evidence that a mixture of randomly selected species would generally perform better than monocultures of the most productive component species. This may be because species that are used in mixtures must have good ecological compatibility; for example, shade-intolerant species can provide good shelter for shade-tolerant species. Furthermore, the species interactions should increase the efficiency of use of a resource such as light or water that limits survival or productivity. Combining species that differ in characteristics such as shade tolerance, height growth rate, crown structure (particularly the leaf-area density), foliar phenology (particularly deciduous versus evergreen leaves), and root depth and phenology is important for designing highly productive mixed-species stands. For instance, the component species in a mixture should occupy different strata in the canopy (e.g., a fast growing shade-intolerant species in the overstory with a shade-tolerant species in the understory) or different rooting zones (deep versus shallow roots) in order to maximize production.

However, several researchers have reported good results with mixed hardwood species (von Althen 1990; Kelty, 1992, 2006; Pedlar et al. 2006, 2007), which often produce superior growth compared to that in single-species hardwood plantations. Pedlar et al. (2006) reviewed 110 growth plots in hardwood plantations in southern Ontario. After controlling for differences in soil conditions, they found that mixed hardwood plantations grew about twice as fast as hardwood monocultures.

von Althen (1988) recommended that when planting a small number of one species with a large number of another species, group or block planting may be more successful because the chances of survival and adequate growth are greater. He further observed that although a random mixture of many species may be the most desirable arrangement ecologically (as it most closely resembles a natural stand), the management of random mixtures to produce high-quality timber requires greater expertise than management of plantations in which a row of one species alternates with a row of another species.

Hardwood plantations established for timber production should contain species with comparable growth rates to reduce the risk that one species will outgrow and shade the other species (von Althen 1988). Edge (2004) went further, noting that species with very different juvenile growth rates (such as walnuts and oaks) may not be compatible.

Many situations in Ontario have involved planting a mixture of species (often white pine and white spruce or white pine and red oak), with the dominant species eventually showing good growth, better spacing, and good form because growth of the other species slowed and its trees eventually succumbed to suppression. With better spacing and larger-diameter residual trees, windthrow and wind damage are less of a concern. So even though the slower-growing and eventually suppressed species did not make up a significant component of the final stand, they performed a valuable role in accelerating canopy closure, improving spacing through natural thinning, and promoting good growth. If you understand and can predict the interactions among species on a site, and understand the costs and impacts on future operations, you can use that knowledge to create species mixtures that achieve a variety of goals rather than the single goal of timber production. See Case Study #3, which describes growing white pine with companion species in the Larose Forest of eastern Ontario, for more information.

2.11 Agroforestry systems

Occasionally, situations may arise where it is neither possible nor desirable to undertake complete afforestation of an area. The classic example is that of a farmer who appreciates the value of trees, but still requires the land for crop cultivation or other farm operations. In these instances, combining afforestation with agriculture (i.e., agroforestry) may be a viable option.

Agroforestry is a land-use system which aims to produce both trees and agricultural crops or animals on the same piece of land at the same time. This practice dates back more than 8000 years in some parts of the world, and has been shown to be economically profitable while simultaneously promoting many environmental benefits, such as reduced soil erosion and nutrient loss, enhanced biodiversity, and carbon sequestration.

Although agroforestry started out primarily in tropical regions, great strides have been made in the last 40 years in temperate regions around the world to understand and implement agroforestry systems. These efforts include southern Ontario, where it is known more simply as "farming with trees".

The Association for Temperate Agroforestry (http://www.aftaweb.org/) lists the following agroforestry practices that would be suitable for temperate regions, including southern Ontario: forest farming, windbreaks and shelterbelts, streamside or riparian plantings, bioenergy plantings, silvopastoral systems, and intercropping systems.

2.11.1 Forest farming

Historically, agroforestry referred to the retention of a small portion of original woodland that was not cleared when the surrounding land was converted to agricultural use (Fig. 2.14). In historical times, these small woodlots contributed both timber and non-timber forest products (e.g., firewood, maple syrup) to the farmer. Nowadays, these woodlots may also be used to produce food (e.g., ginseng, shiitake mushrooms) and pharmaceuticals (e.g., taxol, an anti-cancer agent derived from the Canada yew). However, the use of existing woodlots to permit cattle grazing can damage the trees and is not recommended by either forest managers or agricultural experts.

Figure 2.14: A farm in southern Ontario that shows the combination of agricultural fields with wooded areas. The farm woodlot can be a source of lumber, firewood, food, and medicinal plants. [Photo source: Earth Haven Farm, Vantage Point Media House]

2.11.2 Establishing windbreaks, shelterbelts, and streamside plantings

These plantations are primarily linear structures. The windbreaks and shelterbelts are usually established around agricultural fields (Fig. 2.15), whereas streamside (riparian) plantings are established along the banks of waterways that pass through agricultural areas (Fig. 2.16). They are non-intrusive because little arable land is lost to the trees, although this depends upon how many rows of trees the farmer plants.

Figure 2.15: A farm landscape in southern Ontario with a windbreak in the top right corner and a woodlot in the foreground. [Photo source: Ontario Ministry of Agriculture, Food & Rural Affairs]

For both windbreaks and streamside plantings, the tree species or type must be matched to the soil conditions; for example, riparian trees must obviously be able to tolerate wet conditions, including occasional flooding.

Figure 2.16: A streamside planting at Washington Creek, Ontario. These hybrid poplar trees are 4 years old, and show the high growth potential of these nutrient-rich sites when they are matched with appropriate tree species. [Photo source: Andrew M. Gordon, University of Guelph]

Windbreaks provide many benefits to farms: they increase crop yield and quality (especially in orchards with high-value horticultural crops); increase biological control of insect pests; reduce soil erosion, and thus reduce crop plant damage due to abrasion from windblown particles; improve animal survival, welfare, and performance in pasture situations; conserve water; produce timber; control snow; conserve home energy; and provide wildlife habitat and carbon sequestration. The benefits of windbreaks can reach downwind as far as 20 times the height of the windbreak.

The porosity (openness) of a windbreak determines the magnitude of the downwind effects. Although it's tempting to aim to produce as dense a wall of trees as possible, an ideal windbreak should let some of the air pass through; as a result, it should have tree spacing and shrub placement that creates a porosity of approximately 40% (Fig. 2.17). This prevents turbulence from occurring upwind and downwind of the windbreak, and thereby reduces plant damage caused by that turbulence or any airborne soil particles that it carries. Windbreaks should be open enough that they can "exhale".

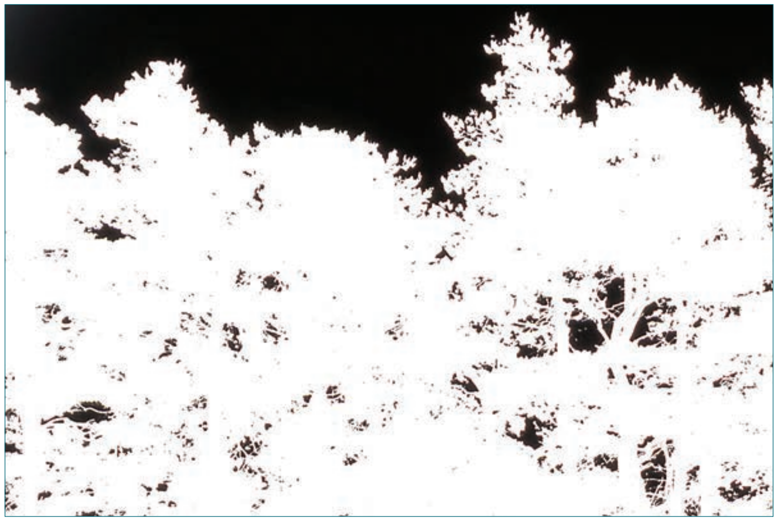


Figure 2.17: A high-contrast black and white photograph of a windbreak in Norfolk County. The optimal porosity of a mature windbreak should be approximately 40%. [Photo source: Anne E. Loeffler, Grand River Conservation Authority]

Streambank plantings offer many of the same benefits as windbreaks. In particular, where fields adjacent to a body of water are not tile-drained, riparian plantings intercept excess fertilizer that leaches from the fields in drainage water. This is especially important for inorganic nitrogen fertilizers that contain nitrate and ammonium, but also for fertilizers that contain phosphorus. The trees utilize this nitrogen source to support a variety of growth processes by converting the inorganic nitrogen into organic nitrogen in tree tissues, which will ultimately be deposited in the stream, especially if the tissue happens to be a leaf. However, inorganic nitrogen and organic nitrogen play different ecological roles in bodies of water. The organic nitrogen promotes a variety of beneficial ecological processes for insects and, ultimately, the fish populations that feed on them. In contrast, inorganic nitrogen can cause algal blooms, and when the algae die and decompose, the microbial community responsible for the decomposition depletes oxygen in the water, resulting in extensive mortality of fish and other aquatic organisms.

Even if the adjacent land has tile drainage and the trees provide minimal nutrient filtering capacity, the trees still offer many environmental benefits, including the provision of shade that cools streams, stabilization of riverbanks, and the provision of nutrient-rich litter to the stream ecosystem.

2.11.3 Bioenergy plantations

This type of planting has been investigated since the 1970s in southern Ontario. Fast-growing hardwoods (usually willows and poplars) can be grown under short rotations to produce biomass, which can then be converted into pellets that can be used as fuel (Fig. 2.18). This requires a fairly large area for the operation to be profitable, and requires some specialized equipment that may not be readily available on a typical farm. Bioenergy plantations will offer considerable economic and environmental opportunities in the future, as they may be carbon-neutral fuel sources.

Figure 2.18: A short-rotation willow bioenergy plantation in Guelph, Ontario. Willows are planted as cuttings, are cut after 1 year to encourage coppicing, and then are grown for seven 3-year rotations. Annual yields after the second or third cut will usually exceed 10 tonnes/ha. [Photo source: Amir Bazrgar, University of Guelph]

2.11.4 Silvopastoral and intercropping systems

Silvopastoral and intercropping systems are more complex types of agroforestry. In these systems, trees are integrated into the pasture production system (silvopastoral system) or the crop production system (intercropping). Nut trees, such as black walnut, or poplars are typically used for the tree component. The density of the planted trees can be varied to meet different objectives. The only rule to remember is that the greater the number of trees you plant (i.e., the more the planting approaches true afforestation), the less room remains to produce pasture or crops. In addition, higher planting densities produce more shade, making it difficult to grow certain pasture and field crops.

Trees in these systems are usually planted in a square grid to accommodate the agricultural equipment. Research over the last 30 years conducted at the University of Guelph indicates that for hobby farms using small tractors and farming implements, a density of approximately 110 trees/ha is optimal. On larger farms with bigger equipment, the spacing between rows of trees and between trees within the rows should be matched to the maximum size of the equipment and implement used; this will result in a lower density of planted trees, but will greatly facilitate tending. Because of this lower density, the trees will likely need to be pruned to create straight stems and to ensure that their lower limbs don’t interfere with the agricultural equipment.

2.11.5 Summary

Agroforestry systems provide many economic and environmental benefits. In a silvopastoral planting, the largest benefit may be improved animal welfare. Think of the last time you drove past a southern Ontario pasture on a hot summer day. Where were all the cows? They were all clustered under that lonely maple the farmer retained in the middle of the field. Silvopastoral planting just spreads that shade out across the field (Fig. 2.19), allowing animals greater mobility and shelter choices.

Figure 2.19: Dairy cows in France enjoy the shade provided by trees in a silvopastoral planting. [Photo source: Christian Dupraz, Institut National de la Recherche Agronomique, France]

If pruned regularly, open-grown trees can develop valuable stems. Pruning is not necessarily an onerous task given that pruning is only required every 2 or 3 years. Most native Ontario hardwoods perform well in silvopastoral and intercropping systems. Tree species should be matched to the soil type, and again, local agencies can generally provide information to guide your choices. Ash species, although they once showed great promise as an intercropping species, are no longer a good choice because of the damage being caused by an invasive insect (emerald ash borer). Black walnut is an ideal choice if soil conditions support good growth (Dixon 2003). See Tables 2.2 and 2.3 for details. There is no deleterious effect of the chemical produced by black walnut trees (juglone) on growth of adjacent crops if walnut is planted at the suggested densities. In silvopastoral systems, young planted trees may need protection from livestock, which may eat young shoots or rub up against larger trees. Many commercial protection products are available. Plan to research the compatibility of your preferred tree species and the animals using the site, since certain trees can cause health problems for the animals if ingested.

The economics of agroforestry systems have proven to be positive, although this depends upon the combination of tree species, planting density, animal or crop, and future timber markets. Agricultural markets are also changing, and tree-based food production systems may have some advantages in the future. For example, beef produced in a silvopastoral system may command a higher price as a result of the improved animal welfare. Similarly, trees in an intercropping system will increase the long-term accumulation of soil carbon because of inputs through litterfall, leading to sustained soil fertility. This may also help farming become more carbon-neutral, which may let farmers take advantage of the carbon offset credits offered by the province's emerging carbon markets. See Case Study #4 for examples of these systems in Ontario.

2.12 Plantation assessment

Trees should be monitored and assessed at several times during the early establishment period, when they are most vulnerable. Assessments should include:

- **Planting quality:** This assessment takes place during or immediately after planting, and focuses on the quality of the planting itself. The results are often used to identify and correct problems early in the planting process, to confirm that the planter's contractual obligations have been met, and to provide any necessary corrections to the planting method.
- **First- or second-year survival and growth:** This assessment is used to determine how well the planted trees have survived and recovered from the shock of planting, and whether follow-up operations such as refill planting, tending, or protection against pests will be required.
- **Free-to-grow status:** The timing of this assessment is somewhat flexible, and depends upon the growth and survival of the trees in comparison with a set of standards. Section 2.12.3 provides more details.

2.12.1 Planting quality assessment

The quality of the planting can be assessed by the planting contractor or by a representative of the landowner or agency that hired them. The assessment can range from informal to formal, and both are acceptable so long as you can determine whether the target planting quality was achieved.

There are several signs of improper planting:

- Unsuitable micro-sites include rotten logs or stumps, depressions subject to flooding, highly eroded locations, roadside fill, or raised humps of loose soil or debris.
- Unsuitable root placement in the planting hole includes roots in an unnatural position, doubled-up roots, twisted and tangled roots, exposed roots, and container stock with excessive damage to the container.
- Unsuitable planting depths include a seedling planted too far below or above the root collar,

living branches or foliage buried in the soil, a visible paper pot or plug of container stock, more than one tree or container per hole, and a planting hole too small to accommodate the seedling's entire root system.

- Unsuitable positioning of the crown and stem includes trees that are planted at an angle greater than 15° from the vertical for hardwoods or 30° from the vertical for conifers.
- Unsuitable spacing occurs when a seedling is planted too close to the next tree within the same row or in the next row. The spacing is typically too tight if it is closer than 80% of the prescribed spacing. For example, for a prescribed spacing of 2.6 m, a spacing <2.1 m would be too close.

In some cases, an informal visual assessment will be sufficient. The goal is more to ensure consistent planting quality than to penalize the planters. To accomplish this:

- When planting begins, check a large proportion of the first planted seedlings (more than 10%) to identify problems with spacing or microsite selection.
- Follow closely behind individual planters to assess their planting quality and provide remedial training if necessary.
- Conduct occasional spot checks behind the planters to ensure that they maintain their quality standards.
- If you detect problems, work with the planting manager to correct them.

In contrast, formal assessments are designed to ensure that contractual obligations are being met. For example:

- During the planting operation, select a random starting point and assess the first 10 trees in a row.
- After examining the first 10 trees, move to the adjacent row to the right or left and examine an additional 10 trees.
- Repeat this process until 100 trees have been sampled.
- If a row ends before a tree sample is complete, complete the sample by returning along the next adjacent row.
- Position the plots so as to sample variation in the planted species, site characteristics, and planting method and obtain an assessment of the average planting quality across the planting site.
- The sample size of 100 trees can be adjusted to provide a certain minimum percentage of the total planting. Sample at least 2% of the trees to ensure statistical reliability, although the sample size can be increased to 5% if significant problems are encountered.
- To cover more of the plantable area, work in groups of 5 trees rather than 10 trees (Fig. 2.20).

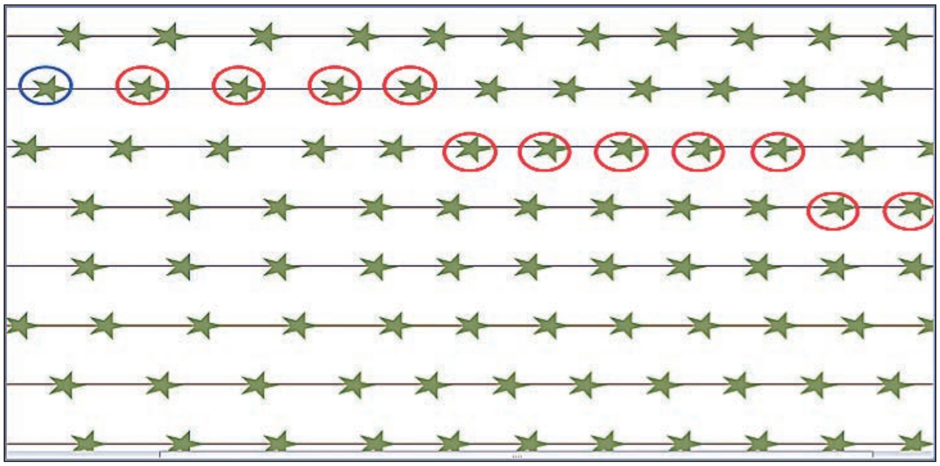


Figure 2.20: Sampling pattern using groups of five trees.

After reviewing the assessment results:

- Communicate any problems to the planting foreman (for general problems) or the tree planter (for individual problems).
- Record all assessment results in writing, but preserve the chain of custody (i.e., the identity of every person involved in the process) so that any future problems with the planting, the stock quality, or the seed source can be investigated and prevented from occurring again.

2.12.2 First- or second-year survival and growth assessment

The growth and survival of the plantation require close monitoring during the first 2 years after establishment, when the seedlings are most vulnerable. The purpose is to determine whether refill planting will be required. This assessment can also measure the growth of the seedlings and highlight issues such as "bud check", in which the terminal bud of conifers does not expand properly or sometimes at all.

Survival and average height are commonly measured to determine the initial success. The quality of the growth can also be assessed to identify the potential future growth and survival. For instance, Paterson and Fayle (1984) suggested that the length of the current year's new needles in red pine is an indicator of the degree of root establishment, and therefore serves as an indicator of next season's potential height increment and foliar development. The change in needle length from the first year to the second year can predict establishment success: trees with a substantial increase in needle length are becoming well established, whereas a short-needled first-year seedling with a minimal increase (or even a decrease) in needle length in the second year suggests poor establishment. You can develop simple criteria to assess the growth quality, ranging from qualitative assessments (i.e., excellent, poor) to quantitative assessment (i.e., measuring needle length and terminal bud elongation).

First- and second-year survival assessments can also reveal whether follow-up operations such as weed control are required (e.g., if the seedlings are being overtopped by weeds in the growing season, or crushed and smothered by weeds under the weight of snow) and can guide recommendations on the optimal type of tending for the site conditions. This inspection may also reveal problems such as damage caused by mice, deer, or other animals.

The assessment methodology can be formal or informal, as described in the previous section. However, we recommend a minimum sampling intensity of 5% at this stage in order to assess more trees and better understand emerging issues. Additional information on the nature of the survival issues or on proposed tending operations should be recorded on a map of the plantation to assist in future operational planning.

The heaviest losses usually occur during the first 2 years. If heavy losses occur, gaps in the coverage should be refilled the following spring, but in no case should this be delayed beyond the first 5 years. How much refill planting should be done will depend upon your planting objectives, and acceptable percentage losses should be specified in the planting plan.

Managers commonly assess survival in the first, second, and fifth growing seasons. Late fall and early spring are preferred. Losses may be distributed throughout an area, or in patches. If the overall survival is too low or you find extensive dead patches, refill planting should be done the following spring.

The following recommendations can guide your refill planting:

- Check survival systematically, as described in the previous section.
- Try to determine the reason for failures, such as grass and weed competition, girdling by mice, browsing by animals, poor drainage, frost pockets, or drought. Take steps to correct or avoid these problems during refill planting.
- If competition is the problem, a tending treatment such as mowing or herbicide spraying should be undertaken. See Chapter 3 for details.
- For the production of timber from conifers, 60% is an acceptable survival rate if there are no large gaps. Under favourable open-field conditions, 75 to 80% is the usual objective. Lower survival rates may be acceptable for ecological plantations if the restoration objective can still be met.
- Where soil protection is the primary objective, 50% stocking should be the minimum.
- Replant with the original species unless there are valid reasons to change (i.e., you determine a need for drought-tolerant or frost-hardy species).
- Hand-planting is usually the only feasible method for refill planting.
- Replant the failed spots the following spring.

2.12.3 Free-to-grow assessment

When a plantation is free to grow (i.e., requires no additional tending to survive and continue growing), this marks the end of the establishment period. At this point, the trees should be relatively free of competition, large enough to survive the typical stresses of their environment (e.g., moderate drought, occasional frost, moderate browsing), and occupy the planting site in the prescribed manner (e.g., spacing). In a well-managed plantation, this assessment should be a simple confirmation of your previous assessments of planting quality, survival, the need for refill planting, and tending, which should have led you to schedule any required follow-up treatments.

You can assess the free-to-grow status of a plantation in many ways. They can be simple to complex, but all share the common goal of assessing the plantation's development in terms of the species distribution, height, spacing, and voids. The free-to-grow standard must be determined during development of the crop plan, before the first tree is put in the ground, and must be directly linked to the future objectives for the stand. Setting the standard before any work occurs ensures an objective measure of the silvicultural effectiveness of the planting and maximizes the potential to learn from each site. By clearly articulating what you expect to happen, objectively measuring whether you were right, and trying to understand any deviations, you can improve your ability to develop realistic prescriptions for future planting sites.

Typical free-to-grow standards for plantations may include:

- the target species and your tolerance for natural ingress of other species
- minimum stem height
- minimum average height for the plantation
- tolerance for missing stems or for density targets
- tolerance for voids of more than one stem or for occupancy targets
- tolerance for spacing variations
- degree of competition

It may be necessary to tailor the standards to match any unique features of your objectives (e.g., wildlife, aesthetics, carbon sequestration).

Under some circumstances, an experienced forest manager will easily see whether a plantation is free to grow. A simple but thorough walkthrough, with occasional measurements to provide a reality check, will confirm that the entire plantation is free to grow and that there are no unacceptably large gaps. However, if there is any uncertainty as to the plantation's status, a more formal survey is necessary.

Before this sampling, divide the plantation area into groups of sites with similar characteristics (i.e., to support stratified sampling). Any significant differences in landform, soil, the treatments applied, or previously observed performance will indicate the need for a separate sampling of that group of sites. Stratification reduces the variation between sites within each stratum (group) and lets you both reduce the number of sample plots required and increase the precision of your estimates (e.g., of stocking).

It is rarely possible and never necessary to survey every tree in a plantation. Conclusions about the free-to-grow status of the entire plantation can be made based on a sample of the whole. For the sample to be useful, it must be large enough to capture the plantation's variability and must be unbiased; that is, every part of the plantation must have an equal chance of being surveyed. As noted above, sampling 5% of the plantation should be adequate.

For very uniform plantations of a single species with similar heights and previously confirmed high survival, you can use the formal assessment procedure described in Section 2.12.1 to assess whether the plantation is free to grow. For moderately uniform plantations that were established using a more or less regular spacing within and between rows, a simple 3.99 m radius (50-m²) circular plot can be used by following transects that run across the rows of trees (Fig. 2.21). For plantations established using irregular or random spacing, we recommend an area-based strategy based on clustered circular plots with a radius of 1.13 m (a 4-m² area), which is often called a "string of pearls" (Fig. 2.22 and Appendix 3).

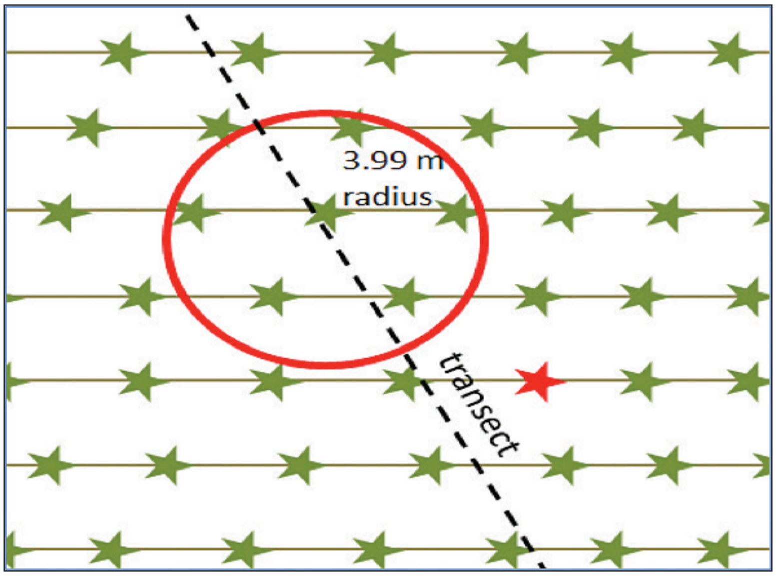


Figure 2.21: Illustration of an assessment based on circular plots distributed along a transect.

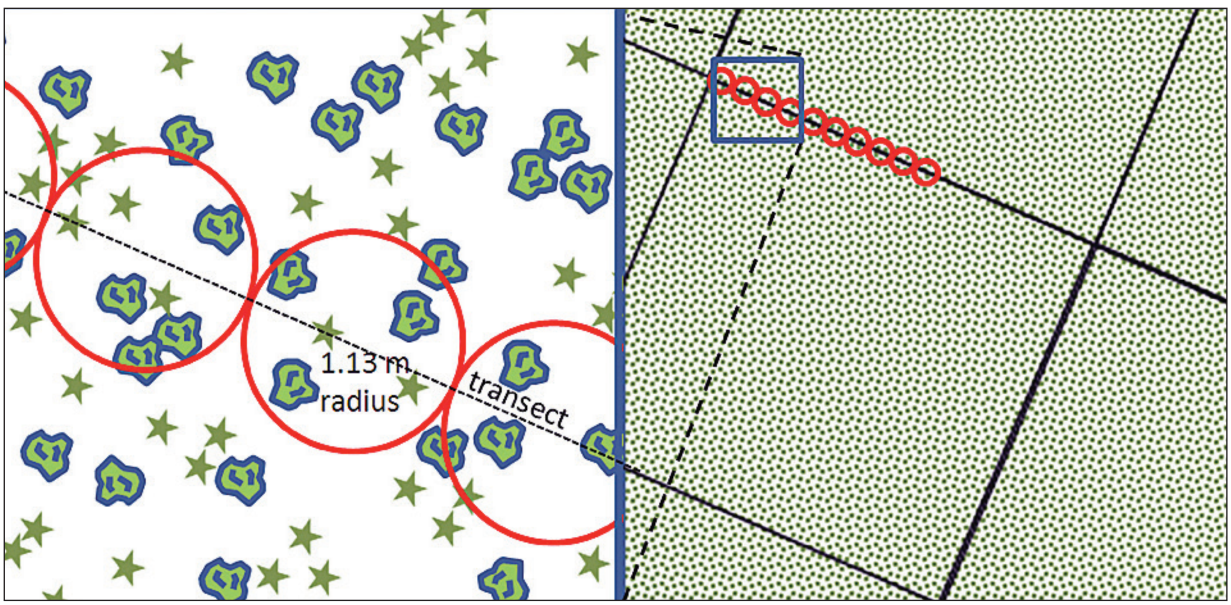


Figure 2.22: Illustration of an assessment based on clustered circular lots (the “string of pearls” method).

The results of the free-to-grow assessment will tell you whether any immediate interventions are required (e.g., additional tending) and whether the plantation is on track to meet your future objectives (Figure 2.23). By the time a stand is free to grow, some treatments become more difficult (e.g., mowing) or ineffective (e.g., refill planting). Although you can still manipulate some aspects of the plantation's condition at this stage (e.g., cleaning to remove unwanted species), you are largely stuck with what you have achieved by this point.

It's important to honestly assess how well the plantation will meet your objectives for the future. If your goal was to produce (for example) a crop of trees suitable for timber production, and was based on certain assumptions about the establishment conditions (e.g., density at the free-to-grow stage), revisit these assumptions to determine whether any adjustments to your thinning plan and final crop will be necessary.

Figure 2.23: Examples of plantations which have reached the free-to-grow stage. Left: A seven year old white spruce plantation. Right: A six year old red pine plantation. [Photo source: Eric Boysen, NewLeaf Forest Services]

Chapter 3
Competition control

3 Competition control

Competition (weed) control may be the most important treatment that you can perform to ensure the success of your afforestation project. A weed is any woody or herbaceous plant that is growing where it isn't wanted, and is competing with more desirable plants for water, nutrients, sunlight, and space (Zeleznik and Zollinger 2004). Weeds can be grouped into three categories: woody plants, annual and perennial grasses, and broadleaved herbaceous (non-woody) weed species. Both woody and herbaceous plants can reduce tree survival and growth in old-field sites through direct competition for light, water, and nutrient resources.

Forest managers have several options for keeping weed competition at a tolerable level: mechanical and chemical site preparation treatments, post-planting mechanical and chemical tending treatments, and the use of cover crops. To succeed, it's necessary to account for weed control right from the start of your afforestation plan, from the initial stages of site preparation until the trees are free to grow. It is essential to learn what plants you will need to control, evaluate the timing of the control treatments, and recognize that no one treatment option will fit all situations.

Ultimately, the key to controlling competition is to implement a series of treatment options that will maintain the competition at levels that will maximize seedling survival or growth, minimize the invasion of new or potentially more difficult weeds, and optimize or reduce the use of herbicides.

3.1 Site preparation

The term "site preparation" is used to describe any treatments of a site to prepare it for planting or direct seeding. Good site preparation will provide optimal conditions for seedling survival and growth in the critical first 3 to 5 years after seeding or planting (OMNR 1995 b,c; Stringer et al 2009). There are three different types of site preparation: mechanical, chemical (herbicide), and the use of cover crops. Typical site preparation options include mowing, band spraying (applying the herbicide in narrow bands), disking, ploughing, and furrowing. In some mechanical planting operations, site preparation may be combined with the planting operation in a single step.

Treatment options may involve complete or partial removal of competing plants and may combine multiple options. For example, a mechanical treatment (mowing in mid-August) can be combined with a follow-up chemical treatment (spraying herbicides in bands in mid-September). Some of the most successful projects combine mechanical and chemical treatments. An effective site preparation program will have the following goals:

- Reduce the level of competition, leading to better tree growth and survival.
- Make tree planting easier, leading to better planting quality.
- Facilitate other pre- or post-planting treatments, resulting in more effective competition control.
- Keep costs low, and possibly minimize the requirement for follow-up tending.
- Create sufficient seedbed exposure or a suitable number of planting spots to control row spacing and ensure optimal tree densities.

3.1.1 Factors affecting site preparation options

Each planting site must be evaluated to determine whether any site factors restrict your treatment options and the timing of the treatment. These factors may sometimes increase the cost of preparing the site, result in additional post-planting tending, affect the planting density, or negatively influence survival. The choice of planting method (seeding, machine planting, or hand planting) will also affect how these factors affect the establishment phase.

Some limiting factors include:

- Steep slopes and imperfectly drained sites may limit the use of large or heavy equipment.
- Shallow soils may limit the use of some chemical treatment options.
- Stoney or rocky sites make mowing difficult.
- Access limitations may limit choices to labour-intensive treatment options (e.g., spot spraying).
- The presence of difficult-to-control weed species (e.g., bedstraw, reed canary grass) often requires additional chemical follow-up treatments.
- Restrictions on herbicide use (e.g., proximity to environmentally sensitive areas, landowners opposed to chemical use) may require multiple mechanical treatments.
- Equipment availability may not overlap the optimal timing for the operation.
- Mechanical site preparation (e.g., mowing) may stimulate re-sprouting or root suckers of shrub species.
- Habitat use by wildlife may restrict the timing of operations.
- Clay sites and poor drainage make site preparation difficult under wet conditions.
- Heavily compacted soils will restrict root growth, resulting in poor growth or excessive mortality.

3.1.2 Mechanical and chemical site preparation options

The best time to begin weed control is before the trees are planted. Most new afforestation sites require some type of site preparation before seeds or trees can be planted. Selecting a site preparation treatment option will be based on the tree species to be established and the characteristics of the planting site (e.g., vegetation, soil, topography, access). It may consist of a single treatment or a combination of treatments. Table 3.1 compares some of the mechanical and chemical site preparation options that have been used successfully in Ontario's afforestation programs.

Table 3.1: Comparison of mechanical and chemical site preparation options that have been used successfully in Ontario.

Option	Timing	Description
Mowing or brush-cutting	Late summer or early fall of the year before planting	Mowing or brush-cutting on sites that contain heavy herbaceous competition or an abundance of small woody brush species may be required to facilitate subsequent site preparation treatments and planting of the site. Mowing is often used in conjunction with a herbicide option (e.g., band spraying) and a scalping treatment. Advantages of this treatment include: • It can improve herbicide efficacy when applied to new re-growth, depending on the species. • It facilitates planting. • It provides even re-growth of grasses to facilitate post-planting tending (e.g., spot tending). • It minimizes the risk of longer grass and brush species clogging planting machines. • It minimizes damage from grass or brush collapsing under a snow load and crushing or bending a seedling. • The cost is low. • The equipment is readily available (e.g., many rural landowners already own this equipment). Disadvantages include: • It may stimulate re-growth of herbaceous or woody brush species and may pose competition issues if a herbicide treatment is not undertaken.
Scalping	In the fall of the year before planting	Scalping is removal of the sod layer at the soil surface to expose the mineral soil, and is generally done in strips or in patches. It is often used in conjunction with mowing and band spraying. Advantages of this treatment include: • It provides short-term competition control. • It exposes mineral soil, thereby creating a good planting medium and conditions suitable for application of a pre-emergence herbicide. • It defines the planting rows, thereby assisting in future tending treatments. • The effectiveness increases when used in combination with a herbicide treatment (e.g., band spraying). • The cost is low. Disadvantages include: • The equipment is less available than regular farm equipment.

Option	Timing	Description
Ploughing and disking	In the fall of the year before planting	This is a two-stage treatment. Ploughing is done first, and involves deep turning of the soil; disking is done second, and cuts and breaks up the large lumps and clods of soil produced by the plough. Often used in conjunction with a cover crop or herbicide treatment to prevent the site from being overrun by invading weeds. Advantages of this treatment include: • It loosens and aerates compacted soils and improves water infiltration. • It provides initial weed control on sites with heavy competition. • It creates a suitable growing medium for trees and a smooth surface for subsequent herbicide application. • The equipment is commonly available on farms. Disadvantages include: • Planting is difficult on barren clay soils due to the short window for planting (the soil is too wet and gummy in early spring and too dry later). • There is potential for soil cracking after planting. • It may stimulate germination from the soil seed bank. • It is more expensive than other mechanical treatments. • On sites with rolling or steep terrain, the exposed soil may be vulnerable to erosion.
Single furrow	In the late summer or early fall of the year before planting	This treatment creates single furrows at a defined spacing across the planting site. Seedlings can be planted on top of the mound (wetter sites) or in the furrow (drier sites). Advantages of this treatment include: • It creates planting spots above the water table on wetter sites. • The overturned sod layer provides good initial competition control. • It exposes mineral soil to create a good planting medium and suitable conditions for application of a pre-emergence herbicide. • It defines the planting rows, thereby assisting in future tending treatments. • The cost is low. • The equipment is relatively available on farms. Disadvantages include: • Pooling may be a problem if you cannot provide drainage. • There is an increased risk of blowdown, especially when the rows are perpendicular to the prevailing wind, because the roots are often shallow and restricted to the furrow, resulting in poorly balanced root systems.

Option	Timing	Description
Creation of pits and mounds	Early summer or fall of the year before planting	Pit and mound creation is a form of mechanical site preparation that creates an uneven topography, but unlike furrowing, the distribution of plantable sites is intermittent (semi-random). This mimics the conditions in a natural forest and provides a range of moisture and sunlight conditions. Advantages of this treatment include: • It emulates natural succession processes more closely than in row planting. • It can achieve certain management objectives sooner (e.g., meeting biodiversity targets by moving the site towards a diverse hardwood community). • The pits or mounds can be hand-planted with bareroot or container stock, direct-seeded, or any combination of these methods. Disadvantages include: • It relies on the use of heavy equipment, which can be expensive. • Difficulties may arise in locating seedlings for future tending due to the semi-random planting pattern. • The variety of planting microsites and species increases the complexity of the planting, leading to higher planting costs, or increases the complexity of the seeding, leading to a requirement for greater species diversity.
Band spraying	Early fall in the year before planting or simultaneous with planting	Band spraying is the application of a herbicide in narrow bands (0.5 to 0.75 m wide) across the planting site. Often used in conjunction with mowing and scalping. Advantages of this treatment include: • It minimizes the use of herbicides. • It can be integrated with spring planting operations (e.g., application of a pre-emergence herbicide during machine planting). • Scalping can be done at the same time. • It provides good weed control on sites with light to heavy competition. • It creates a better planting medium. • It clearly defines the planting rows, thereby assisting in future tending. • It is the most cost-effective chemical treatment. • The equipment is readily available (e.g., a modified agricultural sprayer). Disadvantages include: • It requires a licensed pesticide applicator. • Taller weeds can crowd in from the side, and may collapse onto smaller seedlings in winter under snow loads. • Competing weeds will gradually extend their roots or rhizomes from the untreated area into the treated strips, leading to a requirement for follow-up tending.

Option	Timing	Description
Full boom spraying	Early fall of the year before planting	Boom spraying is the application of a herbicide over the entire planting site. Generally used in conjunction with a mowing treatment. Advantages of this treatment include: • It may provide better control than band spraying on sites with heavy grass competition. • It creates a good planting medium. • The equipment is readily available. Disadvantages include: • It requires a licensed pesticide applicator. • It does not define the planting rows, thereby failing to assist future tending. • It is more expensive than band spraying. • When combined with tillage (e.g., ploughing, furrowing, pit and mound creation), it may increase soil vulnerability to erosion and invasion by other unwanted weeds.

Figures 3.1 to 3.6 Illustrate some of the equipment used in site preparation work. This equipment often includes modified agricultural equipment.

Figure 3.1: Mowing. Left: Sites containing heavy herbaceous competition or an abundance of small woody brush species can be mowed or brush-cut to facilitate planting. [Photo source: Martin Streit, Ontario Ministry of Natural Resources and Forestry] Right: Various types of mowers can be used to prepare the site to facilitate planting or supplementary site preparation treatments such as band spraying. [Photo source: Scott Danford, Rideau Valley Conservation Authority]

Figure 3.2: Scalping. Left: After using a sod scalper as a site preparation treatment, seedlings can be planted down the middle of the strip. [Photo source: Glen McLeod, Forests Ontario] Right: A scalper can be mounted on a planting machine, as seen in this photo, or pulled behind a tractor using its three-point hitch. [Photo source: Mark McDermid, Forests Ontario]

Figure 3.3: Single furrows can be created across the planting site at a defined spacing. This photo shows a combination treatment that combines furrowing with herbicide application: full boom spraying, which is a herbicide application across the entire site to better control heavier grasses such as reed canary grass. [Photo source: Rideau Valley Conservation Authority]

Figure 3.4: Band spraying. Left: To control competing plants, narrow bands of herbicide are applied in the fall at a prescribed spacing across the planting site. [Photo source: Scott Danford, Rideau Valley Conservation Authority] Right: A band of herbicide is sprayed on either side of the seedling as part of the planting operation. The seedlings are protected from the spray by guards on either side of the seedling. [Photo source: Paul Robertson, Trees Unlimited]

Figure 3.5: Band spraying and scribing (marking the planting rows with a single-toothed spring harrow). This combined site preparation treatment includes applying a band of herbicide and tilling the soil. The treated strips are shown in the early spring before the grass has full greened up. [Photo source: Scott Danford, Rideau Valley Conservation Authority]

Figure 3.6: Band spraying. Left: The results of a fall herbicide application (band spraying) with tree planting completed in the following spring. [Photo source: Wade Knight, Forests Ontario] Right: A site after band spraying in the fall, followed by machine planting in the following spring. [Photo source: Glen Mcleod, Forests Ontario]

3.1.3 Cover crops

Cover crops are an appropriate site preparation treatment for planting or direct seeding of sites to prevent the invasion of competing vegetation. This approach is most applicable on sites with a high percentage of exposed mineral soil (e.g., when converting a cultivated field to forest). Methods using native wildflowers and tree seed mixes often more closely emulate natural succession processes and can be cost-effective for many restoration projects.

Additional benefits of a cover crop include reduced use of herbicides, increased soil fertility by adding nitrogen (e.g., white clover; Fig. 3.7), control of soil erosion, provision of food for wildlife, reduced or eliminated drying of the soil after tillage, reduced influx of competitive species, and weed control by certain species (e.g., ryegrass, oats) that produce allelopathic chemicals capable of suppressing the growth of certain competitive plants (Zeleznik and Zollinger 2004).

Figure 3.7: A clover cover crop 1 month after planting. Band application of simazine has controlled the cover crop within the planting strip. Dutch white clover is emerging below a cover of barley. [Photo source: John Enright, Upper Thames River Conservation Authority]

A common recipe used in southwestern Ontario for afforestation work is a mix of white Dutch clover and barley, as shown in Figure 3.8. The clover is perennial, and adds nitrogen to the soil. The barley is an annual grain that becomes established quickly and serves as a nurse crop, providing time for the clover to become established during the first growing season. The site is seeded in the early spring, with the ground still frozen, using a broadcast seeder at a rate of 5.7 to 7.9 kg/ha of clover combined with 61.8 kg/ha (2.47 bushels) of barley (John Enright, Upper Thames River Conservation Authority and Wade Knight, Forests Ontario, personal communication).

Figure 3.8: Seeding a cover crop. Left: A small cyclone seeder is mounted on the back of an ATV to seed a cover crop of clover and barley in the early spring. [Photo source: Rick Grillmayer, Nottawasaga Valley Conservation Authority] Right: An industrial agricultural seeder is used in the late winter or early spring to seed a cover crop in a corn field. [Photo source: John Enright, Upper Thames River Conservation Authority]

Cover crops such as barley, wheat, ryegrass, or Dutch white clover have been established in conjunction with herbicide treatments on some sites, with the objective of reducing the requirement for subsequent herbicide applications or mowing. This type of application has been successful in several areas of southern Ontario (e.g., the Essex Region Conservation Authority, the Upper Thames River Conservation Authority). In some cases, the cover crop is more easily controlled by band spraying as a tending treatment after planting than would be the case for the competing plants that would have invaded the site in the absence of the ground cover. See Case Study #5 for more information.

The choice of cover crop type sometimes requires a trade-off between overall effectiveness, seed availability, and cost. For instance, clover is relatively inexpensive but because it is attractive to deer, it may increase browsing damage in areas where deer populations are high, and it could provide habitat for rodents unless mowing is done throughout the growing season.

Native clump-forming grasses or wildflowers can be very effective. However, the seed may be more costly to purchase than crop seeds. Native perennial grasses (e.g., warm-season prairie grasses) have primarily vertical root systems and do not appear to compete with the seedlings. Seeding rates should be low to minimize the creation of rodent habitat, as heavy rodent damage has been observed on tree seedlings where warm-season grasses covered more than 50% of the ground. To achieve this coverage, we recommend seeding native grasses at low rates (<1 kg/ha) and higher rates of biennial and perennial forbs (Paul Gagnon, Long Point Region Conservation Authority Wade Knight, Forests Ontario, personal communication).

Mowing can help to manage and maintain your cover crop by giving it a competitive edge over competing weeds. The aboveground portions of ryegrass and most clover grow more vigorously after being mowed. To stimulate growth by mowing, it is best to mow high before the plants have flowered. However, mowing when the plants are stressed by drought or by frost may kill the plants rather than stimulate growth (Wallace and Scott 1995).

When choosing a cover crop, select a species that will achieve your site preparation objectives without negatively affecting tree growth. Knowing the establishment characteristics of the cover crop is therefore very important. Table 3.2 compares several cover crop species that have been used in southern Ontario. The information in the table was adapted from OMNR (1994) and Wallace and Scott (1995), supplemented by personal communications from Mary Gartshore, ecological restoration consultant, and Wade Knight, Forests Ontario.

Table 3.2: Comparison of white clover, ryegrass, and wildflowers as cover crops.

Characteristics	**White clover**	**Ryegrass**	**Wildflowers**
Varieties	The three main types of white clover are ladino, Dutch white, and wild white. All are perennials.	The two main types are perennial ryegrass and annual ryegrass.	Common varieties include brown-eyed Susan, wild bergamot, evening primrose, showy tick-trefoil, foxglove beardtongue, grey goldenrod, arrow-leaved aster, blue vervain, common milkweed, Canada wild rye, slender wheatgrass, little bluestem, and white millet.
Establishment characteristics	A shade-tolerant nitrogen-fixing perennial that develops slowly in the first year. Once established, it provides long-term cover. Low drought resistance. Grows best on fertile, well-drained sites, but tolerates wet soils better than other legumes.	Germinates and becomes established quickly. Prefers loam or sandy loam soils, but will grow on any soil, including acidic soils. Tolerates wet periods but not drought. Needs plenty of moisture and nitrogen. Annual ryegrasses are less shade-tolerant than perennial ryegrasses.	During the first year, native perennials appear as non-flowering rosettes. Millet provides shading and weed control and dies as a result of exposure to winter conditions, including its seed. The following year, large perennial wildflowers and grasses flower and go to seed, providing continuous cover. Tolerant of a wide variety of weather and soil conditions.
Lifespan	Most varieties live at least 5 years.	Annual varieties, and perennial varieties that live 3 to 4 years.	Evening primrose is biennial, brown-eyed Susan and grey goldenrod are short-lived perennials, and the others will remain on the site for about 10 years, until crown closure.

Characteristics	White clover	Ryegrass	Wildflowers
Time of seeding	Early-spring seeding is optimal. Late-fall seedings (September or October) rarely survive.	As these are cool-season grasses, they can be sown in early spring (before May) or early fall (mid-August to mid-September).	Seeding should occur after spring tree planting (May) or in the fall (November). Add white millet to your cover crop seed mix. Hand-sow at a rate of 0.7 kg/ha of native wildflower seed to 5 kg/ha of white millet.
Competitiveness	Offers only fair weed control, with better results when it is mowed. Can spread into plant-free areas around the tree seedlings. Can be controlled with herbicides if required. Requires little maintenance and has excellent regrowth after cutting.	Provides excellent weed control due to its rapid establishment and allelopathic suppression of other plants. Mowing stimulates its growth. Can spread into plant-free areas around the tree seedlings. Can be controlled by tillage or herbicide if necessary.	Native mixtures on site-prepared sites with bare soil compete very well with non-native weeds. They do not compete with native trees. Mowing and herbicides are not required nor are they recommended.
Wildlife values	Provides favourable habitat for upland game birds, rabbits, and deer. Mice and vole populations can be minimized by mowing.	Good winter feed for deer.	Provides food for beneficial insects, and habitat for birds, amphibians, reptiles, and some mammals, but less attractive to rabbits, voles, and deer.

Characteristics	White clover	Ryegrass	Wildflowers
Other characteristics	Extremely susceptible to simazine herbicide. Tolerates shade and can be used as a companion crop with perennial ryegrass. Wild white clover does not do well in monocultures; the best results are obtained in a mixture with short grasses such as creeping red fescue. Adds nitrogen to the soil. Dutch white clover grows up to 20 cm, wild white clover grows up to 25 cm, and ladino clover grows up to 35 cm. Some managers are using the Huia variety of clover as a cover crop; it produces low growth, similar to that of Dutch white clover.	It increases the soil organic matter content. Large quantities of plant material are produced both above the soil and in the fibrous root systems. Annual ryegrass grows to a height of 60 to 120 cm, whereas perennial ryegrass grows to 30 to 90 cm and lives for 3 to 4 years.	Good site preparation is important. If corn was cultivated in the previous year, till the site to incorporate its stalks in the soil. The extra soil carbon provided by the corn will benefit both the trees and the wildflowers. Use white millet as a cover crop at 5 kg/ha of seed. Native plants usually flower in the second or third year, produce a large amount of seed, and thus, secure the planting site.

3.1.4 Native wildflowers and grasses

North American trees have evolved with and grown beside native wildflowers and grasses. It is only since European settlement that forage crops, lawn grasses, and non-native weeds have dominated the rural landscape. Non-native grasses are particularly hard on native trees because they consume too much water and dry the soil, can smother trees, rob the soil of essential nutrients, physically damage tree roots, or provide shelter for destructive rodents.

In contrast, native meadow wildflowers and grasses are good companions for native trees. Unfortunately, their seeds are difficult to purchase due to the limited number of suppliers and the difficulty of harvesting the seed. The term “wildflower” is loosely used to describe a range of commercial cultivars, domestic species, and weeds from other continents that you should avoid. If you cannot source true native seeds, try collecting your own. Stick to easily recognized species such as brown-eyed Susan, wild bergamot, evening primrose, blue vervain, common milkweed, and Canada wild rye. Collect dry plant material with mature seeds in fibre bags, and save them in a cool, dry place for the next planting season.

Figure 3.9: Wildflower cover crops. Top left: The first growing season, showing white millet as the crop, in the Nature Conservancy of Canada (NCC) Upper Big Creek Block. Top right: The second growing season, showing brown-eyed Susan planted in the spring over tilled corn stubble in the NCC Upper Big Creek Block. Bottom left: The third growing season, with brown-eyed Susan still present but other wildflowers such as Virginia mountain mint showing in the NCC Upper Big Creek Block. Bottom right: The ninth growing season, with the site now dominated by black oak, American hazel, and wild lupine in the NCC Central Big Creek Block. [Photo source: Mary Gartshore, ecological restoration consultant]

Good site preparation is important. Start with a well-prepared, grass-free site. If corn was grown in the previous year, till the site to incorporate the crop residues in the soil. The extra soil carbon provided by the corn will benefit both the trees and the wildflowers. After the trees are planted, thinly hand-spread native plant seed over your site. The seed will bury itself over time, so there is no need to cover it. For a pure seed mix, we recommend less than 1 kg/ha.

If you prefer a cover crop, hand-sow white millet (*not* red millet) at a rate of 5 kg/ha. White millet is short and sturdy and provides shade, humidity, and a wind break without smothering native tree seedlings, whereas red millet grows taller and denser, and will often fall over and smother tree seedlings. Hand-sowing can be quicker than using a seeding machine on smaller planting sites. White millet will only grow if planted after all danger of frost has passed. It suppresses weeds, provides a sturdy and airy cover, and dies completely during the following winter, including its seed. White millet does not harm native plants, perhaps because there are many closely related native species.

If native plants are used, there is no need for soil amendments, herbicides, or mowing, and these treatments are not recommended. Native plants usually flower in the second or third year after seeding, produce a lot of seed, and subsequently secure the planting site until the tree canopy closes at around 10 years (Mary Gartshore, ecological restoration consultant, and Wade Knight, Forests Ontario, personal communications). See Environment Canada 2000 for more information on establishing wildflowers and grasses.

3.2 Tending

The overall goal of tending is to maximize early survival and growth of tree seedlings so that the newly established trees can achieve free-to-grow status as soon as possible. Several tending treatments are available to control competition around individual trees and within the planting rows. These options include mechanical treatments such as tilling, mowing, or mulching, and chemical control options based on pre- or post-emergence herbicides. If you prefer to use a herbicide, the specific product should depend on site conditions, tree species, and the weeds that must be controlled. See Section 3.3 for details of the main options that are currently available.

On sites in southern Ontario with high levels of competition, experience has shown that up to three separate chemical applications will be necessary to ensure successful seedling establishment. Mechanical tending is also an option, but the competition control it provides is generally short-lived, and less effective than chemical treatments.

For large-scale operations, both chemical and mechanical competition control are facilitated by establishing a regular spacing and distribution of the crop trees. This improves both planting efficiency and the effectiveness of tending. Most tending treatments used in young plantations are based on traditional or slightly modified agricultural equipment. This includes rotary mowers (e.g., bush hogs, brush saws), boom and band sprayers, and ploughs and disking equipment mounted on farm tractors.

3.2.1 Factors affecting tending options

The amount of tending required to bring tree seedlings to the free-to-grow stage will depend on several factors:

- **The effectiveness of the initial site preparation:** If the site preparation provides good control of the existing competition, less subsequent tending will be required.
- **The tree species planted:** Native hardwood species are generally more susceptible than conifers to moderate or high levels of competition, and require more tending.
- **The site's productivity:** The more productive the site, the greater the level of competition. Moist, nutrient-rich sites generally support more vigorous competition.
- **Perennial versus annual weeds:** Perennial weeds are more difficult to control because they regrow rapidly from the root system after the top of the plant has been removed by a chemical or mechanical treatment.
- **The size of the planting stock:** On sites with strong competition, larger or faster-growing planting stock will compete more effectively and is therefore a better option if you don't have a large budget for tending. Projects that use direct seeding will be challenging without implementing effective site preparation, monitoring, and tending programs, particularly on sites with high levels of competition.

3.2.2 Mechanical and chemical tending options

Selecting the best tending treatment depends on the factors discussed in the previous section and the characteristics of the site (e.g., vegetation, soil, topography, access). On easier sites, a single treatment may be possible, but more difficult sites may require a combination of treatments. Table 3.3 provides an overview of the various mechanical and chemical tending options that have been used in southern Ontario's afforestation programs.

Table 3.3: A comparison of mechanical and chemical tending options that have been used in southern Ontario.

Option	**Timing**	**Description**
Spot spraying of herbicide	Early May (e.g., once the grass has greened)	Herbicide is applied around individual trees (within a 0.7-m radius) to control competing vegetation (Fig. 3.10). Advantages of this option include: • minimal herbicide required • when properly applied, effective control of competing vegetation • able to treat a range of sites (e.g., wetter, steep slopes, small areas) Disadvantages include: • timing of application (in the spring) is important (e.g., too late, and the trees will be re overtopped by competing vegetation and become difficult to locate) • labour-intensive • to avoid injury or mortality, trees must be individually shielded to prevent contact with the herbicide • more expensive than some mechanical treatments • requires a licensed pesticide applicator
Shielded band spraying		Herbicide is applied by a tractor with a sprayer, with shields attached to protect the trees. Advantages of this option include: • minimal herbicide use • when properly applied, effective control of competing vegetation • good control when used during the active growing period of the trees • requires less labour than spot spraying Disadvantages include: • to avoid injury or mortality, trees must be properly shielded to prevent contact with the herbicide • not suitable if the original spacing was not carefully controlled • requires a licensed pesticide applicator

Option	Timing	Description
Mowing	Late spring and early fall	Mowing of competition between the rows of planted trees (Fig. 3.11). The row spacing is critical to ensure that trees are not damaged (mowed down). Advantages of this option include: • minimal herbicide use • moderately effective control of competing vegetation • can be done by the landowner without requiring special equipment or licenses • low cost • minimizes damage caused by grass collapsing under a snow load and crushing seedlings Disadvantages include: • does not reduce belowground competition, unlike a systemic herbicide • requires more than one treatment per year • equipment can damage seedlings (e.g., inattentive operator, row spacing too narrow for the equipment)
Chemical band application over the trees	Late fall	A band of herbicide is broadcast sprayed over the top of the row of trees (Fig. 3.12). Advantages of this option include: • effectively controls competition • reduced herbicide use compared with full-site application • cost-effective Disadvantages include: • risky because timing and weather conditions are critical; application window is short and trees must be dormant to prevent injury or mortality • choice of herbicide and surfactant is critical; some may harm the trees requires a licensed pesticide applicator
Tillage	Late spring and early fall	The area between the rows of trees is tilled or harrowed, as shown in Figure 3.12. Advantages of this option include: • can improve soil aeration and drainage • equipment is readily available on most farms • can be undertaken by the landowner Disadvantages include: • requires more than one treatment per year • short-term control of competition • more expensive than chemical treatments • equipment can damage the seedlings (e.g., inattentive operator, row spacing too narrow for the equipment)

Option	Timing	Description
Chemical full-boom spray application over the trees	Late fall	A herbicide is broadcast sprayed over the top of the entire planting site (Fig. 3.12). Advantages of this option include: • effective competition control • row spacing is not critical and entire planting site is treated • cost-effective Disadvantages include: • risky because timing and weather conditions are critical; short application window, as trees must be dormant to prevent injury or mortality • choice of herbicide and surfactant critical, as some may harm the trees • more herbicide used than in band spraying of the whole site • requires a licensed pesticide applicator
Mulching	In the spring, immediately after planting	A layer of organic material (mulch) is spread around the base of individual trees. The mulch should be applied in a 60-cm-diameter circle around the base of the seedling to a depth of 5 to 10 cm. When using wood chips, we recommend a mix of coniferous and hardwood chips to mitigate the high resin content of the coniferous chips (which may acidify the soil). Advantages of this option include: • an option for small-scale plantings, steep slopes, and sites where herbicide use is restricted • minimizes the need for herbicide • effective control of light to medium competition; helps to retain soil moisture and to moderate soil temperatures • can be installed by the landowner • many options available (e.g., wood chips, straw, compost) • readily available from local sources Disadvantages include: • because of decomposition, organic mulches need periodic replenishment • labour-intensive • over-application of organic mulch may cause stress and seedling mortality (e.g., promote fungal disease, starve plant roots of oxygen) • expensive if the mulch is not produced by the landowner

Option	Timing	Description
Brush mats	In the spring, immediately after planting	A commercially manufactured fabric mat (circular or square) can be placed around the base of individual trees (Fig. 3.14). Plastic mulch films (Fig. 3.15) are also available. These are strips of plastic that block water and sunlight from reaching the soil around a seedling, thereby starving weeds of these essential resources. Advantages of this option include: • an option for small-scale plantings, steep slopes, and sites where herbicide use is restricted • can effectively control light to medium competition • can be installed by the landowner • readily available from seedling nurseries Disadvantages include: • labour-intensive to install • mats made from artificial fibres may not break down in the environment • expensive • plastic mulch films are expensive and labor-intensive to apply, but can provide effective competition control. Most suitable for tilled fields, where installation is easier.
Tree shelters	In the spring, immediately after planting	A shelter is installed around the tree's stem. The shelters protect the young seedling from browsing by deer, rabbits, mice, and other animals. Advantages of this option include: • an option for small-scale hardwood plantings • minimizes browsing damage • good designs allow sufficient airflow to prevent overheating in summer or extending vegetative growth into the frost period in the fall • can be installed by the landowner • readily available from seedling nurseries • compatible with other tending methods Disadvantages include: • labour-intensive (requires annual maintenance) • not a suitable means to control competing plants • expensive

Figure 3.10: Spot spraying. Left: Herbicide is applied around individual trees to control adjacent competing plants. A stove pipe or cone is placed over the seedling to protect it from the herbicide. [Photo source: Rideau Valley Conservation Authority] Right: the results of a spot spraying application. [Photo source: Tim Gray, Forests Ontario]

Figure 3.11: Mowing between rows to reduce competition between the rows of trees. Choosing an appropriate spacing between rows of trees is critical to ensure that the trees are not damaged by the mowing. [Photo source: John Enright, Upper Thames River Conservation Authority]

Figure 3.12: Chemical tending. Left: A band of herbicide is broadcast-sprayed from above the row of trees. This tending method can be cost-effective and very effective in controlling weed competition. However, it requires a licensed pesticide applicator. [Photo source: John Enright, Upper Thames River Conservation Authority] Right: When broadcast spraying over the top of the seedlings, the application window is short and the crop trees must be dormant to prevent tree injury or mortality from the treatment. [Photo source: Rick Grillmayer, Nottawasaga Valley Conservation Authority]

3.3 Commonly used herbicides

Herbicides used to promote seedling establishment can be categorized as either pre-emergence or post-emergence herbicides. Pre-emergence herbicides are applied before weed seeds germinate and control weeds by interfering with their seed germination and establishment. They do not control existing weeds. Post-emergence herbicides are applied to actively growing plants and control existing weed competition. Post-emergence herbicides can be further classified as contact or systemic herbicides. A contact herbicide will only kill the part of the plant that it contacts. They will therefore not affect root systems (rhizomes or taproots). In contrast, a systemic herbicide is absorbed by the foliage and green bark and moves throughout the plant, including the stem and root system. Systemic herbicides are ideal for controlling established perennial weeds with well-developed root systems. Table 3.4 compares pre-emergence and post-emergence herbicides. Information in this table was adapted from DuPlissis (1998a,b).

> **Note:** We recommend that you carefully consider using alternative silvicultural options before prescribing any herbicide treatment whenever it is feasible and cost-effective to do so. See Section 3.4.4 for details.

Table 3.4: A comparison of pre-emergence and post-emergence herbicides.

Pre-emergence herbicides	Post-emergence herbicides
• Weeds and grasses are controlled by interfering with seed germination and seedling establishment. • They must be applied before weeds emerge, usually by broadcast spraying. They do not control weeds that are present at the time of application. • Most require 1 to 2 cm of rainfall within 7 to 10 days after application to become activated (OMAFRA 2015). • They can be applied to the soil surface before or after the trees are planted. • Soil texture, organic matter content, and soil pH will affect the application rate: higher rates are often needed on fine-textured soils, such as clay soils, or on soils that have a high organic matter content. • Some pre-emergence herbicides should not be used in sandy or alkaline soils.	• Weeds are controlled by disruption of biochemical processes within the plant. • They are applied directly to the foliage of established and actively growing weeds. • Their effectiveness depends on having adequate contact with the shoots and leaves of the target plants. • Additives such surfactants can help increase herbicide uptake. • They can be applied at any time during the growing season. However, their effectiveness increases during periods of active growth and will decrease as weed species become larger and more established or during hot and dry conditions, when water stress within the plant can decrease herbicide effectiveness. • They are usually applied as a directed spray rather than being broadcast. • It is critical that you minimize contact with foliage, green bark, or non-woody surface roots of desirable species. • Some products can be applied as a broadcast application. However, this application must be in late summer to fall, after the seedlings have gone dormant, or prior to initial bud swelling in the spring. An exception is that some graminicides (herbicides that target grasses) can be applied in-season.

Several herbicides have been approved for afforestation work. They are manufactured under various trade names and come in a variety of formulations. Table 3.5 compares some of the most common of these herbicides. The information in Table 3.5 was adapted from McLaughlan et al. (1996) and White et al. (2005).

> **Note:** The information in Table 3.5 is only a general description of some of available products and is not intended as an endorsement of any particular herbicide. We recommend that you discuss your options with experienced pesticide applicators and research these chemicals to learn how they can best be used to achieve site preparation and tending goals for your combination of site and species.

Table 3.5: A comparison of herbicides that are commonly used in afforestation projects.

Generic name (active ingredient)	Target vegetation	General comments
Glyphosate	A broad-spectrum herbicide used to control most annual and perennial grasses, herbs, and woody vegetation	• a non-selective post-emergence systemic herbicide that is applied to actively growing vegetation • absorbed through the foliage, freshly cut surfaces, and green stems • effective on a wide array of woody species, annual and perennial grasses, and broadleaved weeds • good results with fall treatments, prior to a killing frost, provided that the targeted plants are mostly green (i.e., <50% fall coloration) • actively growing trees are prone to injury • concerns about development of glyphosate-resistant weeds, and potential non-target impacts such as damage to aquatic wildlife
Simazine	A herbicide that is active in the soil and is used to control grasses and broadleaved weeds	• a selective pre-emergence herbicide that is mainly absorbed through the roots • application should be before weed emergence in the spring or in the fall before freeze-up • will not kill plants that re-sprout from established roots • requires 1 to 2 cm of rainfall within 7 to 10 days to become active • container stock may be less susceptible to chemical uptake than bareroot stock of the same size due to the container's presence • where rainfall is sufficient to cause erosion, soil that contains simazine may be transported downslope and injure existing or new vegetation • mostly remains in the top few cm of the soil

Generic name (active ingredient)	Target vegetation	General comments
Hexazinone	A systemic herbicide that is active in the soil and is used to control a broad range of annual, perennial, and woody vegetation	• primarily a non-selective soil herbicide with some foliar action • can be applied as a pre- or post-emergence herbicide • site-specific, as the use and application rates depend on the soil texture, soil organic matter content, weed species composition, and (if being used for release) plantation age • higher rates often needed on fine-textured soils, such as clay soils, or on soils that have a high organic matter content • not suitable for sandy or gravelly soils • absorbed through the roots and acts throughout the plant • species-specific tolerance (e.g., red pine is very tolerant; spruces are less tolerant; other pines are sensitive; hardwoods are very sensitive) • persistence in the soil reduces seed germination
Triclopyr	Controls broadleaved weeds, including perennials, woody shrubs, and tree species	• a selective post-emergence herbicide that can be absorbed through the stem, foliage, and cut surfaces of plants • can be applied as a foliar spray or basal bark application when in an oil solution • foliar applications should be during the active growing period • applications to bark or cut surfaces can be at any time of year • actively growing trees are prone to injury • will not control grass
2,4-D	Controls many broadleaved weeds and woody vegetation	• a selective post-emergence herbicide absorbed by foliage and roots • best results with application during the active growing period • ester formulations are volatile and may move off-site as a vapour to damage adjacent vegetation • re-sprouting of some woody species is common, often requiring a second application • will not control grasses

Before prescribing any herbicide, it is essential to determine the weed species that must be controlled, learn and ensure the proper application methods and rates, use trained and licensed applicators, and maintain records (e.g., application amounts, dates, and conditions). Proper use and calibration of your spray equipment is important to ensure an accurate and uniform herbicide application, minimize costs, avoid injury to your seedlings, and prevent any environmental contamination. Regular maintenance is required to protect the workers.

> **Read the pesticide label!** The label lists the tree and shrub species for which it can be safely used and the weed species it will control. The label also provides information on the recommended application rates, timing of the application, safe handling, and disposal, as well as other directions and precautions. OMAFRA (2015) provides additional useful information about weed control.

In Ontario, the use and application of all herbicides are strictly regulated. Unless you have been granted an exemption, you require a licence from the Ontario Ministry of the Environment, Conservation and Parks (MECP). For more information on pesticide training, licencing and exemptions, visit the Ontario Pesticide Training & Certification site (http://www.ontariopesticide.com).

More information about pesticide regulations, certification, and licencing are available from these sources:

- Canada Pest Management Regulatory Agency site (https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management.html)
- Ontario Ministry of the Environment, Conservation and Parks site (www.ontario.ca/page/ministry-environment-conservation-parks)
- Ontario Ministry of Agriculture, Food and Rural Affairs site (www.ontario.ca/omafra)
- Ontario Pesticide Education Program (University of Guelph, Ridgetown Campus) site (www.opep.ca)

3.4 Site preparation and tending on former agricultural land

The following sections provide an introduction to several site preparation and tending management options to promote seedling establishment on former agricultural land. We have divided the management options into three broad categories based on the type of agricultural site. Under each category, we discuss the most common site preparation and tending approaches:

- agricultural lands removed from crop production
- agricultural fields and pastures, and
- abandoned pastures

We also describe several non-herbicide management options.

Implementing a successful site preparation or tending program requires a good understanding of what you want to control, an ability to evaluate the best timing for the treatment option, and the recognition that no one treatment option will fit all situations. The information we have provided on each option should be used only as a guide. Variations in the characteristics of the planting site, in equipment availability, in your budget, in landowner objectives, in the available stock types and sizes, and in the species to be established will require modifications to the options. We discuss some of these modifications, but it's your responsibility to determine what modifications will be necessary.

3.4.1 Agricultural lands removed from crop production

These sites were being used to produce row crops (e.g., corn, soybean) at the time of afforestation, and have a high percentage of exposed soil. The site may currently have a low level of competition, but this is because of aggressive weed control during crop cultivation. The exposed soil provides a perfect environment for invasion by weeds, and the primary competition on these sites will come from seeds deposited directly on the soil before or after planting of the site. These sites may have some residual pre-emergence herbicide left over from agricultural use.

We will describe two options, both based on a pre-emergence herbicide treatment, but in the first option (Table 3.6), we will supplement this by establishing a cover crop, and in the second option (Table 3.7), we will combine the herbicide with mowing. Our goal is to illustrate the potential modifications that are required to account for the different site conditions encountered.

Table 3.6: Option 1—Establishing a cover crop and a pre-emergence herbicide treatment.

Timing	Description of operation	General comments
Late fall (year before planting)	If applicable, mow corn stalks or till them into the soil.	Mowing of the corn stalks and debris reduces the risk of the residues clogging the planting machine. Debris from other crops such as soybeans is generally less robust, and does not interfere with planting.
Early spring (before planting)	Establish a cover crop to occupy the site and hinder weed development.	Broadcast-seed a clover cover crop over the entire site in early spring, when there is still frost in the ground. When using clover, consider adding a fast-growing annual grain species (e.g., barley) to serve as a nurse crop for the slower-growing clover. This will provide some early ground cover before the clover becomes fully established.
Spring (at the time of planting)	Machine-plant the trees and apply a pre-emergence herbicide.	Machine-plant the site, with a sprayer mounted on the rear of the planter. This configuration allows for band spraying of a pre-emergence herbicide and completion of the planting in a single operation. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over crop trees.
Fall or spring after planting	Apply a pre-emergence herbicide treatment.	Broadcast-spray (band spraying) a pre-emergence herbicide is applied overtop of the crop trees in the late fall or early spring of the next year. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over crop trees.

The method based on a cover crop has several variations. These depend on factors such as variability of the planting site, equipment availability, your budget, landowner objectives, stock type availability and size, and the species to be established. Modifications of this approach relate to site preparation and tending:

- Conditions may allow establishment of the cover crop in the fall of the year before planting or may allow a fall seeding of wheat as a nurse crop, followed by seeding of clover on the frozen soil in the early spring of the following year.
- Using a no-till seed drill or an air-flow seeder rather than a broadcast seeder to establish the cover crop will result in better germination and require less seed.
- For sites that are hand-planted, a pre-emergence herbicide may be broadcast-sprayed in bands from above the crop trees after planting in the early spring. Check the pesticide label for timing recommendations and restrictions when over-spraying crop trees.
- If a broadcast over-spray application of a pre-emergence herbicide is not feasible, a manual spot-spraying is an alternative. Depending on the timing of the application, the crop trees should be shielded from the spray. Check the pesticide label for timing restrictions.
- A herbicide treatment applied at the time of planting may vary in its effectiveness. Thus, assess the level of competition to determine whether a subsequent application of a pre-emergence herbicide or a combination of pre- and post-emergence herbicides will be needed. Check the pesticide label for timing recommendations and restrictions on broadcast spraying over crop trees.

Table 3.7: Option 2—Pre-emergence herbicide and mowing.

Timing	Description of operation	General comments
Fall (year before planting)	The site is left fallow over the winter. If applicable, mow corn stalks.	Mowing of the corn stalks and debris reduces the risk of the residue clogging the planting machine. Debris from other crops such as soybeans is less robust, and does not interfere with planting.
Spring (year of planting)	Machine-plant and apply a pre-emergence herbicide.	Machine-plant the site with a sprayer mounted on the rear of the planter. This configuration allows for broadcast band-spraying of a pre-emergence herbicide and the planting can be completed as a single operation. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over crop trees.
Mid- to late summer (after planting)	Mow between the rows of trees.	Mowing provides a moderate level of competition control, minimizes damage from winter collapsing of vegetation (due to the snow load) that can crush the trees, and reduces rodent populations. This tending can often be undertaken by the landowner.
Fall or next spring (after planting)	Apply a pre-emergence herbicide.	Apply broadcast band-spraying of a pre-emergence herbicide overtop of the crop trees in late fall or in early spring of the next year. Check the pesticide label for timing recommendations and restrictions when over-spraying crop trees.

Several variations of this management option are available. These depend on the variability of the planting site, equipment availability, the budget, landowner objectives, stock type availability and size, and the species to be established. Modifications of this approach relate to site preparation and tending:

- Instead of leaving the site fallow, consider establishing a cover crop to occupy the site and hinder invasion by weeds and their subsequent development. See the discussion of Option 1 earlier in this section for guidelines on establishing a cover crop as a site preparation tool.
- To help suppress the weed population, consider establishing a cover crop (clover or grasses) between the rows of trees during the same spring as the planting or in the fall after the planting. Follow-up mowing is recommended.
- For sites that are hand-planted, a pre-emergence herbicide treatment may be broadcast band sprayed over the top of the crop trees in the spring after planting. If this is not feasible, manual spot-spraying is an acceptable alternative. Depending on the timing of the application, the crop trees should be shielded from the spray. Check the pesticide label for timing recommendations and restrictions related to when over-spraying crop trees.
- The herbicide treatment applied at the time of planting may vary in its effectiveness. Thus, assess the level of the competition to determine whether a pre-emergence herbicide or a combination of pre- and post-emergence herbicides will be required. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over crop trees.

3.4.2 Agricultural fields and pastures

These sites are dominated by grasses, but sometimes also include a mixture of annual and perennial weeds. The sites are still being used or have been recently removed from use as a pasture or for hay production. These sites can be further defined by the level of competition and the site's physical limitations (e.g., soil type, terrain, drainage). Tables 3.8, 3.9, and 3.10 describe three very different management options and possible modifications based on the site conditions.

Table 3.8: Option 3—Mowing and herbicide treatment.

Timing	Description of operation	General comments
Mid- to late summer (year before planting)	Mow the site.	After mowing, allow some time for re-growth of weeds and grasses before herbicide application. Application to new growth improves the efficacy of the herbicide treatment for some species.
Early fall (year before planting)	Apply a non-selective post-emergence herbicide.	The non-selective post-emergence herbicide should be applied in bands throughout the planting site to control weeds and grasses.
Spring (same year as planting)	Machine-plant and apply a pre-emergence herbicide.	Machine-plant the site with a sprayer mounted on the rear of the planter. This configuration allows for broadcast band spraying of a pre-emergence herbicide and the planting to be completed as a single operation. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over crop trees.
Early to mid-summer (after planting)	Mow between the rows of trees.	Mowing provides moderate control of competition, minimizes damage from winter collapsing of competition of herbaceous vegetation (under a snow load) that can crush trees, and reduces rodent populations. This option can often be undertaken by the landowner.
Spring (after planting)	Apply a post-emergence herbicide.	Apply a manual spot-spray around individual trees to control the competition. Depending on the timing of the application, the crop trees should be shielded from the spray. Check the pesticide label for timing recommendations and restrictions related to when over-spraying crop trees.

There are several variations of this management option. These modifications depend on the variability of the planting site, equipment availability, your budget, landowner objectives, stock type availability and size, and the species to be established. Some of the modifications to consider include issues related to site preparation and tending:

- Applying both a non-selective post-emergence herbicide and a pre-emergence herbicide in a single treatment can both control existing plants and impede weed invasion.
- For hand-planted sites, a scalping treatment combined with band spraying would help delineate the planting rows in the early spring, before green-up, and would create optimal site conditions (exposed mineral soil) for applying a post-emergence herbicide. Pre-emergence herbicides are activated in the soil and are more effective when applied directly to exposed soil. This option could also be used on sites scheduled for machine planting when the planter is not configured to allow simultaneous broadcast band spraying and planting.

- On coarse, dry sands to finer sands (e.g., red pine sites), mowing may be sufficient as the initial site preparation treatment. The competition on these sites is often minimal and may not require a herbicide treatment. Follow-up mowing between rows may be needed, and will control competing plants and minimize damage from winter collapsing of vegetation (under a snow load) that crushes the trees.
- Rocky and bouldery sites may limit equipment access and site preparation options (e.g., may prevent mowing or machine planting) and require hand-planting. However, some of these sites have high enough levels of competition to require subsequent control. A post-planting spot spraying of a non-selective post-emergence herbicide may be required around individual trees, possibly with a pre-emergence herbicide, to control existing plants and to impede weed invasion.
- A broadcast band spraying of a post-emergence or pre-emergence herbicide (or both) may be applied over the top of the crop trees in late fall or early spring of the next year after the planting to control existing plants and to impede weed invasion. Check the pesticide label for timing recommendations and restrictions related to when over-spraying crop trees.
- On nutrient-rich soils, heavy competition from perennial grasses and weeds such as reed canary grass or bedstraw is often encountered. Thus, plan for additional tending treatments in subsequent years.

Table 3.9: Option 4—Ploughing, disking, and herbicide treatment.

Timing	Description of operation	General comments
Early fall (year before planting)	Apply a non-selective post-emergence herbicide.	A post-emergence non-selective herbicide can kill the established vegetation.
Fall (year before planting)	Plough and disk the site.	Plough the site to turn over the soil and disk the soil to break up any large lumps and clods of soil.
Spring (same year as planting)	Machine-plant and apply a pre-emergence herbicide.	Machine-plant the site with a sprayer mounted on the rear of the planter. This equipment configuration allows simultaneous broadcast band-spraying of a pre-emergence herbicide and planting. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over the top of crop trees.
Mid- to late summer (after planting)	Till between the rows.	The amount of tilling required between the rows depends on the level of new competition that becomes established (e.g., one to three times per year).

Timing	Description of operation	General comments
Spring or fall (after planting)	Apply a pre-emergence herbicide.	Broadcast band-spraying of a pre-emergence herbicide is applied over the top of the crop trees in late fall or very early spring. (Note that spring applications are generally riskier because physiological changes occur in seedlings during breaking of dormancy, before morphological changes are visible.) Check the pesticide label for timing recommendations and restrictions related to over-spraying crop trees.

There are several variations of this management option that depend on the variability of the planting site, equipment availability, your budget, landowner objectives, stock type availability and size, and the species to be established. Some of the modifications to consider include issues related to site preparation and tending:

- Consider establishing a cover crop throughout the site in the year before planting to control future weed competition from seed deposited on the soil directly before or after ploughing and disking of the site. See Table 3.6, earlier in this section, for a discussion of a cover crop as a site preparation tool.
- For sites that are hand-planted, a pre-emergence herbicide treatment can be broadcast band-sprayed over the top of the crop trees in the early spring after planting. Check the pesticide label for timing recommendations and restrictions related to when over-spraying crop trees.
- If broadcast spraying of a pre-emergence herbicide over the top of the crop trees is not feasible, manual spot spraying is an alternative. Depending on the timing of the application, the crop trees should be shielded from the spray. Check the pesticide label for timing restrictions.
- Depending on the effectiveness of a herbicide treatment applied at the time of planting, assess the level of competition to determine whether application of a pre-emergence herbicide or a combination of pre- and post-emergence herbicides is needed. Check the pesticide label for timing recommendations and restrictions related to broadcast spraying over the top of crop trees.
- To help suppress the weed population, consider establishing a cover crop (e.g., clover or grasses) between rows during the spring of the planting or in the fall after planting. Follow-up mowing is recommended.

3.4.3 Abandoned agricultural pastures

These sites include abandoned marginal pastures that have not been actively used for a number of years. These sites often have less weed and grass competition due to their poor productivity and will instead have brush species present (e.g., dogwood, willows, buckthorn, hawthorn) and may have a scattering of advanced regeneration of desirable species present. Table 3.10 describes one management option that may be suitable for this site type. We also describe several possible modifications based on the site conditions encountered.

Table 3.10: Option 5—Brush-cutting and herbicide treatment.

Timing	Description of operation	General comments
Mid-summer (year before planting)	Brush-cut the site to improve herbicide efficacy.	After brush-cutting, wait 4 to 6 weeks to allow re-growth of shrubs and grasses prior to herbicide application. Application to new growth improves treatment efficacy for many species.
Early fall (year before planting)	Apply a non-selective post-emergence herbicide.	The application of a non-selective post-emergence herbicide in bands based on tree row spacing throughout the planting site can control brush, weeds, and grasses.
Spring (same year as planting)	Hand-plant the site.	Choose a spacing appropriate for your silvicultural goals.
Spring or fall (after planting)	Apply a post-emergence herbicide.	Broadcast band-spray a post-emergence herbicide over the top of the crop trees in the late fall or very early spring. (Note: Spring applications are generally riskier because physiological changes occur in seedlings during breaking of dormancy, before morphological changes are visible.) Check the pesticide label for timing recommendations and restrictions related to over-spraying crop trees.

There are several variations of this management option. These modifications depend on variability of the planting site, equipment availability, your budget, landowner objectives, stock type availability and size, and the species to be established. Some of the modifications to consider include issues related to site preparation and tending:

- On some less-fertile sites (e.g., coarse gravelly or sandy soils) or on sites with a shallow soil, the competition may be sparse and may pose little threat to the crop species. In these circumstances, hand-planting without site preparation may be a suitable option.
- If the primary competition is brush species, consider using a selective herbicide specific to broadleaved woody vegetation rather than a non-selective herbicide.
- Depending on the density of the brush competition, consider treating the entire site instead of band-spraying.
- If the site allows (e.g., a minimal brush root mat is present), consider scalping the rows that will be planted in combination with a band-spraying treatment. Scalping will help delineate planting rows in the early spring, before green-up, and will create optimal site conditions (exposed mineral soil) if a post-emergence herbicide is needed.
- If grasses and weeds are the major competitors, consider combining a pre-emergence herbicide with a post-emergence herbicide.

- If a broadcast spraying of a post-emergence herbicide over the top of the crop trees is not feasible, manual spot-spraying is an alternative. Ensure the treatment is done before the brush species grow too tall. Depending on the timing of the application, the crop trees should be shielded from the spray. Check the pesticide label for timing restrictions.
- Manual tending using brush saws is an alternative to herbicide treatment when it's necessary to control brush species. This treatment can be combined with herbicide treatment of the stumps.
- Basal application of a herbicide can also control brush.

3.4.4 Non-herbicide options

This management option is generally best suited for small plantings or plantings in environmentally sensitive areas where herbicides may cause adverse environmental impacts, as in the case of riparian areas. These sites include agricultural land recently removed from crop production that has a high percentage of exposed soil and agricultural fields and pastures dominated by grasses or by annual and perennial weeds.

When you consider non-herbicide options, remember that you must be able to control competing plants until the trees are free to grow to achieve successful afforestation. Experience has shown that the treatment costs are often higher without using herbicides, and the level of success can be lower if you can't devote adequate planning and other resources to the project. Table 3.11 describes one management option for agricultural fields and pastures, and we also discuss a number of modifications based on the site conditions encountered.

Table 3.11: Option 6—No herbicide treatment.

Timing	Description of operation	General comments
Late fall (year before planting)	Mow the site.	Mow the site in late fall to temporarily reduce grass competition and facilitate tree planting and brush mat installation.
Spring (year of planting)	Hand-plant the site.	Hand-plant the site at the designated spacing.
Spring (year of planting)	Install brush mats.	Install a commercially manufactured fabric mat (circular or square) around the base of individual trees.
Spring or fall (after planting)	Check the condition of the brush mats.	Check the brush mats; if necessary, reposition or replace them.

There are several variations of this management option. These modifications depend on the variability of the planting site, your budget, landowner objectives, stock type availability and size, and the species to be established. Some of the modifications to consider include issues related to site preparation or tending:

- On fields being removed from crop production (e.g., corn, soybean), consider establishing a cover crop to minimize the competition. (See Table 3.6, earlier in this chapter, for a discussion of cover crops.) Note that some cover crops such as clover, if not controlled (e.g., mowed between rows), may overtop the trees and create competition.
- On nutrient-poor sites, such as coarse dry sands and sites with finer sandy soils, site preparation may not be necessary because the competition is generally sparse.
- If mowing isn't feasible (e.g., steep slopes, wet riparian areas), manual brush-cutting using brush saws or a grass trimmer attachment may be an option.
- Scalping to invert a shallow sod layer can be effective.
- Organic mulch may be an alternative to using brush mats. Keep in mind that applying a too-deep layer of mulch may be detrimental to seedlings (e.g., oxygen starvation of the roots, promotion of fungal and bacterial diseases). Also, organic mulches need periodic replenishment due to their decomposition.
- Manual tending using brush saws or a grass trimmer is an alternative to completely removing the competition.

Chapter 4
Plantation management

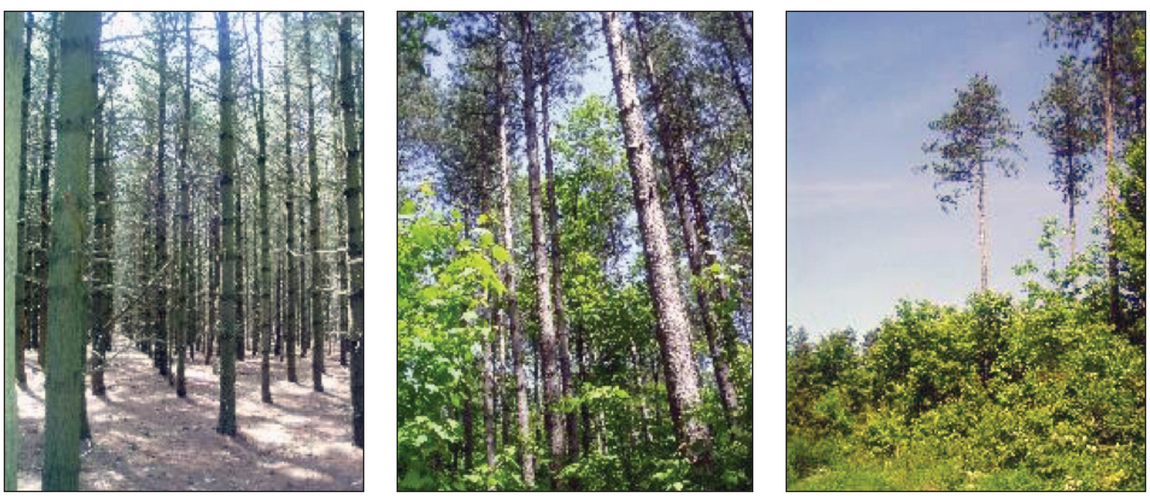
4 Plantation management

After a plantation reaches the free-to-grow stage (usually between 5 and 8 years after planting), little monitoring or management activity is required until the first thinning. However, you should continue to monitor the plantation annually for issues such as insects, diseases, and invasive species and take the necessary corrective actions. For example, pruning to correct stem deformities caused by insects such as the white pine weevil, or other minor interventions, may be required. Keeping track of the plantation development over time through data collection, formal assessments, and personal observations will help you predict changes in the stand conditions, including the level of species diversity, over time. It may also help you to design more effective afforestation prescriptions for other new forests, particularly in the context of long-term landscape-level goals.

In this chapter, we describe plantation growth and development from the time immediately after establishment, through first and subsequent thinnings, to the final harvest age or the time when your management objectives have been met.

4.1 Understanding natural processes that affect your management objectives

The planting design is guided by the owner's objectives, the site's condition, the stand's growth potential, and the funding available to manage the site. The landowner's objectives should have a temporal component: they should explicitly include an expression of both the desired short-term conditions and the long-term goals for species composition, stocking, and stand structure. Landowner objectives may change over time, or the forest may not develop as you originally projected. The new forest should be carefully re-evaluated in terms of these objectives to ensure that your original assumptions on growth and development, market conditions for forest products, and general forest health considerations are still valid.



A B C

Figure 4.1: Stand development after establishment of a coniferous plantation. (A) White pine plantation at the stem-exclusion phase, 35 to 40 years old, unthinned. (B) Red pine plantation at the understory re-initiation stage, 60 to 70 years old, after two thinnings and with two more scheduled, showing a dense hardwood understory up to 6 m in height composed of tulip tree, sugar maple, red maple, white ash, green ash, red oak, American beech, bitternut hickory, yellow birch, and sassafras. (C) Red pine plantation at the mature phase, with a small component of Scots pine, white spruce, and white pine. The plantation is 70 years old, has been thinned four times, and the overstory was removed. A naturally established understory composed of red oak, white oak, shagbark hickory, American chestnut, sugar maple, red maple, largetooth aspen, and sassafras has developed. The hardwood understory has been evident for 30 years. [Photo source: Al Corlett, Forests Ontario]

Even without management intervention, both natural forests and plantations go through significant changes as they mature. Understanding these changes will help you focus on the long-term management objectives. Oliver and Larson (1996) described four phases of stand development after a disturbance (Fig. 4.1): stand initiation, stem exclusion, understory re-initiation, and maturity. We'll discuss these phases in the rest of this section.

4.1.1 Stand-initiation phase

The period after disturbance, as a new forest begins its development, is one of high species diversity, with new species continuing to appear for several years. This variety produces an abundance and diversity of foods and habitats, since the unoccupied growing space lets plants either invade the site or reappear from the soil seed bank and adjacent forests. Many individuals die and some species may even disappear as the trees and shrubs increase in size. Many herbaceous species eventually die out due to a lack of direct sunlight, or through direct competition with the taller woody plants. Generally, highly productive sites have shorter stand-initiation periods because of the improved growth of trees and shrubs.

In a natural forest, species composition is determined by the type of disturbance, by which germinating seeds are favoured by that disturbance, and by which species have produced seeds before the disturbance or immediately after. The species establishment pattern and density will vary, since species don't all invade at the same time, and don't begin growing at a uniform spacing unless they were planted. Many new forests begin with an aggregated (clumped) pattern, with clumps in different areas and of varying size; some areas may contain no individuals at all. The clumped pattern is caused by the spatial distribution of the sources of the regeneration, as propagules tend to be clustered close to their parents. Thus, the pattern depends on the distribution of advance regeneration, stumps and roots that produce vegetative regrowth, suitable seedbeds, and competition from other plants, as well as on the characteristics of the original disturbance (e.g., wind, fire, harvesting). Some ecological restoration efforts will try to emulate natural processes by planting multiple species in random groups rather than as monocultures.

Single-species plantations of the same age and uniform spacing tend to develop different growth patterns, stand structures, and wood properties from those of natural stands. The extended period preceding crown closure in many natural stands may create longer periods of herb and shrub growth than in plantations. These herbs and shrubs may provide beneficial effects in terms of soil development, eradication of tree pathogens, and protection against browsing animals. As well, a diverse herbaceous layer can promote increased insect diversity (including pollinators, herbivores, and predators) and an increased diversity of breeding birds, with both effects contributing to ecosystem stability and resilience (Mary Gartshore, ecological restoration consultant, and Al Corlett, Forests Ontario, personal communication). Many herbaceous species that are prevalent during the stand-initiation phase can fix nitrogen (transfer it from the atmosphere into plant-available forms in the soil), which is then recycled in the stand during later phases. Shortening the stand-initiation phase through weed control and closely spaced planting of vigorous seedlings can affect the growth of the stand. The long-term consequences for planting sites may or may not be significant, but these factors, as well as any site-related constraints, should be considered when prioritizing areas to receive a particular afforestation treatment.

4.1.2 Stem-exclusion phase

During the stem-exclusion phase, tree species and individual trees that cannot compete successfully with the dominant trees gradually become suppressed and die, leading to natural thinning of the stand. Both natural stands and plantations go through the stem-exclusion phase. A stand may take several decades before all components make the transition from the stand-initiation phase to the stem-exclusion phase, but eventually the stand achieves crown closure, new individuals no longer appear, and some of the existing ones die. Survivors grow larger and differences in height and diameter develop, allowing first one species and then another to dominate the stand.

The height of the foliage layer rises as the trees grow taller, because leaves and lower branches of the dominant trees cannot survive in the diminished sunlight beneath the canopy. Plants that cannot grow tall enough to stay in the foliage layer often die, although some shade-tolerant species such as hemlock may persist for many decades.

Trees expand their crowns horizontally and intercept more light as they become bigger. Most of the competition between trees in southern Ontario is for light and to a lesser extent for nutrients and moisture, so the larger and taller trees tend to dominate and suppress the smaller and shorter trees, eventually causing them to die.

Growth patterns vary by species. For instance, some species cannot compete with woody or herbaceous competition unless they can become dominant during the brushy phase at the beginning of the stem-exclusion phase, when all trees are within the same layer. For instance, red pine must be dominant during this phase to survive, whereas yellow birch may outgrow the competition. Shade-tolerant species are able to survive in subordinate positions, thereby creating vertical stratification of the forest's foliage.

The height growth pattern of individual trees is also affected by stand density. When Miller et al. (2007) examined the development of young red oak, they observed that when the canopy closes, lateral crown expansion is limited and the tree maintains its competitive position through height growth. When neighbouring trees are removed, crown expansion shifts to lateral growth and height growth slows. This suggests that if you deliberately set the initial stocking at a low level, height growth may decrease.

Trees compete and die earlier when they are planted at a narrower spacing or when they form natural clumps. The surviving trees change from a clumped to a random or semi-random distribution, and then, over time, approach a more regular, evenly spaced distribution. Species in mixed stands are particularly likely to appear clumped at first and to become more regularly distributed over time. Dominant trees approach a regular distribution even more rapidly, although the spatial patterns continue to reflect the initial spacing and relative ages within the stand. These development patterns become increasingly complex and more difficult to predict as the number of species increases.

In summary, the stem-exclusion phase is influenced by the following factors:

- shade tolerance of the species growing in the understory of the site
- increasing shade in the understory
- development of spatial patterns

- development of age differences
- variation in regeneration mechanisms
- adaptation of survivors to the site
- changes in the numbers of trees of each species

4.1.3 Understory re-initiation phase

As the forest ages and trees grow larger, tree crowns may thin, allowing more light to penetrate the lower strata. Overlapping limbs from adjacent trees abrade and break against each other until the crowns no longer overlap. Individual trees will continue to die, while the heights and crown sizes of the remaining trees become less uniform as differentiation progresses and more light penetrates diagonally between the crowns. At this point, forest-floor herbs and shrubs and advance regeneration that have survived in the understory reappear from the seed bank or resume more active growth. Shade-tolerant species usually predominate, but tend to grow little unless a gap develops in the canopy that allows enough sunlight to reach the forest floor. Understory re-initiation may occur sooner on drier sites because trees retain less of their lower foliage or develop sparser crowns. If the understory includes an undesirable species, additional tending may be required, particularly for invasive species such as European buckthorn that may disrupt the stand's successional trajectory and prevent normal stand evolution.

The nature of the final mature forest that develops at a site and that persists at that site in the long term depends on the species that are present in a region, the region's climate, and constraints imposed by the site conditions.

4.1.4 Mature and old-growth phases

A mature forest can persist for centuries, depending on the tree species, climate, and site conditions. However, even long-lived trees are not immortal, and all will eventually die. As the forest moves from the mature phase to the old-growth phase, individual large overstory trees begin to decline in vigour and die in an irregular fashion. Other overstory trees are unable to rapidly reoccupy the released space. Newly germinating or sprouting trees and advance regeneration begin to grow upward into the main canopy. Younger trees usually include several age classes, which begin to develop at different times and in different locations as older trees die at irregular intervals. The result is the development of a wide range of ages and heights, with foliage well distributed vertically. The time required for the onset of this phase is usually more than 100 years in Ontario, but may occur sooner on poorer sites because less time is needed for older trees to begin senescence. Depending on whether your objectives are primarily ecological or traditional, harvesting may occur near the beginning of this phase, before trees begin to undergo senescence and experience damage that reduces their value.

4.2 Developing a spacing and thinning strategy

Plant ecologists have repeatedly confirmed that forests naturally undergo self-thinning (Drew and Flewelling 1977, 1979; Smith and Woods 1997). In other words, after the establishment and growth of a forest (whether plantation or natural), there is a point at which the density becomes so high that the available resources are no longer sufficient to sustain the life of all of the trees. As a result, the smallest and most supressed trees will begin to die. The time when this self-thinning occurs depends on the initial tree spacing, the natural mortality rate, the combination of species, their genetic characteristics, the site productivity, and the relative growth rates of the species. Thus, allowing single-species plantations to develop to the point of self-thinning may compromise your goals for the plantation. Forest managers strongly recommend avoiding this situation, and suggest that you develop a thinning strategy that will remove some trees before they interfere with growth of the crop trees, thereby maintaining consistent growth and vigour and achieving your long-term management objectives. A recent study by Bottero et al.(2017) suggests that heavy (i.e. SDI generally below 0.5) and regular thinning of pine plantations may better resist the increasing frequency of drought that is expected to occur under a changing climate. Refer to section 5.7 for additional discussion of climate change.

Mixed-species stands will also undergo self-thinning, but the consequences are likely to be less significant because the goal is not to produce a uniform timber crop. If the self-thinning process proceeds in a direction that will produce an increasingly natural-seeming stand, you can allow it to continue. But if competition seems likely to eliminate certain species that are the goal of management (e.g., unique or uncommon species), intervention may be required to protect those species.

Several factors will affect the timing of spacing and thinning operations. Spacing refers to the initial planting density, or to an operation that may be undertaken to reduce densities to an optimal level in the early stages of plantation development. This may be necessary where natural regeneration has supplemented the original planting density. In particular, the initial density of the trees (whether planted, seeded, or otherwise established) will affect how long it takes to achieve crown closure and to reduce growth rates due to crowding. Section 2.8 discusses the various considerations that will help you determine the optimal initial plantation spacing. For example, you should consider operational factors such as the amount of space needed to operate typical silvicultural equipment between the rows of trees in early stages of development (before the stand reaches the free-to-grow stage) and the type of forest products you hope to produce. Each of these factors can affect future growth rates and the viability of future thinning operations. That viability depends on whether the goal of thinning is simply to reduce competition for the remaining trees (i.e., pre-commercial thinning) or to earn an income from sales of forest products produced by the thinning (i.e., commercial thinning).

The technology used to accomplish thinning will depend on the size of your plantation, the species that are present, and your management goals. For example, smaller blocks of smaller-diameter plantations or ecological plantations can often be spaced manually with brush-saws or chainsaws, whereas large forests require larger and more powerful equipment. In particularly difficult terrain, mechanical operations using such equipment may be impossible, and manual thinning may be required. However, by the time the trees are big enough to have significant economic value, manual operations will have typically become impractical. Most commercial thinning operations now use

Figure 4.2: Left: A single-grip harvester fells and processes a mature red pine. Right: A forwarder brings the products to the landing and loads them onto a haul truck. [Photo source: Ken Elliott, OMNRF]

systems of heavy equipment, such as a single-grip harvester that fells and delimbs the trees, and then cuts them into logs of the desired length (also known as a “cut-to-length processor”). These harvesters work with a forwarder that carries the logs rather than dragging the trees along the ground; a common alternative teams a feller-buncher, which fells the trees and groups them into bunches, with a grapple skidder that drags them along the ground to a landing, where they will be processed and loaded onto trucks (Fig. 4.2).

Based on our experience with afforestation in Ontario, economically viable plantations have the following characteristics:

- **A minimum size of 4 ha:** Small adjacent blocks owned by different landowners can be managed and marketed collectively to provide a sufficient merchantable volume to make harvesting economical (i.e., at least 200 to 500 m³, depending on local markets).
- **A market:** For commercial thinning, you must be able to sell the type of products the stand can produce. In addition, the future market must support the kind of products you intend to produce from the final crop trees.
- **Sufficient size:** Commercial thinning products require trees with an average diameter of 18 to 20 cm in DBH, with the potential to produce at least three 2.54-m logs (also known as “bolts”), each with a top diameter of at least 10 to 15 cm. For most conifers, this requires a total tree height of at least 12 to 14 m.
- **Wide spacing:** A spacing of 4.3 m between rows of trees is necessary to allow passage of most machinery without damaging the residual stems. To achieve this, the initial between-row spacing at the time of planting should be at least 2.1 m, although 2.4 m provides more flexibility, especially for red pine.
- **Alternatives:** Smaller blocks can be commercially thinned using smaller equipment if you’re willing to bring the wood to a landing rather than relying on a commercial logging operator. The minimum amount of wood required to fill a standard tractor-trailer is 35 to 40 m³, and the wood must be easily accessible (i.e., must be brought to a road large enough to accommodate such a large vehicle). It is important to plan for operational constraints such as room for turning the vehicle around, sufficient distance from phone and electrical lines to allow operation of its loader, sufficient distance from ditches, and the need to avoid compaction of a road caused by fully loaded trucks.

All harvesting workers must have enough experience to perform their work without damaging the forest or any infrastructure such as roads and without endangering themselves or others; if they lack this experience, they should undergo sufficient training to learn how to work safely. Care must be taken not to damage the residual stems with the harvesting equipment, and to avoid damaging the site by working under wet conditions, when the soil is particularly vulnerable to damage. OWA (2009) provides details on careful logging techniques.

How often a plantation will need thinning depends on several factors:

- **Density:** Thinning must be sufficiently frequent to maintain the desired density of standing residual trees (based on the number of trees removed in previous thinnings).
- **Size:** The average diameter of the residual stems.
- **Growth:** The growth rate of the plantation can be estimated using a site index such as the mean tree height, and thinning can be prescribed when the target trees have reached that index value.
- **Quality:** For both pre-commercial and commercial thinning, the residual stems must have sufficient quality to survive and grow well. Early thinnings (i.e., the first and second thinnings) will focus on removal of the weakest or lowest-quality trees, on creating initial access corridors to the interior of the stand, or a combination of both objectives. Subsequent thinning will focus on retention of the highest-quality stems.
- **Forest health:** Where diseases or insect infestations are a risk, removal of damaged trees can reduce the risk of future damage to the residual trees.
- **Market conditions:** Whether commercial thinning is possible depends on the types of products demanded by local markets and by the distance to the nearest processing facilities; longer distances increase the cost of transporting the wood and therefore decrease its value.
- **Site characteristics:** The location and size of the site, as well as its proximity to adjacent plantations and markets, will determine the economics of thinning.

In the following sections, we will discuss the factors to consider when you plan a thinning operation. Note that although we focus on commercial thinning, pre-commercial thinning may be necessary to achieve different goals. In that case, each of those goals will create a need to consider different factors or constraints, such as the protection of desired species.

4.2.1 Site and stand conditions

- **Terrain:** Difficult or complex terrain may be inaccessible to heavy equipment.
- **Site productivity:** Commercial thinning should focus on the most productive sites to maximize the growth response to increased resource availability, and to minimize the risk of a reduction in stand volume growth because of the risk of windthrow of residual stems.
- **Species composition:** Prioritize commercial thinning of stands composed of pines and hardwood species over stands dominated by spruces or other coniferous species due to the faster growth of the pines and hardwoods.

- **Stand development phase:** Candidates for thinning should have achieved full site occupancy (full use of the available growing space), yet without becoming so dense that tree growth has begun to decrease. This typically occurs at the stem-exclusion phase of stand development, when few stems are being added to the main canopy. The trees to be removed must also have reached a merchantable size.
- **Stand history:** Candidates for thinning should ideally be stands with a history of density regulation (i.e., planting or pre-commercial thinning to achieve desirable stand characteristics), because such stands develop evenly and are most likely to maintain conditions that support good growth and good responses to thinning by the residual stems.

4.2.2 Tree vigour, stability, and health

- **Live-crown ratio:** Commercially thin stands to maintain a live-crown ratio of between 25 and 35% (i.e., roughly the top one-third of the stem should be live branches). Coniferous trees with small crowns and suppressed diameter growth will respond poorly to the increased light and growing space provided by thinning and may suffer from "thinning shock" (i.e., stress that causes reduced growth for one or more years). For particularly valuable species, such as hardwoods, pruning may be necessary to remove lower branches and achieve the desired crown ratio. (See Section 4.5.1 for more details.)
- **Growth rate:** During a stand's early development, it may be possible to tolerate progressively slowing growth rates, but this will eventually lead to declining tree health and yield. Ontario has many examples of single-species and mixed plantations that appear to have stagnated because they have been left too long (50, 60, or even 70 years) without thinning. If the live-crown ratio has dropped below one-third of the stem length, the tree will not respond well to thinning and may not survive. Individual trees that reach this point are usually weak and spindly, and are at risk of stem breakage in heavy winds or under the loads imposed by snow or freezing rain. Vigilance is required to prevent this problem, but if it develops, consider alternatives to commercial thinning; in extreme cases, clearcutting the stand and starting over again may be the best option. (See Section 4.5.2 for details.)
- **Height/diameter ratio:** Trees with a height/diameter ratio greater than 100:1 (with both measures in the same units of measurement) are unstable and at high risk of damage from wind, snow, and ice. Below this threshold, trees are more stable and therefore more resistant to such damage. You should only commercially thin stands if the height/diameter ratio of the residual trees is lower than 70:1.
- **Stand health:** Select stands that are mostly free of insects and diseases. For example, stands with significant occurrence of various root rots are poor candidates for thinning; instead, they require a re-evaluation of the original management objectives, and should be considered for salvage logging and conversion to other species that resist these diseases. Signs and symptoms of these and other insect and disease infestations are described in Section 5.3.

Normally, no more than one-third of the standing basal area should be removed during any single thinning operation. A growth model such as a density-management diagram (DMD) or a stocking guide will provide the necessary guidance based on data collected prior to defining the thinning prescription (OMNR 2000, OMNRF 2015). We discuss DMDs in section 4.3.2. Lighter initial thinnings with more frequent returns to the stand are often recommended for stands that have been left beyond the ideal initial thinning time, as this reduces the shock to the trees. Depending on your management goals and the desired forest succession pattern you want to follow, it may be necessary to switch from thinning to establishing regeneration at around the time of the second thinning. If so, the objectives for thinning must change to account for both the residual trees and the new regeneration.

4.2.3 Operational and economic considerations

If your local market accepts all types of species and a range of tree sizes, you can simply grow the forest to the point at which its volume increment begins to slow and then conduct the first and subsequent thinnings. However, the reality in Ontario is that there is limited interest in the small material (<20 cm in DBH) that is normally produced by the first thinning. This is problematic because, at an initial planting spacing of 1.8 m × 2.1 m, the plantation may begin to experience reduced growth rates when diameters are much smaller than this. Use of a DMD will help you to develop the initial crop plan for the species in your plantation by determining the optimal initial spacing that corresponds to the desired minimum diameter when the first thinning will be required. Wider initial spacing will help to delay the initial thinning until the trees have a more commercially valuable diameter. Alternatives to commercial thinning include pre-commercial thinning to eliminate poor-quality stems and release higher-quality stems. However, this is a costly operation for all but the smallest plantations or the most valuable tree species, and should be avoided if possible. Choosing an optimal initial spacing at the time of planting will help accomplish this goal at a much lower cost. (Section 2.8 provides more information on optimal spacings.)

Several other factors affect how you will conduct thinning operations:

- **Season:** Winter is usually a good time to conduct operations in coniferous plantations because the ground is frozen, which will reduce the impact on the site. Because the sap is frozen, it will not gum-up equipment as quickly. Harvested materials can be stored on the site longer at this time of year without risking deterioration from blue-stain fungi and wood-boring insects. Late summer and fall are also acceptable periods, so long as the ground is dry enough to permit machine travel without damaging the soil. Thinning operations should be avoided in the spring and early summer to avoid damage to the actively growing bark of the residual trees, and to avoid rutting or soil compaction; it also reduces interference with wildlife, as spring to early summer is typically the breeding and fledging period in Ontario.
- **Seed collection:** Gathering cones and seeds from conifers during a good seed crop, before the seed is naturally released from the cones, can be combined with the thinning. Alternatively, thinning can be conducted after seed release has occurred, thereby scarifying the site to promote the development of advance regeneration (OTSP 2014).
- **Layout:** The site layout should be planned to facilitate mechanical operations. In addition to choosing a row spacing that facilitates travel between the rows, it is safer for equipment to travel up and down slopes (perpendicular to the contour lines) rather than parallel to the contours. In addition, equipment will need room to turn around at the end of each row.
- **Communicating the thinning plan:** Explain your thinning plan and its goals to all workers. Use marking paint or flagging tape to guide the operators to achieve the desired results. Training (e.g., on the need to remove damaged or diseased trees) may be required for inexperienced machine operators.

- **Landings:** As a plantation matures, the diversity and dimensions of the products will increase. Older plantations may produce tree-length products (e.g., utility poles) that will require more room at the landing. Landings should be close to main roads to allow access by logging trucks (Fig. 4.3).

4.2.4 Timing of thinning

Commercial thinning operations should occur before the mean annual volume increment (MAI) begins to decline and during the period of active height growth. Waiting any longer may miss the opportunity for good crown expansion by the residual trees and a good growth response to the thinning. Depending on the stand density and site productivity, the first thinning should generally not occur later than 25 to 30 years for red pine, 30 to 35 years for white pine, and 35 to 40 years for white spruce. No specific guidelines exist for other species, so you will instead need to monitor the crop trees to determine when they are beginning to show signs (e.g., slow growth) that they need to be released.

Figure 4.3: Landings should be large enough to accommodate both the length of the harvested products, and the total volume removed. Small-diameter logs (left) need less room than utility poles (right). [Photo sources: Fraser Smith Consulting (left); Eric Boysen, NewLeaf Forest Services (right)]

However, density can be adjusted earlier to delay the time of peak MAI by several years or even, in some cases, decades. For red pine and white pine, the latest age for the final thinning therefore depends on the number of treatments and their timing. Some of the oldest plantations in Ontario that have been periodically thinned are still being thinned beyond the age of 70 years. An upper age limit for thinning may therefore not exist for red pine and white pine. Within the window for biologically feasible thinning, the *ideal* time to commercially thin depends on the site quality (e.g., the site index) and stand density (OMNRF 2015).

The actual configuration (pattern) of the thinning will vary, depending on your short-term management objectives. The pattern should generally work in conjunction with the target density. For example, a target reduction of one-third of the basal area works well under an initial thinning pattern that removes every fourth row (i.e., a 25% reduction in basal area), leaving three rows in which selective removal of poor-quality stems can occur, up to the maximum removal of one-third of the total basal area.

After the first thinning, the pattern of subsequent thinnings will be dictated by your objectives for the residual canopy and stem quality, as well as by the types of products to be removed. In the rest of this section, we will describe the main thinning patterns used in Ontario (Fig. 4.4).

Figure 4.4: Left: A young 25-year-old red pine plantation prior to first thinning. Right: A plantation ready for second thinning at age 35. Note the row of trees that was removed to create an access corridor for harvesting equipment. [Photo sources: Fraser Smith Consulting (left); Martin Streit, OMNRF (right)]

Access thinning

The first (initial) thinning in plantations is often designed to maintain optimal growth rates and a strong growth response by the residual trees, but an equally important goal may be to create open lanes in which machines can travel and work during future thinning operations. The original spacing and survival of the trees and the width of the equipment you expect to use will dictate whether single rows or double rows should be removed, or whether access lanes should be created that run perpendicular to the rows of trees.

If you plan to use large equipment such as a feller-buncher up to 3.7 m in width, and have chosen an initial row spacing of at least 1.8 m, one row can be removed. However, an initial row spacing of at least 2.1 m is preferable, as it leaves enough room on either side of the machine to facilitate manoeuvring and limit damage to the residual trees.

With single-row thinning, you must decide how many rows to leave between the rows that will be removed. One problem is that removing an entire row is arbitrary, and does not account for the size, quality, species, wildlife value, and other characteristics of the removed trees. For most forests, removing every other row (i.e., 50% removal) would be too aggressive, as it reduces the likelihood of improving the growth of a large number of potentially high-quality stems, many of which will be removed while they are still fairly small. As well, this may leave the stand more vulnerable to wind or ice damage. This is because trees that grow in dense stands are protected from the wind, and therefore have smaller and less widely distributed root systems than trees that grow in the open.

The first access thinning can sometimes be followed quickly (within 5 years) by selection thinning. In that case, the number of rows left between the access rows will depend on the reach of the machines that will do the thinning work. Up to five rows can be left if the equipment can still reach the centre row between adjacent access rows.

Where you plan to use full-size harvesting equipment and the rows were either planted at a spacing of 1.8 m or less or were not planted in straight lines, it will be necessary to remove two adjacent rows to provide access for the larger machines. The number of rows that you leave between these access rows depends on when you plan to return for future selection thinning and what residual spacing target was defined as the goal of this first thinning. With modern harvesting equipment that can reach more than 9.1 m into the stand, as many as five rows can be left between the access rows. To limit the removal to one-third of the basal area, it will be necessary to leave at least four rows between adjacent access trails.

To facilitate manoeuvring of machinery, it may be necessary to thin perpendicular to the original rows at a predetermined spacing (i.e., cross-row thinning) instead of removing entire rows (i.e., row thinning). The width of these access corridors must provide sufficient room to accommodate the equipment you expect to use during the first and subsequent thinnings.

Cross-row thinning (creating access corridors perpendicular to the orientation of the planted rows) is often necessary in plantations where the row spacing was 1.8 m or narrower. It can also be used on hilly terrain where the tree rows were established along the contours on slopes, but where the harvesting machines must travel up and down the slope for stability and safety. Calculations of the distance between the access rows should again consider the target thinning density, return times, and reach of the equipment.

Access thinning with selection

In some cases, it is necessary or helpful to combine access thinning with selection thinning. This is the pattern of first thinning most often prescribed for coniferous plantations in Ontario. A typical prescription is to remove one in four rows to improve future access to the stand, while also removing poor-quality stems in the residual rows to achieve the overall density reduction target. This is ideal in cases where thinning occurs before stand growth has slowed, the live-crown ratio is within the desired range, and there is a strong market for smaller-diameter products. However, because this method will remove a greater proportion of stems with lower diameter or quality, it may affect the economic viability of the operation. For stands that have been left beyond the optimal timing for their first thinning, the trees will tend to have small live-crown ratios, and the additional thinning from selection may open the stand too much and expose trees to wind and ice damage. In these cases, it may be preferable to achieve the desired density reduction in two phases: first, remove trees in the access rows, and then return 2 to 5 years later to undertake the selection thinning. This is more expensive, but the delay will let the stand stabilize, while permitting the salvage of any remaining stems that may have bent over into the access rows (Fig. 4.5).

Figure 4.5: This series of photos shows the normal sequence of operations during an access thinning with selection. (A) The single-grip harvester removes trees within an access row, and also reaches into adjacent rows to harvest trees. (B) It will process the trees at the stump into the desired products. (C) The forwarder will retrieve the logs and bring them to the landing. (D) At the landing, the logs are loaded onto the haul trucks. [Photo sources: A, B, Fraser Smith Consulting; C, Martin Streit, OMNRF; D, Ken Elliott, OMNRF]

Selection thinning from below

After the initial access thinning, subsequent thinning will focus on maintaining good growth of the dominant retained stems and on improving their quality. Once the optimum density has been determined, the thinning prescription can then aim to achieve this density by selectively removing the smallest and lowest-quality trees (i.e., thinning from below) while releasing the very best trees (the crop trees) from competition on one to three sides.

This technique can also be used for smaller plantations where it is uneconomical to undertake an initial access thinning, or for mixed-species plantations where you want to release more desirable stems from competition with adjacent crowns.

Crop tree release thinning

For the second and subsequent thinnings, the focus will shift to the crop trees, with the goal of providing optimal growth opportunities for high-quality stems and the most desirable species. First, choose a spacing or a target number of crop trees to be retained per unit area. This is usually based on the ideal spacing for mature crop trees of a specified diameter to be present when the crop is ready to harvest (i.e., when it is time to establish a new stand by performing a regeneration cut), and is then scaled back to the current age using a DMD or stocking guide. Using white pine as an example, we can consider a scenario in which 85 crop trees per hectare with an average diameter of 40 cm will be retained until a future regeneration cut. In this scenario, the initial crop tree selection should be designed to identify 170 to 200 crop trees per hectare (at a distance of about 7 to 7.5 m between the crop trees). That is, the first thinning will reduce the density of identified crop trees by one-third, to about 120 trees/ha, and the second thinning will reduce the density of previously identified crop trees by an additional one-third, to about 85 trees/ha. These trees can be released on two sides of the crown. As well, for certain species that benefit from pruning, such as red pine and white pine, the crop trees can be pruned at the same time as the thinning or in a subsequent operation (Fig. 4.6).

Figure 4.6: A crop tree release in a 55-year-old red pine plantation. [Photo source: Martin Streit, OMNRF]

When plantations begin to mature (usually after the third thinning), you can consider markets for high-quality longer and larger stems for speciality products such as utility poles or logs for building log homes. In these circumstances, the desired BA reduction will focus on dominant or codominant trees that meet the required product specifications (e.g., large diameter). This approach is possible because by that time, the trees should all be of sufficiently good quality to be considered acceptable growing stock. As is the case for any good forestry practice, you must consider both the stand's current health and your long-term objectives for the stand, including the eventual renewal of the stand. Removing dominant or high-quality trees could reduce the current stand's health or its future health and genetic diversity. If advance regeneration from these trees has already been secured, or if that species is not part of your future plan for the site, then these concerns may not be important. However, given the length of these products, there may be unavoidable damage to the advance regeneration in the understory when these trees are felled (Fig. 4.7).

Figure 4.7: Advanced natural regeneration of sugar maple in the understory of a 40-year-old red pine plantation. [Photo source: Martin Streit, OMNRF]

4.3 Assessing plantation condition prior to thinning

Because the success of thinning depends strongly on the site and stand conditions, you should conduct field assessments to verify site and stand conditions before the operation (e.g., Bidwell et al. 1996; OWA 2003a,b). Changes in site conditions or differences from the assumed conditions may require you to modify your plans. Sampling both before and after the operation will provide important data to guide future monitoring and operations.

When the plantation is approaching the time of its first thinning, you should measure and assess stand conditions in order to develop an appropriate thinning prescription. Areas within the plantation that have similar conditions should be mapped, since they will receive different treatments than areas with different conditions. Although stand conditions may be relatively uniform in single-species plantations with a high survival rate, they may be quite variable in mixed plantings, in plantations with lower survival rates, and in areas with diverse soil and site conditions. You may need to develop different thinning prescriptions for each of these unique areas. Within a given area, assess the trees to determine their:

- species (especially for mixed-species plantings)
- diameter at breast height (DBH at 1.3 m) for all trees above a given minimum size
- quality class (acceptable or unacceptable growing stock)
- height, including an estimate of the merchantable length of the stem
- age (if the planting date is not known)

Summarize the following stand characteristics from your field data to support the use of stocking guides or DMDs:

- **Quadratic mean diameter at breast height (DBHq):** This is the DBH (cm) of the tree of average basal area, calculated as the square root of the average of the squared DBHs. This calculation gives more weight to larger trees and thereby provides a better representation of typical future crop trees.
- **Basal area (BA):** This is the sum of the basal areas of the individual trees (i.e., their cross-sectional area at breast height) in a plot per unit area, and then expanded to the whole stand (m^2/ha).
- **Species composition:** This is generally expressed as the proportion of the total basal area accounted for by each species.
- **Top height (or dominant height):** This is the average height (m) of the 100 stems with the largest diameter per hectare. The average height of the dominant trees in the upper canopy of the stand can also be used as a rough estimate of this parameter. To calculate top height, measure the height of the tree with the largest DBH in a 100-m^2 plot, or the height of the two trees with the largest DBH in a 200-m^2 plot. The average height of the sampled trees is the top height.
- **Density:** The density is the number of stems per hectare.

- **Age at breast height:** If the stand age is known, then the age at breast height can be calculated as the total age minus the estimated number of years for the tree to reach breast height. In coniferous plantations, the age at breast height can be estimated by counting the number of branch whorls below breast height. If the stand age is unknown, it can be quickly estimated by taking an increment core at breast height from a dominant individual and counting the growth rings.
- **Spacing:** The distance between the rows and the orientation of the rows are both important.

Collecting this minimum amount of information will provide a general description of the forest to be thinned. The following additional information may prove to be useful:

- **Advance regeneration:** The species and distribution of advance regeneration can help you predict the response of the stand to thinning.
- **Wildlife:** If one of your goals is to provide wildlife habitat and increase biodiversity, look for signs of wildlife (e.g., nests) and survey the vegetation to determine the number of species, especially for species at risk.
- **Access:** Record the locations of existing access points and landings, and potential future locations.
- **Seasonal water features:** Record any unusually dry areas or areas with standing water and how these characteristics vary among the seasons.

4.3.1 Sampling

To obtain reliable data on the stand characteristics, it's necessary to develop a robust and reliable sampling design. The two main approaches are fixed-area sampling, in which you define sample plots of a standard size and sample all trees within the plots, and point sampling, in which you define a sample point, and then sample stems using a wedge prism with a known basal area factor (OWA 2003b). To ensure that you can compare results between samples, try to use similar proceduresfor all assessments.

For most plantations, the simplest way to gather the required data is to use fixed-area sampling plots. First, the plot size, shape, sampling intensity, and layout should be determined:

- **Plot size:** For young plantations with uniform stand conditions, we recommend sample plots of 100 to 200 m^2. For more variable stands, we recommend more plots (see "sampling intensity" later in this list). As the plantation matures and the tree size increases, larger plots should be used.
- **Plot shape:** Circular plots are recommended because they are easy to use, since you can locate the plot centre, pin a tape measure to that point, and then extend the tape to the appropriate radius. You can then use flagging tape to mark the edges of the plot. In some plantations, you can mark the plot boundary by scuffing the duff layer in the summer; in winter, you can instead scuff the snow. The radius is 5.64 and 7.98 m, respectively, for 100- and 200-m^2 circular plots.
- **Sampling intensity:** Determine how many samples you should establish. In relatively uniform stands, a 1% sample is feasible; this requires one 100-m^2 fixed-area plot per hectare. For less uniform stands, a 2% sample would require one 200-m^2 plot or two 100-m^2 plots per hectare. We recommend this intensity for most stands. However, the intensity could be increased to as high as 5% (five 100-m^2 plots per hectare) in highly variable stands.

- **Layout:** Sampling should follow a roughly parallel series of lines (also called transects or cruise lines) to ensure that you sample conditions throughout most of the forest. The cruise lines should run up and down slopes, since stand characteristics often vary with respect to slope positions. For convenience, the sample plots can be located at regular intervals along the line (Fig. 4.8). A statistically unbiased sample would involve randomly locating each sample plot. This is time-consuming to implement and does not ensure that the sampling covers the entire area.

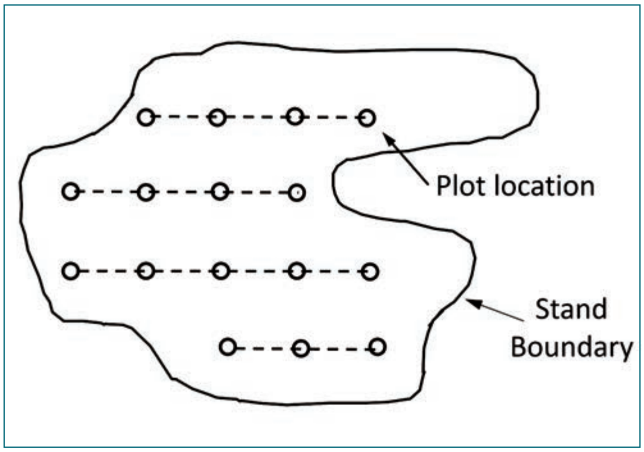


Figure 4.8: Cruise lines can be laid out in a grid fashion to cover most of the stand, and should generally run up and down slopes.

Point sampling offers an alternative to fixed-area plots. This approach is known as "prism cruising" if a wedge prism is used to detect the trees that should be included in the sample, or as "variable-radius" plot sampling. In this approach, trees are selected for inclusion in the sample with a probability that is proportional to their basal area. One common method of selecting trees is to use a wedge prism. Each selected tree represents the same basal area in this method, and that area equals the basal area factor (BAF). Basal area is then estimated by multiplying the number of trees tallied in the sample by the prism's BAF. In practice, DBH is generally measured for all trees to allow estimation of DBHq and a subsample of the trees is measured to determine their height. DBHq is calculated from a prism plot as the arithmetic average DBH of the tallied trees.

Generally, a BAF is chosen so that 7 to 12 trees are tallied at each sampling point (OWA 2003a). Prisms with BAF = 2 m^2/ha are commonly used. If a prism with BAF = 1 m^2/ha is used, a minimum stand basal area of 7 m^2/ha is required to achieve the minimum of 7 trees. Point sampling requires an unobstructed view of the stem at breast height. As a result, this method can be difficult to use in stands with younger closer-spaced trees. It becomes an efficient sampling method in older plantations with larger and fewer trees and a more open understory.

4.3.2 Density-management diagrams

DMDs are graphs that relate the average tree size (stem diameter, basal area, or volume) and the stand volume (yield) to the stand density, but may also include the height of the dominant trees and other parameters (Fig. 4.9). DMDs are used to identify optimal conditions for growth and for when density-related mortality is likely to begin. They can therefore guide the development of commercial thinning prescriptions and help you compare alternative thinning strategies (the timing and intensity of thinnings) in terms of their ability to achieve your management objectives. You can also use DMDs to estimate the average dimensions (e.g., length and diameter) of extracted forest products. The maximum density lines in DMDs are based on the -3/2 power law, which does a good job of describing self-thinning, and therefore applies best to thinning from below.

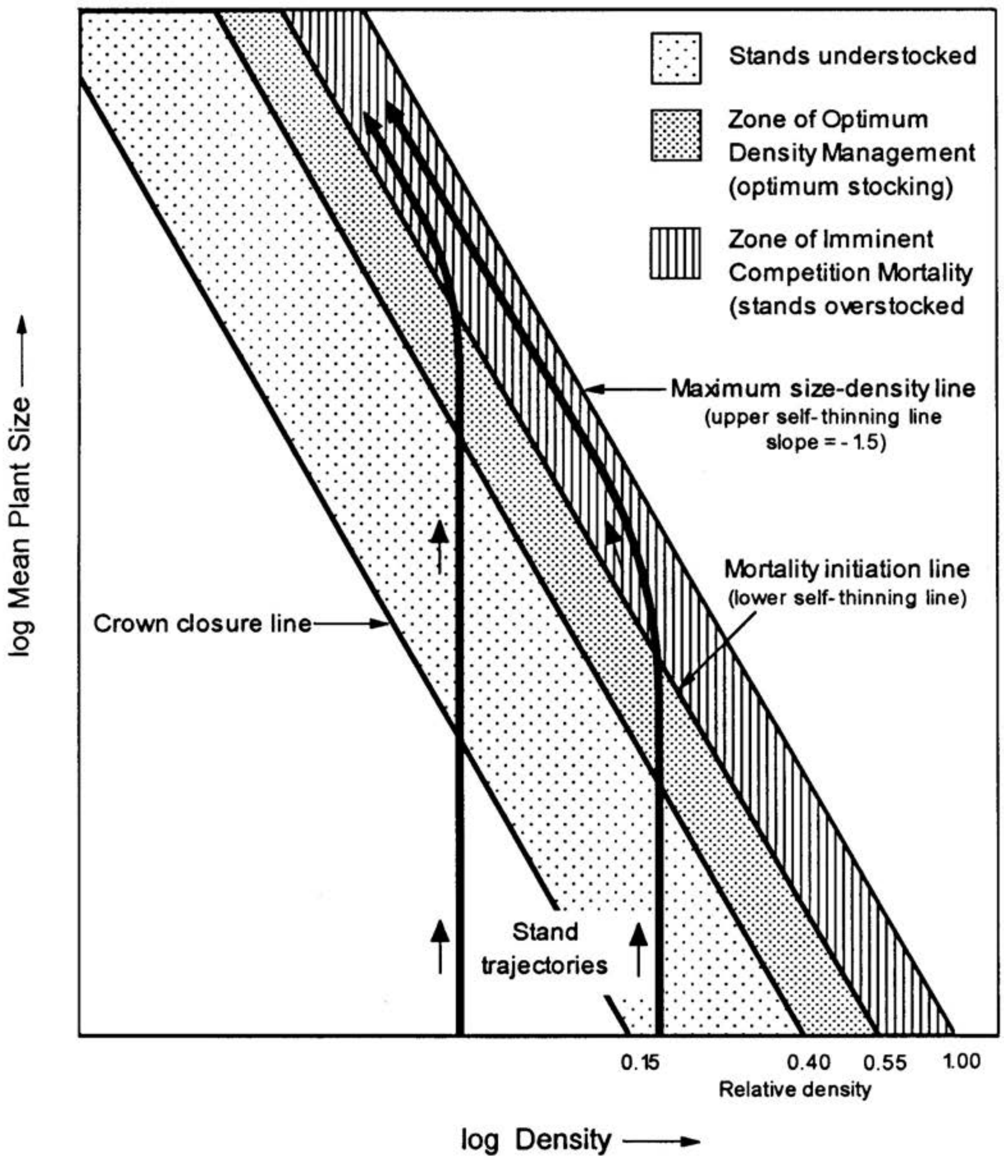


Figure 4.9: A typical presentation of a density-management diagram (Smith and Woods 1997). The "overstocked" region indicates conditions where mortality occurs due to competition among the trees. The "mortality initiation line" represents the point at which natural self-thinning begins. The line for "maximum size–density" indicates the maximum mean plant size for a given density, and has a slope of -3/2, or the self-thinning power law.

You can supplement the information provided by a DMD by using site-index curves, which show the expected height of dominant trees as a function of their age at breast height and site index. DBHq isolines, which show the relationship between the volume of dominant trees, the stand density, and DBHq, can be added to a DMD (Fig. 4.10 for red pine; Fig. 4.11 for white spruce). Similarly, top height isolines can be added to show the relationship between the volume of dominant trees, the stand density, and the top height.

A typical DMD is constructed using four parameters: DBHq, top height, stand density, and the mean tree volume. The first three parameters can be easily calculated or assessed in the field. The mean tree volume can then be read directly from the diagram. Although we recommend that you plot the values of the first three parameters in the graph for each stand, you can use any two of the three parameters in practice. We also recommend that you estimate the age at breast height to determine the site index.

The DBHq isolines and the top height isolines in the DMD permit estimation of additional information and provide a further check when you position a stand within the DMD. Once you've located the stand within the DMD, you can make silvicultural decisions to ensure that a stand develops in a direction that will achieve your management objectives. (In Section 4.3.3, we will provide an example of how this is done.) The future density, DBHq, and stand basal area, plus approximations of the mean tree volume and total stand volume, can be estimated. Site index curves enhance this analysis by adding a temporal scale that lets you schedule silvicultural interventions. The age corresponding to a given top height can be estimated from the site index curve.

DMDs are also useful before you establish a plantation, since they can help you to prepare a crop plan. Select an initial plantation density that will produce a DBHq and top height that meet the minimum requirements for the target wood products in your local market. Account for estimates of the initial survival rates and subsequent thinning rates when you estimate future densities.

Archibald and Bowling (1995), Smith and Woods (1997), and Newton (2009) provide a more detailed discussion of DMDs. Additional information is available for white spruce DMDs (Saunders and Peuttmann 2000), red pine DMDs (Smith and Woods 1997), and white pine DMDs (Smith and Woods 1997).

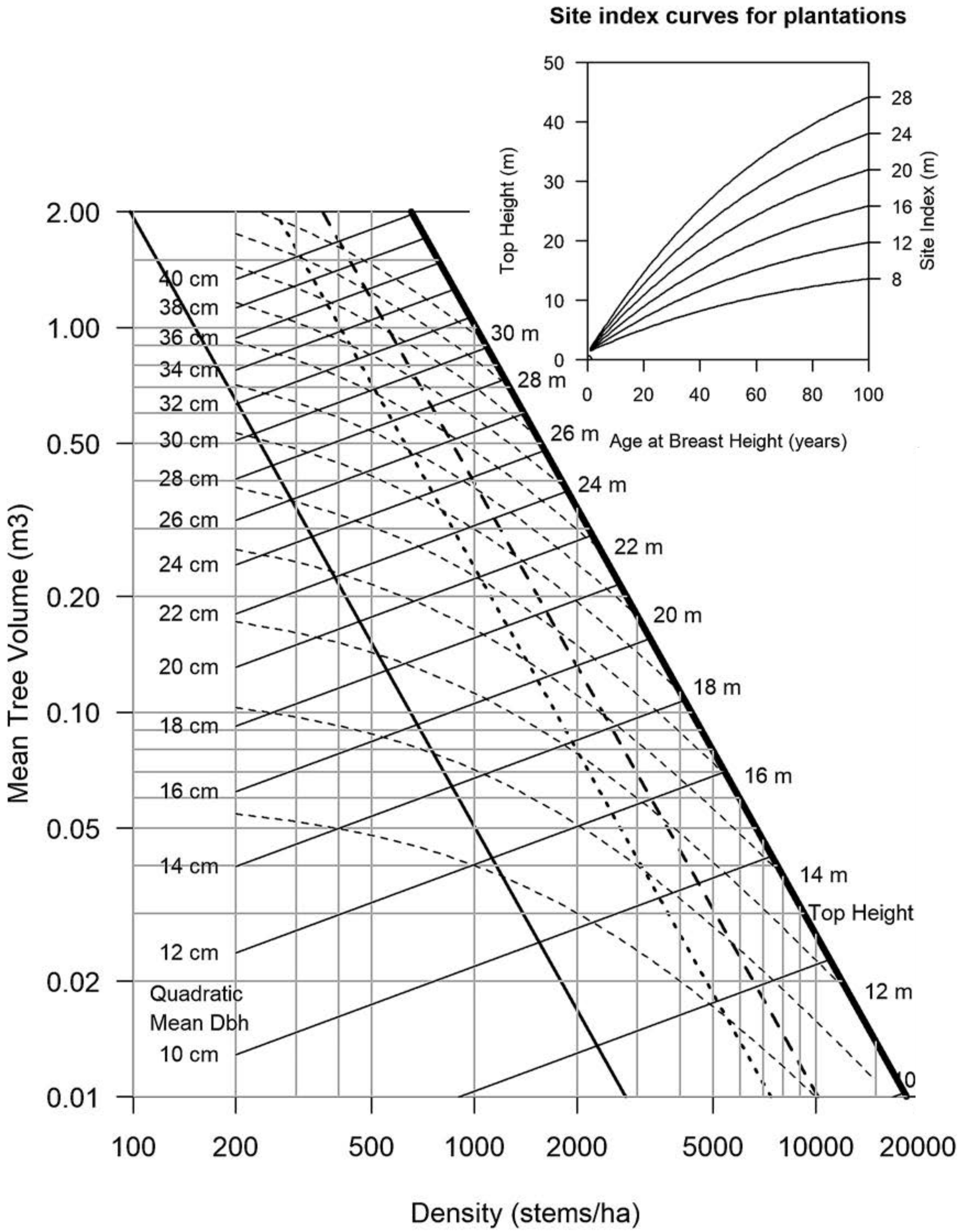


Figure 4.10: Site-index curves and density-management diagram for red pine in Ontario (Smith and Woods 1997), with DBHq isolines. The DBHq isolines are the solid, parallel lines with a positive slope. The top height isolines are the dashed, curved lines.

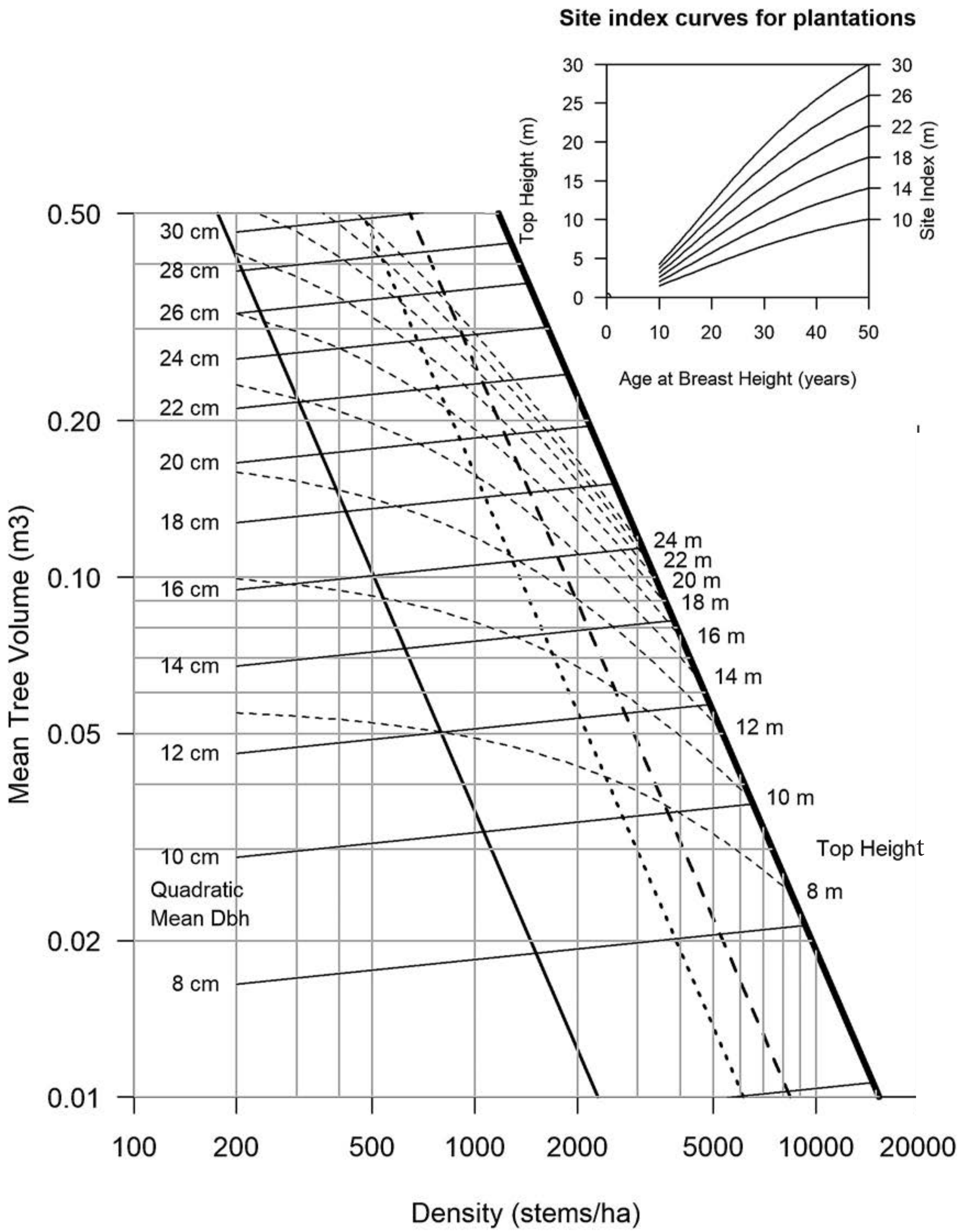


Figure 4.11: Site index curves and density-management diagram with DBHq isolines for white spruce in Ontario (Penner 2001, unpublished). The DBHq isolines are the solid, parallel lines with a positive slope. The top height isolines are the dashed, curved lines.

4.3.3 Analyzing stand stocking

You can analyze stocking using a DMD if you know the DBHq, stand density, and top height. Start by calculating the stand density index (SDI), which represents the ratio of the actual density to the maximum density. To determine the SDI, locate the current stand conditions in an appropriate DMD for that type of stand. Determine the maximum density by reading horizontally to the right from the mean tree volume at that location to the maximum size–density line.

In the example shown in Figure 4.12, the current stand conditions are a density of 1000 stems/ha and a DBHq of 13 cm (point 1 in the DMD). Reading horizontally from that point to the maximum size / density line (point 2 in the DMD) reveals that the maximum density for that volume is approximately 6000 stems/ha. Thus, the SDI = 1000/6000, or approximately 0.17. See Case Study #6 (Red Pine Afforestation Crop Plan) for more details on how to use a DMD.

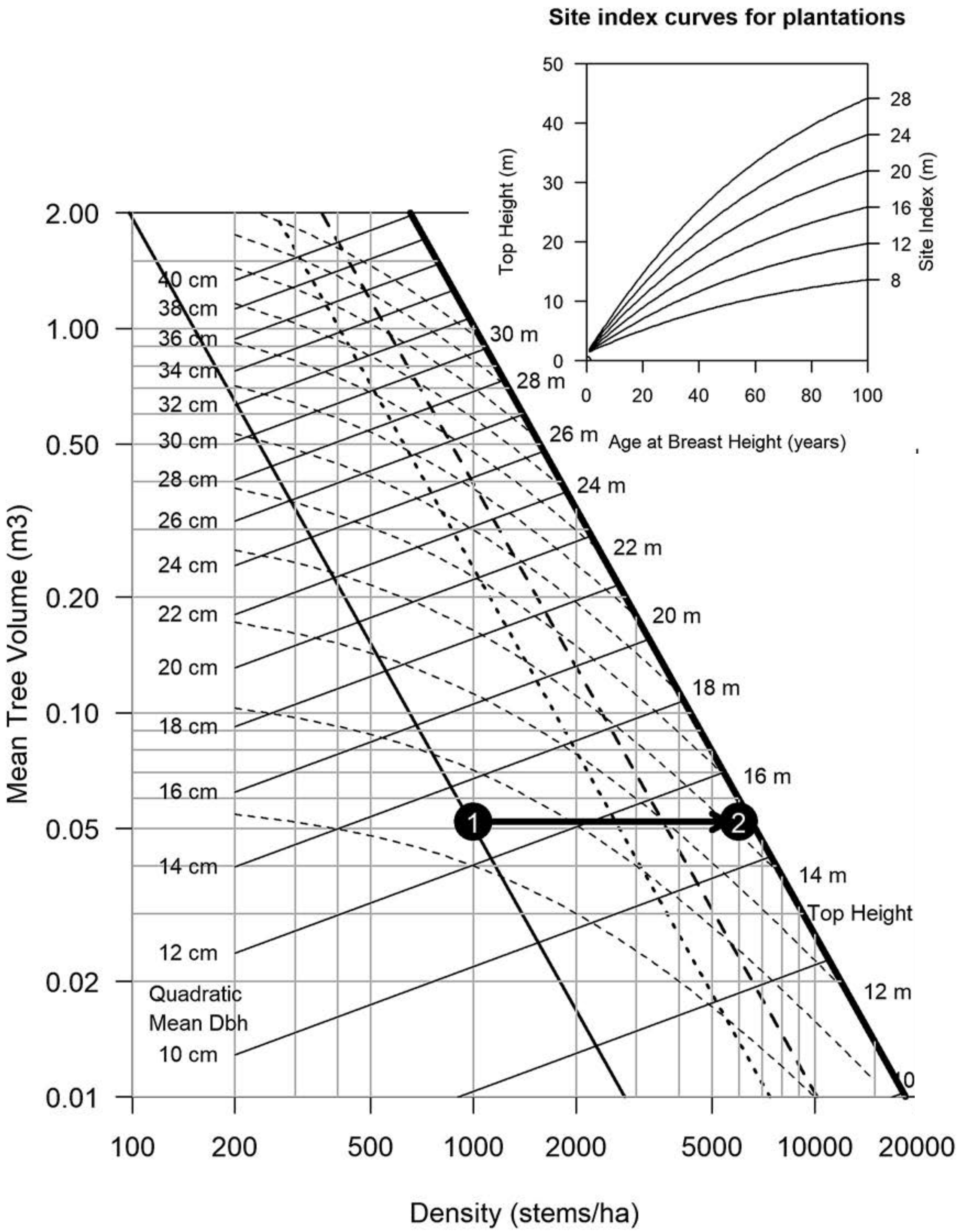


Figure 4.12: To calculate the stand density index (SDI), locate the current stand conditions within the DMD (point 1). Estimate the maximum density for the same mean tree volume by reading horizontally until you reach the maximum size–density line (point 2). SDI = the current density at point 1 divided by the maximum density at point 2.

The DMDs and other yield relationships for mixed-species plantations are less well understood (Farnden 1999). For an area planted with a mixture of species A and species B, managers generally assume that the yields will be somewhere between the yields of single-species plantations of species A and B. Exceptions occur when one species enhances the growth of another, as occurs in some mixtures of Douglas-fir and red alder, or when one species inhibits the growth of another, as occurs in some mixtures of red pine and white spruce. The growth of the two species depends on the relative proportions of the species as well as on their spatial arrangement. Alternating species A and B during planting (Fig. 4.13a) may produce lower yields than planting pure patches of each species (Fig. 4.13b,c) if one species starts to dominate the growing space. This may occur if one species has faster height growth.

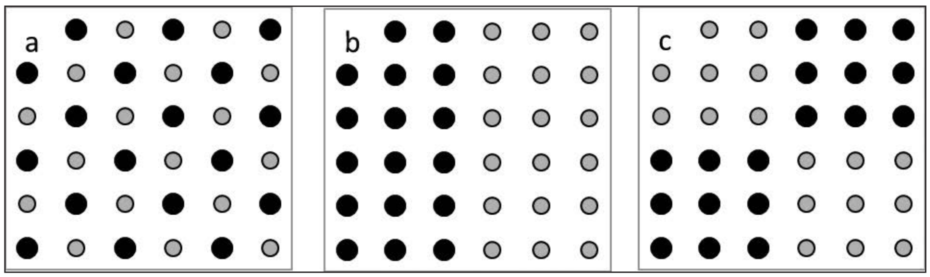


Figure 4.13: A heterogeneous mixtures of species can be planted by (a) alternately planting individuals of the two species or (b,c) planting each species in single-species patches.

Once you know the current SDI and your target, you can estimate the minimum residual basal area that must be maintained after the thinning. Tables 4.1 to 4.3 provide estimates of the removal rates required to achieve a given basal area that you feel will achieve the optimal stocking for a site. This represents a basal area approach to the SDI information used with DMDs (OMNRF 2015). Table 4.4 presents typical management scenarios for the three species in these tables based on a combination of the approaches described in this section.

Table 4.1: Guidelines for basal area (BA) reduction to achieve a target residual BA for red pine. SDI = stand density index.

DBHq (cm)	Fully stocked BA (m^2/ha) SDI = 1.0	Residual BA (m^2/ha) at target SDI	Removal (% of BA)	Minimum residual BA (m^2/ha) based on 33% BA removal (m^2/ha)
15.0	37.1	28.3	24	24.7
17.5	38.5	30.1	22	25.6
20.0	40.8	31.4	23	27.2
22.5	42.1	31.8	24	28.0
25.0	44.2	33.4	24	29.4
27.5	44.5	34.4	23	29.6
30.0	45.9	34.6	25	30.6
35.0	47.1	36.5	23	31.4
40	48.4	37.7	22	32.2

Table 4.2: Guidelines for basal area (BA) reduction to achieve a target residual BA for white pine. SDI = stand density index.

DBHq (cm)	Fully stocked BA (m^2/ha) SDI = 1.0	Residual BA (m^2/ha) at target SDI	Removal (% of BA)	Minimum residual BA (m^2/ha) based on 33% BA removal (m^2/ha)
15.0	24.7	18.5	25	16.5
17.5	27.6	20.4	26	18.4
20.0	30.8	22.6	27	20.5
22.5	33.0	23.8	28	22.0
25.0	35.6	25.8	28	23.7
27.5	37.4	27.6	26	24.9
30.0	40.6	29.0	29	27.0
35.0	44.2	31.7	28	29.4
40.0	47.7	35.2	26	31.8
45.0	50.9	37.4	27	33.9

Table 4.3: Guidelines for basal area (BA) reduction to achieve a target residual BA for white spruce. SDI = stand density index.

DBHq (cm)	Fully stocked BA (m^2/ha) SDI = 1.0	Residual BA (m^2/ha) at target SDI	Removal (% of BA)	Minimum residual BA (m^2/ha) based on 33% BA removal (m^2/ha)
15.0	34.3	25.1	27	22.8
17.5	36.7	26.4	28	24.4
20.0	39.3	28.3	28	26.2
22.5	40.7	29.8	27	27.1
25.0	42.9	31.2	27	28.6
27.5	43.6	32.7	25	29.0
30	45.9	33.9	26	30.6

Table 4.4: Recommended management scenarios for red pine, white pine, and white spruce plantations.

Red pine	
Establishment phase	
Recommended spacing: 2.4 m × 2.1 m = 1984 trees/ha or 2.4 m × 1.8 m = 2314 trees/ha (a higher density for more intensively managed sites) Minimum between-row spacing: 2.1 m (e.g., 2.1 m × 1.8 m) Minimum 85% survival, or requires refill A crop plan can help determine the best initial spacing so that the first thinning occurs when the trees achieve a desired minimum diameter. See Case Study #6 for more details. Consider including 5 to 10% white pine, red oak, or both, planted in groups of 10 to 25 trees, to increase future diversity and provide regeneration options.	
Management phase	
Initial thinning	Often after 25 to 30 years. Don't delay thinning past 35 years, because this produces trees with weak stems and thin crowns that are susceptible to bending and breakage. Average DBH of marked trees at the first thinning should be 16 to 18 cm (≥90% of stems ≥14 cm). They should have sufficient merchantable height to provide three usable logs (i.e., 8 m of straight bole to a 12 cm top to produce three 2.54-m logs). If planted at higher densities, pre-commercial thinning may be required. The first thinning should establish access rows and should include a light selection thinning from below to remove poor-quality stems in the residual rows. Typically, every fourth or fifth row is completely removed. The first thinning should remove 25 to 33% of BA, and the minimum residual basal area should be 26 m^2/ha. You may need to remove two adjacent rows if the initial spacing is too narrow for the thinning equipment. Select between 250 and 300 crop trees/ha, and prune lower branches to height of 3.0 m during the first thinning (here and for subsequent pruning, leave at least 33% of the live crown) if utility poles are the desired final product. Maintain or release acceptable (AGS) crop trees of other species to meet wildlife, regeneration, and diversity needs.

Red pine	
Subsequent thinnings	After the first thinning, focus on thinning from below. Typical removal is 25 to 33% of basal area during each thinning. Return 9 to 12 years after the first thinning (exceptionally, as soon as 7 years or as late as 15 years), depending on the site quality, number of trees, and forest management objectives. After the second thinning, residual trees should all be of acceptable quality. You may still need to remove a few trees with v-forks, recently damaged trees, and declining trees. Start looking more at crown health than tree size for crop tree selection. Prune lower branches of crop trees to a height of 5.1 m. Prune lower branches of future utility poles to height of 7.4 m. Develop a long-term objective for natural or artificial regeneration when you plan the second thinning. Typical pathways are natural regeneration of hardwoods, white pine, or both; artificial regeneration of white pine, red oak, or both; and re-establishment of red pine. Time these thinnings to coincide with a seed crop to permit cone collection and increase the financial return from the plantation. At maturity (between 60 and 80 years), switch from thinning to improve stem quality to thinning designed to maximize the financial return, accounting for market demand. Most red pine stands will eventually be converted to other species. If they will be regenerated to red pine, new planting stock will be required. In areas with competition from invasive species (buckthorn; dog-strangling vine), openings will tend to exacerbate their invasion.
Final harvest	The potential harvest (rotation) age depends on the site and stand quality and on its regeneration status. Establish high-quality hardwoods or white pine to prevent establishment of invasive species, or to control existing invasives prior to the final harvest. To improve species diversity, minimize competition from invasive species and other species that are not part of your restoration objectives.

Red pine	
Other considerations	
Maximizing growth and quality	Regular thinnings will provide more uniform growth, reduce competition, and allow poor-quality trees and those that would normally die to be removed and marketed early and utilized. Removing trees with defects through selective thinning early in the stand's development allows good growth and maximizes quality and value. Use DMDs or stocking guides to manage stand density within the range that will provide the best growth. Red pine is a good self-pruner. If pruning operations are necessary or desirable, focus on the high-quality crop trees (approximately 250 to 300 per hectare). Red pine has low genetic diversity, and individual trees tend to not differentiate themselves, leading to stagnant stands if regular thinning is not implemented. During the final thinning, consider the impact of skidding tree-length products; consider an alternative such as forwarding shorter products if high-quality regeneration has become established. Most of the high-end products, such as utility poles and wood suitable for building log homes, will come from the dominant and co-dominant trees that have been selected for low accumulated knot diameters, straightness, low taper, no forks, uniform growth, and few or no defects. Once all the trees have achieved acceptable quality, begin removing the high-value products when market conditions are favourable. As stands mature, watch for stress indicators in the crowns (e.g., tufting of needles, short needles, browning needles, thinning of the leaves or canopy). Trees with these types of symptoms are usually growing slowly and will not normally recover. Where possible, they should be removed.
Critical pest management issues	Heterobasidion root disease Red pine pocket decline (various insects and diseases) Red-headed pine sawfly
References (for further reading)	Horton and Bedell (1960) OMNR (1986) Smith and Woods (1997) Woods and Penner (2000) Gilmore and Palik (2006) Burgess et al. (2011)

<table>
<tr><th colspan="2">White pine</th></tr>
<tr><td colspan="2">Establishment phase</td></tr>
<tr><td colspan="2">Recommended spacing: 2.4 m × 1.8 m = 2314 stems/ha for sites that are not susceptible to white pine blister rust or weevil damage.
Minimum between-row spacing: 2.1 m (e.g., 2.1 m × 1.8 m). Consider tighter spacing (e.g., 1.5 m × 1.5 m or 1.8 m × 1.8 m) to reduce weevil incidence; however, this will significantly increase establishment costs and require earlier thinning.
A crop plan can help determine the best initial spacing.
Planting white pine is not recommended in areas prone to infestation by white pine blister rust. Consider planting an alternative species.
Consider mixed-row planting (e.g., red pine, tamarack, European larch, or hybrid poplar, or consider using red oak in every fourth row to increase species diversity. See Case Study #3 for a description of mixed plantings to promote high quality white pine.</td></tr>
<tr><td colspan="2">Management phase</td></tr>
<tr><td>Initial thinning</td><td>The first thinning can occur after 30 to 35 years, depending on the initial spacing.
If there is a market for low-end fibre (e.g., pulpwood), thinning can occur earlier.
Crop trees should be identified at this time so that thinning can benefit their future growth.
Markets for small-diameter trees with crooked stems (e.g., caused by weevils or ice damage) are limited, making early thinning uneconomical.
The intermediate shade tolerance and high genetic diversity of white pine encourages better differentiation and self-thinning than with red pine, permitting a delayed first thinning. The average DBH of marked trees at the first thinning should be 18 to 20 cm (≥80% of stems ≥14 cm).
To be merchantable, a tree must have 8 m of straight bole to a 12-cm top and produce three 2.54-m logs from that wood.
Typically, every fourth or fifth row is completely removed to provide access. Light selection thinning from below should also occur in the remaining rows at the same time.
The first thinning should remove 25 to 33% of BA, and the minimum residual basal area should be 26 m^2/ha.
It may be necessary to remove two adjacent rows if the initial spacing is too narrow for the thinning equipment.
If crop trees of other species are present, maintain them to meet wildlife, regeneration, and species diversity considerations.</td></tr>
</table>

White pine	
Subsequent thinnings	Subsequent thinnings should focus on selective thinning from below. Return after 9 to 12 years (exceptionally, as low as 7 years or as long as 15 years), depending on the site quality, number of trees, and forest management objectives. Define a long-term objective for natural or artificial regeneration at the time of the second thinning. Regular thinnings should transition to a shelterwood management system (discussed in Section 4.6.3) if white pine renewal is desired. If thinning operations are not economically viable, release the crop trees when canopy closure occurs. Select 170 to 200 crop trees/ha for crown release. Consider pruning lower branches to a height of 5.1 m at the same time. (Here and for any subsequent pruning, retain at least 33% of the live crown.) The existence of natural patchiness or the use of approaches that focus on crop trees often allow the development of stand patterns that do not necessarily require the removal of full rows.
Final harvest	The age at the final harvest (rotation) will depend on site and stand quality and on the regeneration status in the understory. Establish high-quality hardwoods or white pine in the understory to prevent the arrival of invasive species or control existing invasive species before the final regeneration harvest. White pine can be regenerated under its own shade through shelterwood management. It can also be regenerated in mixedwoods with some hardwood species (e.g., red oak, white oak, or bur oak, or black oak in the southwest).
Other considerations	
Maximizing growth and quality	Regular thinnings encourage consistent, uniform growth, reduce competition stress, and allow early removal of poor-quality trees, including trees that would normally die if they were not removed. Young white pine with heavy crowns and branching are susceptible to breakage from ice accumulation. To maintain stand density within the range that provides the best growth, use the basal area–based stocking targets (Table 4.2) for application in plantations with an average DBH ≤25 cm. Based on field experience, the white pine DMD presented by Smith and Woods (1997) is only accurate and effective for stands >25 cm in DBH, but this has not been validated, so should be used with caution.
Critical pest management issues	White pine blister rust White pine weevil Browsing damage by deer and rodents
References (for further reading)	Hodge et al. (1990) Smith and Woods (1997) Burgess et al. (2011)

White spruce	
Establishment phase	
Recommended spacing: 2.4 m × 2.1 m = 1984 stems/ha Minimum between-row spacing: 2.1 m (e.g., 2.1 m × 1.8 m) A crop plan can help determine the best initial spacing. White spruce performs best in pure plantings. Limit other species in mixtures to 1 to 5% of the stems, established as small groups of 10 to 25 trees to provide species diversity and future regeneration.	
Management phase	
Initial thinning	White spruce plantations typically exhibit wide variation in diameter and height due to high genetic variation. The first thinning can typically be delayed to 35 to 40 years after planting. The first thinning should generally remove a single row, with no selection between rows. Initial row removal will typically be every third row. With tight spacing (e.g., 1.8 m × 1.8m), two rows out of every six should be removed. Retain a residual basal area of at least 26 m²/ha. Average DBH of the marked trees at the first thinning should be 18 to 20 cm (≥70% of stems ≥14 cm DBH). To be merchantable, a tree must have 8 m of straight bole to a 12 cm top (to provide three 2.54-m logs). White spruce has shallow roots and is prone to windthrow. Define a clear objective for natural or artificial regeneration at the time of the second thinning, as natural regeneration of hardwoods will tend to become established and develop from this point forward.
Subsequent thinnings	As long as the stand remains healthy and the live-crown ratio exceeds 1/3, conduct subsequent selection thinnings from below based on a DMD diagram at intervals of 15 to 20 years, with the goal of reducing overall stand basal area by 25 to 33%. For low-quality, off-site white spruce plantations, the second entry may be a harvest cut 20 to 30 years after the initial row thinning. Maintain crop trees of other species within and adjacent to the plantation to meet wildlife, regeneration, and species diversity considerations.
Final harvest	Thinning is necessary to accelerate succession to a new stand composition and structure. Identifying and preserving crop trees and moving from thinning towards a shelterwood management system (discussed in Section 4.6.3) will provide the greatest opportunities to establish regeneration from existing white spruce and available natural seed sources.

Other considerations	
Maximizing growth and quality	To maximize growth, maintain a live-crown ratio ≥1/3 (particularly after any pruning). Thin from below. Early pruning of lower branches will help to provide access to the plantation (Fig. 4.14). To improve the lumber value, identify between 250 and 300 crop trees/ha, and prune their lower branches to height of 5.1 m when DBH is between 15 and 20 cm. Stiff horizontal branches make stands difficult and hazardous to mark. Though you can manage the stand over time as a multi-generation white spruce stand, you may need to plant seedlings in the understory to get good stocking of white spruce. Site productivity dramatically alters the success of thinning. The most productive sites respond better to thinning. Poor-quality sites may need to be converted to other species by clearcutting. A number of studies, including the Ontario provenance trials (Teich et al 1975; Morganstern and Copis 1999), indicate that white spruce has high genetic variability. Select provenances with the desired phenotypes for your management goals (e.g., branch size, branch retention).
Critical pest management issues	Tomentosus root rot
References (for further reading)	Nienstaedt and Teich (1972) Teich et al. (1975) Stiell (1980) Rauscher (1984) Morganstern and Copis (1999) Saunders and Puettmann (2000) Penner (2001)

Figure 4.14: Left: A 40-year-old white spruce plantation before and Right: after the initial access thinning. Note the limbiness of the trees, which can make tree marking operations difficult and sometimes hazardous for forest workers. [Photo source: Fraser Smith Consulting]

4.4 Growth and yield

Some of Ontario's longest continuously running studies of forest growth come from the work conducted by Al Beckwith of OMNR. Many of the permanent sample plots established under this program were in pure coniferous plantations, often of red pine but also including other species such as white pine. Data continues to be collected and analyzed (Woods and Penner 2000).

The choice of species depends on many factors, including the site (mainly the soils and climate) and the objectives of forest management. We discussed how to choose appropriate species for a site in Section 2.2. The growth rates for a given species will vary among sites (Table 4.5). On productive sites, several species may grow well; on poor sites, even the most suitable species may grow poorly. Thus, landowners may want to select species with a higher growth rate or accept species that will not grow well, but that will survive and protect the site. Growth rates and fibre production are strongly correlated with the site index, and extensive fieldwork was conducted in southern Ontario in an effort to link the site index to soil properties for each species. Taylor and Jones (1986a,b) measured trees across a range of soil textures and depths to mottling (an indicator of drainage) to determine the site index range. Appendix 1 summarizes their results. Figure 4.15 illustrates how to interpret the data.

Table 4.5: Sample growth rates from a range of plantations in southern Ontario. Generally, conifers had higher growth rates and were more suitable for afforestation. However, hardwood species may provide higher value for wildlife, biodiversity, and specialty products such as veneer. Abbreviations: GTV, gross total volume; MAI, mean annual increment; SI, site index. Numbers in brackets for some species are the range.

Forest cover type	Region	SI (m) at a total age of 50 years	MAI (m^3 GTV/ha/yr)	Age (years)	Comment *N* = number of plantations	Source
Red pine plantations	6E	16 – 26	7.6 – 14.6	50	unthinned	Beckwith and Roebbelen (1983)
Red pine plantations	6E	18.3 – 23.5	8.4 – 14.0	50		Love and Williams (1968)
White spruce plantations	6E	15.8 – 19.5	6.6 – 10.8	50		Love and Williams (1968)

Forest cover type	**Region**	**SI (m) at a total age of 50 years**	**MAI (m^3 GTV/ha/yr)**	**Age (years)**	**Comment *N* = number of plantations**	**Source**
Hybrid poplar	6E		12.5 – 12.8	16	Wide spacing (4.9 × 4.9 m and 5.5 × 5.5 m)	Harvey Anderson, OMNR, Fast Growing Forests Expert Workshop, 21 January 2004
Early-successional hardwoods	6E		4.0			OMNR (2000)
Lowland or swamp hardwoods	6E		5.0 – 5.9			OMNR (2000)
Upland oaks	6E		5.9 – 6.3			OMNR (2000)
Upland oaks	7E		4.9			OMNR (2000)
Upland shade-tolerant hardwoods	6E		2.9 – 4.4			OMNR (2000)
Upland shade-tolerant hardwoods	7E		0.3 – 6.1			OMNR (2000)
White ash	7E	0.2 (0.1 - 0.2)	2.4 (0.4 - 4.3)	33.7 (30 - 36)	*N* = 6, includes experiments ≥30 years old	McKenney et al. (2008)
Basswood	7E		4.3 (2.1 - 7.1)	35.6 (35 - 36.2)	*N* = 5, includes experiments ≥30 years old	McKenney et al. (2008)
Hard (sugar) maple	7E	0.2 (0.2 - 0.2)	3 (2.9 - 3.2)	30.7 (30 - 31)	*N* = 3, includes experiments ≥30 years old	McKenney et al. (2008)
Soft (red and silver) maple	7E		2.2	30	*N* = 1, includes experiments ≥30 years old	McKenney et al. (2008)

Forest cover type	Region	SI (m) at a total age of 50 years	MAI (m^3 GTV/ha/yr)	Age (years)	Comment *N* = number of plantations	Source
Red oak	7E	0.2 (0.2 - 0.2)	6.4 (4 - 9.9)	35.3 (35 - 36)	*N* = 3, includes experiments ≥30 years old	McKenney et al. (2008)
Black walnut	7E	13.2 (0.3 - 26.6)	3.2 (0.8 - 10.6)	33.5 (30 - 36)	*N* = 12, includes experiments ≥30 years old	McKenney et al. (2008)

Species	Depth to mottles > 150 cm	
European larch	*(Poor) (19.0 - 20.9)*	Italics indicate subjective extrapolation of site class, but with no data collected
Red pine	**Mod (19.0 - 20.9)/Poor r (17.0 - 18.9)**	"r" indicates site class when a root-restricting layer occurs within the top 60 cm of the soil (e.g., a sandy soil overlying a clay); Mod = moderate
White pine	**V Poor (< 19.9)**	white cells with data indicate poor or very poor productivity
Norway spruce	**Mod*c (23.0 - 24.9)**	green cells indicate moderate to very good productivity "c" indicates the site class when free carbonates are within the top 50 cm of the soil; asterisks indicate insufficient data for proper site class prediction
Scots pine	n.a.	n.a. indicates no data
White spruce	**Good* (24.0 - 25.9)/V Poor*c (< 19.9)**	

Figure 4.15: An example of productivity data from Appendix1. This example shows the predicted productivity of coniferous species as a function of soil texture, depth to mottles (a proxy for drainage), and site region. It has been modified slightly to illustrate the formatting conventions. The productivity rating is followed, in brackets, by the range of site index values. This example is for gravelly sandy soils with a depth to mottles > 150 cm in site region 6E. Adapted from Taylor and Jones (1986b).

Figure 4.15 shows an example of the productivity ratings for gravelly sandy soils with a depth to mottles > 150 cm in site region 6E. White spruce has a good productivity rating but the "*" indicates that there is limited data and the "c" indicates that the productivity is very poor if free carbonates are present within the top 50 cm of the soil. There are no data for European larch. Both red pine and Norway spruce have moderate productivity, but the range of site index values associated with this rating are higher for Norway spruce, indicating better height growth and likely more volume.

One note of caution: Before you select a species based on the data in Appendix 1, review Table 2.3 to determine whether any species–site interactions might rule out that species.

4.5 Improving forest health and value

Although stand tending can improve the health of a forest, it will have the greatest impact when your goals for a plantation are to produce a monetary return on the investment. We will therefore focus on economic issues (pruning, thinning, and plantation renewal) in this section, but without neglecting other issues (invasive species, recreational uses, and biodiversity). Pruning is a good investment when the goal is to provide knot-free timber. Regular thinning is generally a good investment because it will provide more consistent and uniform growth, reduce competition, and allow removal and utilization of poor-quality trees and those that would normally die, thereby adding this volume to the harvest.

4.5.1 Pruning

Pruning is the removal of live or dead branches from standing trees to produce knot-free sawlogs, while maintaining at least one-third of the tree's height in live branches to sustain growth. To avoid damaging the tree, ensure that all pruning tools are sharp and well maintained. To accelerate healing of the wound, we recommend a technique in which the cut is as close as possible to the bark (without damaging the bark) and perpendicular to the branch to ensure that water runs off of the exposed wood. No paint or other substance should be applied over the wound. The selection and pruning of crop trees can add significant value to plantations, particularly on the most productive sites, and where active management practices such as regular thinning are being carried out. Before you identify and select crop trees, we recommend that you define the thinning regime and pattern, since this will reduce the risk of removing crop trees in a future thinning. A crop tree should be a dominant or co-dominant tree, with a well-developed leader and a full, round, finely branched crown, and it should have a straight, injury-free stem. The ultimate value of pruning will depend on the amount of usable, clear wood the tree produces. The larger the diameter of the tree when it is pruned, the longer it will take to produce the desired amount of clear wood.

Red pine

Although red pine is relatively good at self-pruning at all ages, there may be economic benefits to pruning selected crop trees to produce clear, knot-free lumber. Between 250 and 350 crop trees/ha should be pruned when the plantation's average tree diameter is between 10 and 15 cm. The trees may be 15 to 20 years old at this time. Pruning can be conducted in conjunction with thinning. At the first thinning, prune the tree's branches to a height of about 3.0 m. Do not remove branches at heights greater than half of the total tree height at this growth stage. At the second thinning, more branches can be removed to bring the total branch-free height to 5.1 m. If you plan to grow high-quality utility poles, prune the branches to a height of 7.4 m. Pruning can be done at any time of the year, and if properly done, will not harm the tree. However, careless pruning can injure the tree and reduce its health. Pruning is easily done by forest landowners who have little to no forest management experience once they have been trained on proper techniques.

White pine

White pine is relatively good at self-pruning, but would still benefit from a pruning program that is designed to remove lateral branches to a height of 5.1 m, to remove the leader if it has been deformed by the white pine weevil, and to reduce the risk of infection by white pine blister rust. If your goal is to produce timber, you can use a pruning regime similar to that described for red pine earlier in this section. However, white pine can be more difficult to prune than red pine because it has more branches per whorl, and the branches are heavier and larger at the base. It also produces more pitch, which can gum-up pruning equipment, and secondary whorls are common. Pruning is best done in the winter because of the large amount of pitch that flows from open wounds during the growing season.

- **Pruning to correct white pine weevil damage:** White pine planted under old-field conditions is particularly susceptible to damage by the weevil, as the larvae prefer to feed in the leader produced in the preceding year, where they effectively girdle the stem. The leader will wither to produce a characteristic "shepherd's crook". The adults emerge from the stem in summer or early fall and then hibernate for the winter (Fig 4.16). Dry sites are ideal for overwintering of the adults. Trees between 2 and 6 m in height are most susceptible. Jack pine and Norway spruce can also be affected. Clipping and burning the infected leaders can be an effective control measure, but should be done before the adults emerge. Select one or two of the healthiest lateral branches to become the new leader, and remove all other lateral branches at that location**.**
- **Pruning to correct white pine blister rust damage:** White pine blister rust is a non-native fungus that enters the stem through the needles and attacks the living bark and cambium. It can cause loss of vigour and even heavy mortality in young, developing stands. Trees growing on wetter sites such as valleys, lower slopes, north-facing slopes, and areas adjacent to open water are most susceptible. To reduce the potential for infection, the lower branches of all trees shorter than 2.0 m can be pruned, to a maximum of one-third of the total tree height.

Figure 4.16: (Left) The damage that can be caused by white pine weevil if no corrective pruning is undertaken. (Right) A 25-year-old plantation that was judiciously pruned by a landowner to correct weevil damage and reduce white pine blister rust damage. [Photo source: Eric Boysen, NewLeaf Forest Services]

White spruce and Norway spruce

White spruce and Norway spruce are very poor self-pruners, and tend to retain their lower branches even after the foliage has died due to shading from adjacent trees. This characteristic makes access into young stands to mark trees for first thinnings difficult, and sometimes even dangerous, for workers. Between 250 and 350 crop trees/ha should be pruned to a height of 5.1 m, to a maximum of two-thirds of the tree's height, when the plantation's average tree diameter is between 15 and 20 cm. The trees may be 20 years old at this time.

Hardwoods

Pruning of hardwoods has two main goals: corrective pruning (elimination of all but one leader) to promote the growth of one straight central stem, and side-pruning to promote the growth of a clear, knot-free stem.

Begin corrective pruning while the tree is still small (<2 m), and continue until a straight stem of at least 5.1 m is achieved. This operation should usually focus on retaining only one terminal shoot, and removing all others. Side pruning should initially focus on removing lower limbs that may interfere with tending operations, and should be done before the limbs are greater than 4 to 5 cm in diameter to promote healing of the wounds. Remove dead or dying limbs during any pruning operation; these are easiest to identify during the growing season, since the wilted or dead leaves or a lack of leaves will be obvious. Pruning of most hardwoods should be done when the hardwood trees are dormant (late winter is best). Exceptions include maples, birches, and elms, which should only be pruned in mid-summer, when they are actively growing; pruning at other times risks excessive loss of the sap that is required for healthy crowns, and the wound may not heal quickly. When you prune younger trees, retain about half of the total height with leaf-bearing branches. You can gradually reduce this proportion to one-third as the tree grows large enough to begin producing sawlogs. As soon as you can identify crop trees, stop pruning the other trees and concentrate on pruning the trees most likely to provide a good return on investment (Dixon 2003, Panill 2005, AAFC 2015).

Pruning is most likely to be required at wider spacing in hardwood-only plantations or in agroforestry systems. Hardwoods planted as companion species in a predominantly coniferous plantation may not require as much attention. In ecological plantations, the trees can be left unpruned unless it’s necessary to increase their height growth or protect understory vegetation that would be excessively shaded by the hardwoods.

4.5.2 Renewing coniferous plantations

Although most pine and spruce plantations established on former agricultural lands will eventually transition, either intentionally or not, into a more diverse mix that includes native hardwood species, you may want to consider re-establishment of another rotation of coniferous species at the same site. Forest managers from the Simcoe County Forest and the Larose Forest have experience with this type of operation, and have offered the following advice:

Site considerations

- Avoid sites where natural regeneration of desirable species is lacking or where the understory is dominated by undesirable or invasive species.
- Avoid sites that promote the growth of hardwood competition.

Broader landscape objectives

Although coniferous plantations are common today, changing land-use patterns and economic considerations (e.g., competing land uses such as agriculture or residential development) will cause them to become rarer over time. Thus, objectives for new plantations could evolve to include:

- maintaining or increasing the proportion of a particular species within the landscape to increase biodiversity
- restoring pre-settlement forest types (e.g., white pine, red pine where it is under-represented compared to pre-settlement conditions)
- habitat objectives such as retaining important coniferous patches within the broader landscape to meet specific habitat needs; for example, Kirtland's warbler, a globally rare migratory bird, requires large areas (100 ha and larger) of young, dense jack pine forest that would have historically been common after wildfires

Future wood supply and revenue expectations

- The timber volumes and associated revenues from productive red pine plantations are unlikely to be replaced by revenues from mixed hardwood stands.
- The local forest industry relies on pine and spruce because they can profitably market the range of products produced from coniferous plantations.

Plantation renewal

- Plantations that have reached or are approaching the end of the rotation can be renewed if the site can support the same species or another conifer (e.g., red pine followed by red pine or white pine).
- Plantations that have no economic future (e.g., due to severe ice or snow damage in red pine, due to heavy weevil damage in white pine) can be renewed or replaced.
- Poorly stocked plantations can be renewed on sites that are well-suited to conifers after heavy ice storm damage or windthrow, in mixed plantations where one species disappeared (e.g., 70% white spruce, 30% white pine), on sites with an overstory of non-native trees (e.g., Scots pine, Norway spruce), and on sites with a non-native understory (e.g., European buckthorn).
- Plantations with health issues that will not affect the newly planted stock (e.g., planting white pine under a red pine plantation affected by diseases such as Heterobasidion root rot.

Treatment options for existing plantations

- selection thinning in red pine plantations to grow more shade tolerant species such as white pine, hemlock, or red spruce
- transition to a uniform shelterwood system to grow white pine, white spruce, red spruce, or hemlock
- transition to a group shelterwood or group selection system to grow red pine, white pine, white spruce, or red spruce
- clearcut, or clearcut with retention of seed trees, to regenerate red pine or tamarack
- clearcut for white spruce

Site preparation and tending

Because large amounts of slash and woody debris (limbs and tops) are likely to accumulate on the site, site preparation and tending operations may take longer and be costlier than those described in Chapter 3. A typical operational sequence could be:

- **Year 1:** mechanical site preparation to reduce slash and mix duff with the mineral soil; where feasible, consider using a prescribed burn to reduce slash loads
- **Year 2:** chemical site preparation to manage herbaceous and woody competition
- **Year 3:** tree planting
- **Years 5 to 10:** manual tending, manual plus chemical tending, or chemical tending
- **Subsequent years:** if the stand is free to grow, focus on pruning and thinning

Cautionary notes

- Focus on sites where you are likely to succeed. You must commit to the afforestation process, so site preparation and tending are a must, especially on productive sites where competition will be high.
- Avoid sites that are susceptible to diseases or insect outbreaks. (See Section 5 for details.)
- Avoid renewing coniferous plantations in areas with high deer populations unless you plant species they will not eat (e.g., red pine, white spruce).
- Avoid sites with soil and drainage issues to reduce the risk of overstory mortality, blowdown, difficult site preparation, and poor survival of the planted stock.
- If you will perform partial cutting rather than clearcutting, time the release cut to avoid suppressing the growth of the planted stock.
- Try to identify and plan around operational constraints. For example, planting will be more difficult after clearcutting due to the heavy accumulation of debris such as tree tops, which may require site preparation (e.g., windrowing, prescribed burning) before replanting becomes possible.
- Consider the potential impacts of climate change. Some species that are currently appropriate may no longer be appropriate in 50 years under a warmer and drier climate, requiring the use of seeds from a different seed zone or different species choices.

4.5.3 Invasive species

Invasive species are plants, animals, or microorganisms that have been introduced outside of their native range. As a result, they frequently lack the predators and pathogens that kept their population levels in balance within their native range. Some invasive animals or microorganisms can affect afforested stands by directly infecting or feeding on the planted stock. Most often, invasive plant species pose a threat to afforestation efforts and established plantation areas because they may out-compete native species, thereby creating different stand dynamics than what you predicted when you designed your afforestation plan.

Currently, the primary invasive threats to afforestation encountered by Ontario forest managers are plants, particularly the dog-strangling vine, garlic mustard, and European buckthorn. Dog-strangling vine and garlic mustard are easily spread by people and equipment through the transport of seeds in contaminated soil and mud, and can be especially difficult and prohibitively expensive to control once they become well-established.

The dog-strangling vine (Fig. 4.17) is native to the Ukraine and surrounding areas of Europe and Asia. It thrives in calcareous soils, where it forms dense mats of vegetation that cover the forest floor. The species is closely related to the native milkweed, and has similar airborne seeds that travel readily on the wind to colonize new sites. The species is an aggressive invader that becomes well-established on both disturbed and undisturbed sites under a wide range of shade conditions. The vine can threaten afforestation efforts at the stand initiation phase (planting and tending), as well as through to stand maturity and succession to a new forest type. Dense patches can suppress native tree seedlings, young saplings, and native understory plants due to the heavy shade that the plants produce. In plantations, the vine thrives under the relatively heavy shade and open understorey, thereby suppressing seedling establishment of native hardwoods and conifers. If the invasion is allowed to continue, regeneration will be compromised, thus posing a threat to a planned stand transition. Anderson (2012a) provides more details on this species.

Figure 4.17: An example of a red pine site in E.T. Seaton Park where the dog-strangling vine has fully occupied the understory. [Photo source: Stephen Smith, Urban Forest Associates]

Garlic mustard is an adaptable, aggressive, biennial herbaceous plant that is native to Europe. The species grows in a wide range of habitats and spreads quickly along disturbed pathways such as roadsides, forest access routes, and recreation trails. The main pathway for long-distance seed spread is through humans, pets, and wildlife that inadvertently carry seeds in mud and organic debris. Garlic mustard forms dense monocultures that displace native species and inhibit forest growth through the release of allelopathic chemicals from its root system. These chemicals inhibit the growth of native plants, including common afforestation tree species. Furthermore, the allelopathic chemicals seriously affect the growth and regeneration of mycorrhizal fungi, which are critical to the ability of vascular plants (such as afforested trees) to take up soil nutrients for growth. This effect can last for years after the garlic mustard has been removed, thereby creating a serious threat to the success of afforestation. Anderson (2012b) provides management advice on controlling this species.

European (common) buckthorn is a native of Europe and thrives under a wide range of forest conditions in Ontario. It tolerates both drought and shade, and is readily spread by birds that deposit its seeds in their feces. Buckthorn is a prolific leaf and seed producer that expands its leaves well before native species in the spring, and drops its leaves well after the leaves of native deciduous species have dropped in the fall. Once established, buckthorn forms dense thickets in the understorey that inhibit the growth of desired successional species, often forming a buckthorn monoculture. Buckthorn is more commonly found in afforestation stands that have received several thinnings, and will persist well into the stand transition period if not controlled. Case Study #7 provides a thorough description of controlling understory buckthorn. Anderson (2012c) also provides more information on this subject.

Regardless of which species is of concern, you can take certain measures to mitigate the problem during your afforestation planning and subsequent ongoing stand management. The most important step is to prevent the spread of invasive species in the first place. Often, the primary vector for their spread is mud and organic matter containing seeds that collects on boots, clothing, and equipment. By carefully cleaning these items before you arrive at a site, it may be possible to prevent any new introductions of invasive species. This will save considerable resources by eliminating or minimizing future eradication efforts, while also assisting with the overall success of the afforestation effort. Cleaning will be most effective if you identify the most common locations where mud and organic matter are likely to accumulate, such as vehicle undersides, radiators, spare tires, footwells, and bumpers. When cleaning is required, focus on containing the equipment within an appropriate area where contamination and seed spread is not possible (or will be limited), such as an enclosed maintenance garage. Furthermore, the cleaning site should be free of mud, should be covered by gravel or a paved surface, or (least desirable) should be in a well-maintained grassy area, where the grass can prevent the invader from becoming established. The site should be gently sloping to guide drainage away from the equipment, and at least 30 m from any body of water, vegetated area, potential habitat, or vector that can spread the materials removed by the cleaning. See Appendix 4 for the Clean Equipment Protocol developed by the Ontario Invasive Plant Council (https://www.ontarioinvasiveplants.ca/).

When you develop your afforestation and forest management plan, include a management strategy for invasive species. Many aspects of this strategy can be easily incorporated into existing practices such as stand monitoring and tending, and control can be scheduled at the same time as thinning operations. Early detection through regular monitoring is particularly important. Early detection will let you remove the invasive species before removal becomes prohibitively labour-intensive and expensive. Use any monitoring protocols and partnerships that have been established by local conservation agencies and citizen science organizations. Once populations of an invasive species have been detected, they should be monitored, and the results of any treatment efforts should be recorded to provide evidence of success over time. Several monitoring and mapping resources exist in Ontario, such as EDDMapS (www.eddmaps.org/ontario). Once you have identified a problem, take particular care to prevent further spread of these populations, and increase your monitoring to detect new invasion sites.

In your plan is to manage invasive plants within an afforestation area, use the principles of integrated pest management (IPM). IPM is a strategy based on using a range of mechanical, biological, physical, cultural, behavioral, and chemical control techniques to suppress pests and invasive species at every stage of their life cycle. This results in a more effective, economical, and environmentally sound solution. IPM involves planning and managing the whole ecosystem to prevent organisms from damaging overall ecosystem health. This requires you to identify potential pest problems through careful monitoring, to record population levels and locations, and to establish thresholds for when it's necessary to reduce pest populations to acceptable levels. Due to the size and complexity of many sites that are undergoing afforestation, it's often necessary to employ chemical control as the primary means of controlling invasive species that have become established in plantations. However, you should only consider pesticide use when alternatives are unsuitable, unavailable, or ineffective in light of the risks and the environmental and social benefits. Chapter 3 provides a comprehensive description of chemical treatments.

Before applying IPM that includes chemical controls, familiarize yourself with the relevant legislation. The Ontario *Pesticides Act* (https://www.ontario.ca/laws/statute/90p11) and *Regulation 63/09* (https://www.ontario.ca/laws/regulation/090063) regulate the sale, use, licensing, transportation, storage, and disposal of pesticides in Ontario. These laws are administered by the Ministry of Environment, Conservation and Parks. The *Invasive Species Act* (https://www.ontario.ca/laws/statute/s15022) came into effect in 2016, and provides the power to develop regulations that define invasive species, classify them as either prohibited or restricted, and prescribe measures to resolve any problems. The *Invasive Species Act* is administered by the Ontario Ministry of Natural Resources and Forestry, and works in conjunction with previous pieces of legislation on invasive plants such as the *Weed Control Act* (https://www.ontario.ca/laws/statute/90w05), which is primarily aimed at agricultural operations.

4.5.4 Recreational uses

If you will be establishing a plantation on public land, you will need to account for the possibility of public use of the land. (This may also be a concern on private land if you cannot control access to the site or if the landowner has traditionally allowed such use.) Whether or not recreation is a planned objective for an afforestation area, we recommend that you consider possible recreational uses from plantation establishment to maturity, including during management activities. As the forest begins to mature, the prevalence and frequency of recreational use often grows, including activities such as snowmobiling, hiking, fishing, skiing, biking, ATV riding, and horseback riding. Considerations for recreational activities include public safety and liability issues, trail layout and design, and harvest planning and management.

In a 2016 survey of 13 Ontario community forest managers (Fraser Smith Consulting, personal communication), all respondents reported that the community forests they manage had either a specific recreation management budget or staff who were partly or wholly responsible for managing recreational activities in the forest. Most of these forests were established through afforestation to rehabilitate degraded lands rather than to provide recreational opportunities. The survey also found that all of the managers accepted that recreation was an inevitable aspect of multi-use forest management, and many made active use of a dedicated group of volunteers that arose in response to the open recreation policies. In addition, all but one of the managers reported that there were active recreation groups or organizations associated exclusively with the forest, but only four received any direct revenues from recreation activities. Of the nine community forests that received direct revenues from recreation, all but one received that revenue through user agreements and memorandums of understanding with established groups. The primary reason given for avoiding user fees or recreation revenues was concern over the liability associated with permitting those activities.

Whether recreation in afforested areas occurs on private land or in community forests, the same legal considerations apply, and you must familiarize yourself with your responsibilities. On private forest land, the primary legislation governing recreational use are the 1990 *Trespass to Property Act*, R.S.O. 1990 (https://www.ontario.ca/laws/statute/90t21) and the 1990 *Occupiers' Liability Act*, R.S.O. 1990 c O.2 (https://www.ontario.ca/laws/statute/90o02). The *Trespass to Property Act* largely deals with illegal entry into private and public property. The Act attempts to codify what was formerly recognized by the Common Law, and lays out mechanisms for enforcement and penalties. The *Occupiers' Liability Act* concerns the duty of care owed to people who visit or trespass by those who occupy real property, through ownership or lease. It primarily addresses the inherent liability that can arise from accidents or injuries caused by the condition of a property.

Management actions such as working through established trail user groups, following trail layout and design standards, and harvest planning and management should explicitly deal with recreation concerns to mitigate your liability while providing management benefits to the forest manager.

Allowing access through established user groups such as snowmobile, off-road vehicle, or trail rider groups can benefit the forest manager. For example, these groups often provide an opportunity to share trail maintenance duties, thereby sharing responsibility for the activity and the quality of the maintenance, as well as gaining access to equipment and experienced personnel who can help maintain the trail network on private land.

The initial layout and design of afforestation areas and the associated road and trail network will have a pronounced effect on future options for recreational and forestry use. Whether or not future recreational use is planned, it would be prudent to plan and design a road and trail network with recreation in mind. This will ensure that if recreation becomes a component of the forest's management, it can be accommodated in a manner that fits well with other planned forest operations such as thinning, tending, and harvesting. Although it is already an established practice to locate trails away from sensitive or erosion-prone areas, future recreational use requires additional considerations. One common approach is to plan tending and extraction trails as a permanent part of the transportation system so they can be used repeatedly for management activities as well as for recreation. Proactive planning to form a trail network rather than simply adopting the more traditional herringbone or branching trail patterns, which create many dead ends, will reduce the likelihood that recreational users will create new trails while increasing options for redirecting them away from tending and harvesting operations. Further consideration of topography, including access to scenic views, the grade (slope) of the trails, trail width, and the turning radius for motorized vehicles should all be considered in your plans. Organizations such as the National Trails Training Partnership (http://www.americantrails.org/nttp/default.htm) and provincial (http://www.ontariotrails.on.ca/), national, and international trail councils can provide information and resources.

When you plan management operations, try to separate recreational users from active tending or harvest operations. With heavy equipment, operators cannot see recreational users, who may be unfamiliar with logging equipment and the need to keep a safe distance from it. Public notices, harvest timing during the work week (when recreational users will be less common), temporary trail closures, and effective signage are integral components of your site management.

Notifying the public of planned management activities is essential in active recreational use areas. Notices should provide a map, a timeframe, and contact details for those who want more information. Several community forests in Ontario also use such notices as a means of outreach and public education about forestry activities to illustrate the "what, why, and how" of sustainable forest management. This can be especially important for forests in southern Ontario, where forest users are less likely to be familiar with forest management activities.

When planning harvest operations, you can use harvest timing and trail closures to limit interactions between workers and recreational users. The fall and winter are good choices for harvest operations, but on dry sites such as pine plantations, spring and summer operations may be better options in areas with heavy winter use for cross-country skiing, snowmobiling, and snowshoeing. Whenever feasible, involving established recreational groups in harvest planning can limit potentially dangerous interactions with recreational users and avoid time-consuming communication work during operations.

Temporary trail closures are the most common means of separating recreational users from harvest operations. Most often, visitors use the same trails created for and used by forestry equipment. With proper planning, construction, and layout, these trails can accommodate multiple uses with minimal degradation. Remind equipment operators of the locations of trails that are not being used for forestry operations, such as smaller "single-track" trails, to avoid excessive damage to or debris accumulation on these trails. The trails can be difficult or impossible for operators to discern, especially when they are working in thick regeneration. Use flagging tape or specific stem markings to help them avoid these trails. This will reduce subsequent maintenance requirements and help to meet the needs of recreational users.

Figure 4.18: Signs are an effective way to warn other forest users about management activities. It's important to remove these signs once operations are completed, or they may lose their effectiveness. [Photo source: Fraser Smith Consulting]

Signage should be prominent and placed well ahead of the area under management, and should recommend alternative routes to trail users. You can use colours such as red, orange, and yellow or readily recognizable symbols such as a red octagon (i.e., a stop sign) or other traffic signs (see Figure 4.18 for an example of signage in an active harvest area). Furthermore, you should use reflective materials in areas where night use can be expected. Organizations such as Parks Canada (https://www.pc.gc.ca/en/index) have established manuals that can help you design effective signage.

4.5.5 Biodiversity

Biodiversity—the variety of life on earth—represents Ontario's rich natural bounty of plant and animal species, and the habitats that sustain them. OBC (2011) reminds us that Ontario's ecosystems provide us with a healthy environment, clean air, productive soils, food, and clean water. This natural infrastructure supports many industries, and provides jobs in the forestry, agriculture, recreation, and tourism sectors. Afforestation projects can sustain or create a variety of ecosystem services during their life, including providing food, raw materials, and water supplies; regulating the climate and preventing floods; supporting water and carbon cycles, soil formation, and habitat for plants and animals; and providing social and cultural benefits to landowners and their communities. Therefore, you should carefully consider the goals of OBC (2011) during all phases of an afforestation project, including the need "to protect, restore and recover Ontario's genetic, species and ecosystem diversity and related ecosystem impacts and functions" and to "use Ontario's biological assets sustainably".

The Ontario Biodiversity Strategy (http://ontariobiodiversitycouncil.ca/ontarios-strategy/) outlines the following management principles for the conservation and sustainable use of biodiversity in the context of afforestation projects:

- Use an ecosystem approach for integrated management of land, water, and living resources.
- Maintain biodiversity as the first priority in conservation initiatives, because this is more cost-effective and less risky than being forced to recover or restore biodiversity.
- Use an adaptive management approach, supported by long-term monitoring and reporting.

As outlined in Chapter 1, one of the most important lessons from previous afforestation efforts was the recognition of the constraints imposed by soils and sites, and that before one can restore the forest (and biodiversity) to a more natural state after the large-scale disturbances that have occurred for centuries, one must first restore the site.

You can consider many approaches, techniques, and tactics throughout the life of a forest to incorporate biodiversity conservation goals and principles into a planting project. We encourage you to consult OMNR (2010b) for a more comprehensive discussion of biodiversity values and forest management options and approaches to support biodiversity. In the rest of this section, we will discuss some of the basics.

Season of operations

- Site preparation and planting should be done during the growing season. Avoid mowing or brush-cutting from late spring to early summer, as this is the fledging period for many birds, and the season for rearing offspring of bats and mammals. Some of these animals may be species-at-risk and require special considerations or government authorizations.
- Thinning is best done in the late summer, fall, and winter from the perspective of tree health (the bark, roots, and site are less likely to be damaged by equipment).
- Some birds and mammals will use a plantation year-round. Conduct an assessment before thinning and other operations to identify the species most likely to be adversely affected so you can develop a mitigation strategy (e.g., performing the operation when it will produce the lowest impacts).

Species selection

- Match the species to be planted to the local soil and site characteristics. (Section 2.2 provides details of the factors to consider. However, if your goal is to protect or promote certain animal species, choose tree species that meet their needs.)
- Plant stock grown from local seed sources. (See Section 2.3.1 for details.)
- Where practical, consider planting a mix of native species, including native herbaceous species (e.g., using wildflowers as a cover crop, as described in Section 3.1.3).

Coarse woody debris

As a plantation matures, natural mortality and damage will create increasing numbers of cavity trees and dead trees, and increasing quantities of downed woody debris. This material serves important roles in creating habitats for a range of organisms. Thus:

- Protect and promote these micro-habitats.
- Allow mature pine to persist beyond the final harvest to become super-canopy trees (trees that extend above the canopy, generally >60 cm in DBH). When such trees are available, OMNR (2010b) recommends retaining at least one such tree per 4 ha.
- About a quarter of all birds and mammals use holes or cavities in trees for nesting, denning, roosting, resting, feeding, or hibernating (Naylor 1998). OMNR (2010b) recommends retaining at least 10 cavity trees per hectare once the plantation approaches maturity.

Bird habitat

Stick nests are platforms that large birds create from sticks and twigs and that they use for nesting. Many are used for many years by the birds that built them. Once they have been abandoned by their builders, they may still be used by other species that do not build their own nests (OMNR 2004). Raptors commonly build such nests, and are beneficial for forests because they prey upon the mice and voles that cause damage to plantations. Thus, you should protect and preserve nest trees wherever possible:

- When you discover a stick nest, ask someone with appropriate knowledge (e.g., an ornithologist or experienced bird-watcher) to confirm the identity and status of the nest.
- Depending on the tree species, age, and location of the plantation, the stick nest may belong to any number of birds.
- Birds that most commonly build such nests in a plantation setting include Cooper's hawk, the northern goshawk (Fig. 4.19), the broad-winged hawk, red-tailed hawk, and sharp-shinned hawk. Crows and ravens are also common. Szuba and Naylor (1998) provide more detailed information.
- Leaving perching trees (i.e., trees with exposed, leaf-free branches) or constructing artificial perches adjacent to the planting site may encourage raptors and owls to move in and help control rodent problems.

Figure 4.19: (Left) A northern goshawk guards its nest. [Photo source: Geoff McVey, Leeds and Grenville Community Forest] (Right) Nests can be difficult to find because they are built in the upper canopy of the plantation. [Photo source: Martin Streit, OMNRF]

Mast trees

Mast trees produce large quantities of edible fruits, including both soft fruits such as cherries and hard fruits such as acorns and beech nuts. These species are sources of food for about 25% of the birds and mammals found within the Great Lakes–St Lawrence forest region (Naylor 1998). Look for ways to incorporate such species in your plantation:

- Oaks, cherry (Fig. 4.20), basswood, hickories, ironwood, walnuts, and butternut are important mast species.
- When available, try to retain a minimum of 10 mast trees per hectare. There may be special requirements under the *Endangered Species Act* regarding individual butternut trees, as this is an endangered species. Discuss these requirements with the local OMNRF office.

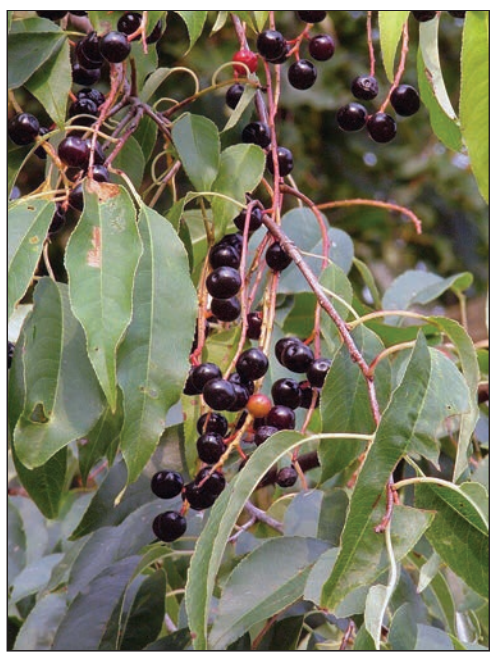


Figure 4.20: Mast is a valuable food source for many species of birds and mammals. (Left) Red oak acorns. [Photo source: John Enright, Upper Thames River Conservation Authority] (Right) Black cherry [Photo source: Mary Gartshore, private ecological consultant]

- Encourage natural regeneration of these species from adjacent hardwood stands. (See sections 2.9 and 4.6.5 for more information.)

Landscape considerations

- Maintain or create other micro-habitat features, such as vernal ponds, drainage areas (small streams and seepages), and old fencerows (Kristensen 1996).
- Consider measures to improve landscape-level connectivity between existing and new forests (OMNR 2011) and avoid operations that permanently reduce existing connectivity.
- Consider creating a larger area of interior forest habitats (i.e., habitats that are not close to the edge of the forest) by planting larger blocks or expanding existing forest areas (Riley and Mohr 1994, OMNR 2000).

4.6 Accelerating succession to a native mixed upland forest

Natural and planted coniferous stands, and conifers mixed with deciduous species, are both important components of southern Ontario's woodlands. In particular, the coniferous plantations scattered throughout the landscape have restored damaged sites and mitigated the loss of conifers associated with settlement by Europeans. Natural coniferous stands and plantations provide a variety of economic, social, and ecological values within this largely human-altered landscape. These forests provide valuable habitat for a number of common and rare birds and mammals, including blue jays, crows, nuthatches, crossbills, and red squirrels. However, the initially dense single canopy layer and often the single tree species in many of these stands can limit the diversity of habitats compared with remnant natural woodlands. Thus, afforestation plans are often designed to encourage succession over their lifespan to a more natural state, with a more complex stand architecture that provides a wider range of habitats, and to encourage the appearance of additional tree species, which increases biodiversity.

Note: Although we will focus on conifers in this section, much of the advice also applies to hardwood plantations.

4.6.1 Coniferous plantations as "nurses" of native forests

As planted conifers grow, their roots stabilize the soil and reduce soil erosion. Their fallen needles and branches gradually enrich the soil with organic matter and nutrients. They also shade the soil, creating the cool, moist forest understory conditions that other plant species need to grow. As plantations reach 25 to 50 years of age, other species begin to invade the site and grow under the shelter of the conifer "nurse crop". Black cherry seeds, for example, are often carried into a plantation by birds and then deposited in their feces. Maple seeds (samaras) are carried into plantations by the wind. Oak acorns are brought by squirrels and blue jays, who bury them to provide a source of food for the winter, then forget the seeds, allowing them to germinate. The level of natural regeneration is highest in managed plantations that are thinned regularly because thinning creates a seedbed for the invading hardwoods, while also providing the space and sunlight they need to grow. In many managed coniferous stands where natural sources of seed are abundant, a dense, diverse understory of native hardwood species often forms below the maturing conifers. This becomes quite evident after the second thinning, or as late as 70 years after establishment for unmanaged plantations. The developing understory tree layer represents the future forest that will naturally replace the maturing planted pine. This natural sequence (succession) can be accelerated through further thinning and harvesting.

In many landscapes, your goals may include managing forests to conserve or increase biodiversity or the forest's resilience against climate change. To accomplish these goals, it helps to emulate natural species compositions and structures. But that, in turn, requires you to solve two problems that will be the subject of the rest of this section: how to speed up succession, and how to deal with a shortage of suitable seed sources (Fig. 4.21).

Figure 4.21: This 40-year-old red pine plantation has been thinned three times and now provides the necessary soil and site requirements to promote an abundant and diverse mix of native species. [Photo source: Martin Streit, OMNRF]

4.6.2 Accelerating succession and increasing diversity

The main factors that limit the establishment of natural tree seedlings under coniferous plantations are:

- **Low light levels:** Once crown closure has been achieved, the forest floor is strongly shaded.
- Poor seedbeds: Thick layers of coniferous needles develop on the forest floor, and unless tree seeds are buried by blue jays or rodents, most germinate poorly. The developing roots of germinants often fail to penetrate into the underlying mineral soil, and if they cannot reach the mineral soil, they eventually desiccate and die.
- **Lack of diverse sources of native tree seeds:** Plantations often form large blocks of a single coniferous species (making it difficult for seeds of other species to reach the center of the stand) or may be isolated from more diverse stands within a mosaic of open farm fields. As a result, there may be few, if any, native seed trees nearby.
- **Low structural diversity:** Stands composed of a single species or two species often have trees that are all of the same age and height, and that are similar in diameter. The stand's vertical and horizontal structure is therefore simple and uniform, providing a limited range of habitat conditions. Only the subset of species that can grow under these conditions can survive.
- **Limited amounts of dead wood:** Due to a combination of the young age of these forests with removal of lower-quality or dying trees during thinning, there are often few standing dead trees (snags) and relatively little dead wood of various sizes and stages of decay on the forest floor. This further limits the number and type of available habitats.

Management strategies that address these limiting factors will accelerate succession and move the forests towards a more resilient and diverse condition. That is, forestry practices can create managed analogues of later stand developmental phases that will encourage natural succession.

4.6.3 Thinning and harvesting

In the mixed hardwood forests of southern Ontario, natural disturbances cause mortality of individuals or groups of trees that creates canopy openings. These openings increase the range of understory light conditions and promote the establishment of vegetation layers with diverse species compositions. These openings may be created by fire, wind, ice storms, insects, or diseases. Removing trees through thinning and harvesting provides a management tool for emulating these natural disturbances and initiating or accelerating succession. With some minor adjustments to thinning programs to maintain the growth, quality, and economic value of the planted trees, you can also accelerate succession, while simultaneously improving biodiversity and resilience. Table 4.6 describes a range of silvicultural strategies that have been tested in coniferous plantations in Ontario and shown to improve light conditions and structural and biological diversity.

Table 4.6: Plantation management practices that have been shown to improve light conditions and stand structural diversity.

Management stage	**Silvicultural strategies**	**Impact on [a]**	
		Light	**Structural diversity**
Thinning			
Early: first entry	Thinning: one row	–	–
	Thinning: two rows	+++	–
	Thinning: one or two rows + selection	–	+
Early: second entry	Thinning: selection	+	+
Mature: third entry	Thinning: selection	++	+
Shelterwood management			
Late mature to final harvest	Shelterwood regeneration cut	++	++
Late mature to final harvest	Shelterwood removal	++++	+
Canopy gaps			
Early: first and second entries	Canopy gaps: group selection, with creation of gap diameters from 0.5 to 1.0 times the canopy height	+++	+++
Late: third and later entries	Canopy gaps: group selection, with creation of gap diameters from 1.0 to 2.0 times the canopy height	++++	+++
Variable-retention harvesting			
Mature: second and later entries	Variable-retention harvesting: dispersed through the stand to resemble shelterwood regeneration or removal, depending on the intensity	++++	++
	Variable-retention harvesting: aggregated to create a range of patch sizes and shapes in a specific proportion of the site	+++++	++++

Management stage	Silvicultural strategies	Impact on [a]	
		Light	Structural diversity
	Variable-retention harvesting: dispersed and aggregated on the same site to achieve a more diverse structure (can provide the full range of light conditions, from complete shade to complete sunlight)	+++++	+++++
Final management			
Final	Shelterwood, group selection or variable-retention harvesting, with some mature or overmature trees retained to increase structural diversity and seed sources.	+++++	+++++

[a] – = poor; + = minimal; +++ = moderate; ++++ = good; +++++ = optimal

Thinning

Forest managers have traditionally used thinning as a tool for maintaining stand growth, while improving quality and capturing the economic value of the materials removed by the thinning. However, regular thinning will also gradually improve conditions for natural regeneration, especially compared to unthinned stands, which exhibit slower growth and sometimes even a decline due to overcrowding of the canopy trees. As the stand matures and regeneration becomes established, you must decide how much additional work will be required to create the desired future forest conditions to promote succession. In particular, you should begin thinking of which harvesting system to choose. We'll discuss the options in the following sections.

Shelterwood harvesting system

For moderately shade-tolerant to shade-intolerant conifers, it's often effective to manipulate the canopy to provide suitable conditions for these species, while the remaining trees provide shelter. This shelterwood system can help to release understory vegetation and establish the new forest using natural regeneration alone or in combination with supplemental planting or seeding. This approach can focus on (1) regeneration of the overstory species, (2) regeneration of tree species that naturally become established in the understory during the course of stand management, or (3) natural regeneration combined with supplemental seeding or planting. Regeneration cuts (in which the canopy closure is reduced to approximately 50%) can promote the development of fully stocked regeneration layers. One or more subsequent removal cuts can then release the established regeneration. Wildlife, biodiversity, genetic, and aesthetic objectives will require you to retain some of the mature to overmature conifers in the canopy or an emergent layer above the canopy in the long term, at a rate of 4 to 10 individuals per hectare.

Group selection harvesting system (canopy gaps)

Group selection, in which several trees growing in close proximity are removed to create larger gaps in the canopy than those created by the removal of single trees, has been successfully used to regenerate species with moderate shade tolerance and mixed-species hardwood stands in southern Ontario. In coniferous plantations, this approach has been tested both during the initial thinning of young plantations and in maturing plantations that are nearing their final harvest age. These larger canopy gaps are particularly effective in providing increased sunlight to natural regeneration, and provide ideal locations for artificial seeding or tree planting. The trees that become established within the gaps grow much faster than those that grow under deeper shade, where the canopy remains intact. In maturing plantations, fully regenerated understories can be released by creating canopy gaps. This requires careful planning to ensure that the regeneration is not damaged by the harvesting activities that create the gaps or by future harvesting. To accomplish this, you must shift your focus and attention from managing the overstory plantation species to managing the natural regeneration.

When you apply group selection, it's important to match the size of the canopy gap to the light demands of the species being regenerated (Fig. 4.22). Table 4.7 provides guidance based on the concept of matching the gap diameter to the height of the main canopy trees to provide adequate sunlight for the selected regeneration species.

Figure 4.22: A harvester creates a canopy gap of 1.5 x the canopy height to create conditions that will encourage natural regeneration of moderately shade-tolerant and shade-intolerant species (Table 4.7). [Photo source: Ken Elliott, OMNRF]

Table 4.7: Recommended gap diameter to promote advance regeneration of various species growing in the plantation's understory.

Regeneration	Gap diameter
Shade-tolerant: sugar maple, beech, hemlock	<1× the canopy height
Moderately shade-tolerant: oaks, yellow birch, basswood, white pine	1 to 1.5× the canopy height
Shade-intolerant: black cherry, tulip tree, butternut	1.5 to 2× the canopy height

Gaps created early in the life of a plantation, when the trees are shorter, may need to be expanded in size (diameter) during future treatments to ensure that the regeneration continues to maintain a relatively fast, competitive growth rate. The application of group selection requires careful planning in terms of the number of gaps, their location, and their distribution. Initial planning should also consider access for future stand entries, including the final harvest. Extraction trail layout and design, including the locations of landings, are important considerations because you must ensure that trees growing in the gaps are not damaged during future tending or harvesting.

Variable-retention harvesting system

Variable-retention harvesting, which is also referred to as "variable-density thinning", is the focus of an Ontario research project that is profiled in Case Study #8. When both dispersed and aggregated patches of trees are retained on the same site, this creates both immediate and long-term increases in the heterogeneity of the canopy and the understory microenvironment. This spatially variable canopy structure also improves the diversity of the soil environment, the understory plant species, and the insect, bird, and small mammal populations, while simultaneously increasing the growth of the residual trees. Although this relatively young field study is still being monitored, early results suggest that variable-retention harvesting may be a viable option to accelerate succession from plantations to more natural forest types. As in the case of group selection, this approach depends on a complex site layout that requires careful thought and planning before the initial harvesting and careful consideration of how to protect regeneration from future stand interventions.

Figure 4.23 provides an aerial view of the Ontario variable-retention harvesting trial site at Turkey Point and an example of variable-retention harvesting as an approach to management of coniferous

Figure 4.23: Variable-retention harvesting (variable-density thinning) at the St. Williams Conservation Reserve Site, Turkey Point, Ontario. [Source: Norfolk County GIS]

plantations. Researchers applied both dispersed and aggregated thinning treatments at two thinning intensities, and the thinned areas, along with the uncut treatment blocks, created a spatially heterogeneous stand structure throughout the plantation.

4.6.4 Improving seedbed conditions

Most of the thinning and harvesting techniques described in this chapter will create some desirable disturbance of the forest floor and mineral soil, and this disturbance can be enhanced by harvesting on unfrozen ground in stands where site damage is not a concern. Alternatively, light mechanical site preparation or hand raking can be used to break up the duff layer and expose a suitable amount of seedbed. Disturbance of the forest floor and mineral soil greatly improves germination and seedling survival and development by creating more favourable seedbed conditions. Hand-planting of desired future species provides an excellent opportunity to place the seedlings in the ideal microsite created by these disturbances.

4.6.5 Promoting regeneration

If hardwood seed trees are not abundant within or near the plantation being managed, or if the diversity of suitable seed-producing tree species is limited, you may need to plant hardwood seedlings or manually disperse or sow hardwood seed in canopy openings. This will increase the amount and diversity of regeneration in the stand, and will provide sources of seed for future natural regeneration. If you rely on artificial regeneration, select tree species that are well adapted to the soil conditions (see Chapter 2 for details) and the size of the canopy openings (see Tables 4.6 and 4.7 for details). Ontario studies of thinning in coniferous plantations have shown that planting or seeding at the time of the disturbance, especially under canopy gaps, greatly improves your ability to stimulate natural succession.

4.6.6 Increasing coarse woody debris

Standing dead trees (snags) and fallen dead trees are not abundant in managed coniferous plantations, and both are often reduced during each management intervention, due in part to safety regulations that require harvesters to fell snags or trees with dead limbs that could potentially fall and injure a worker. In addition, weak or slow-growing trees may be removed to increase the growth and quality of residual trees or to eliminate diseased or infested trees from the plantation.

When you implement any of the thinning or harvesting strategies described in this chapter, you must make a special effort to retain or create dead wood and coarse woody debris because of the important habitat it provides. (It can also improve soil fertility by contributing organic matter to the soil over a long period of decay and can improve soil biodiversity by providing food sources for a diverse range of organisms.) We recommend that you consider the following approaches:

- Retain snags that will not threaten workers during silvicultural operations. Variable-retention harvesting is particularly well suited to this approach.
- Retain live cavity trees, as they are already serving an important habitat role (providing homes for birds and other organisms) and are likely to become future snags.
- Require operators of mechanical felling equipment to create “stubs”. A “stub” is a live tree that has been cut well above the normal stump height (i.e., 3 to 5 m tall). Depending on the availability of natural live cavity trees and protected snags, the prescription could call for the

creation of 5 to 10 stubs per hectare. These can be preferentially created from canopy trees with poor form and low timber value.

- Girdling (cutting or removing a ring of cambium and live bark entirely around a tree to kill the tree) is not usually suitable for public forests due to safety concerns. However, it may be acceptable in some plantations on private land where you anticipate few visitors.

Creating snags and stubs (Fig. 4.24) and retaining fallen dead wood will help to increase the proportion of coarse woody debris, both above and on the ground. Other helpful practices include leaving tree tops on the ground after harvesting, delimbing trees before removing them from the stand, and long-butting of harvested trees at the stump (i.e., removing the butt portion of a stem and leaving it in the stand, especially for trees that exhibit butt-rot).

Figure 4.24: A harvester creates a canopy gap of 1.5 x the canopy height to create conditions that will encourage natural regeneration of moderately shade-tolerant and shade-intolerant species (Table 4.7). [Photo source: Ken Elliott, OMNRF]

4.6.7 Final harvest of conifers

Once the plantation has reached maturity and you are preparing to harvest the conifers, plan to leave some of the trees (up to 10 per hectare) scattered through the stand to provide seed for natural regeneration and to grow above the new canopy (thereby increasing the forest's structural complexity) or provide future snags. These super-canopy trees provide important nesting and roosting sites for many bird species, as well as serving as landmarks for migrating songbirds. Snags also provide habitat for many wildlife, insect, bacterial, and fungal species. Protect hardwood trees that have established their value as habitat (especially those with large crowns) for nesting, perching, and feeding sites for birds and that will produce seeds for natural regeneration.

4.6.8 Protecting advance regeneration

When you plan the final harvest, consider how to protect the existing seedlings and saplings from damage, which can reduce their survival and future value for wood products. Implementing directional felling (i.e., controlling how trees fall so that they don't strike and damage residual trees) and restricting machine travel to designated corridors within regenerated areas of the stand can greatly reduce damage to the residual stand. In some cases, it may be necessary to remove advance regeneration of hardwood saplings in stand openings to stimulate coppice growth from their stumps and the development of new, undamaged stems with greater vigour or better form. At the very least, damaged stems should be cut to ground level to promote good-quality coppice growth.

Chapter 5
Forest health

5 Forest health

Forest health must be considered throughout the life of a plantation. Choices that you made during establishment (e.g., species suitable for the site) and choices that you make throughout the life of the stand (e.g., thinning regimes) will influence its susceptibility to insects and diseases and its resilience against other stresses. Some health issues are particularly prevalent during establishment and early growth, whereas others may only become apparent in later stages. Some problems may be predictable based on conditions in the surrounding area (e.g., insects infesting an adjacent stand; Fig. 5.1).

Many interacting factors influence the potential for forest health issues to arise and their impact. When multiple stressors combine (e.g., drought plus an insect infestation), the risk of damage can increase dramatically.

The first step to managing forest health problems is careful planning to avoid them. For example, you shouldn't plant species that can't tolerate flooding on a site that is occasionally flooded. But even then, adequate monitoring of the plantation by a knowledgeable individual will help you detect problems while they're still relatively easy to solve. Observations of a forest's health can be made during any operation, but because these management operations are often separated by many years, it's wise to plan health inspections as part of a regular, ongoing monitoring program.

Figure 5.1: The reddish colour of the trees in the center of this photo indicates that an insect (here, the pine shoot beetle) is causing damage. The adjacent stands are at high risk of infestation. [Photo source: Ed Czerwinski, University of New Brunswick]

5.1 Insects and diseases

This guide cannot provide a comprehensive treatment of all insect or disease issues that might affect a plantation. Instead, there are many other sources that can help you avoid forest health issues, diagnose and treat them before they become serious problems, or tolerate them once they occur. Chapters 22 to 24 in Wagner and Colombo (2001) are a good start. Natural Resources Canada's Web site "*Trees, insects and diseases of Canada's forests*" (https://tidcf.nrcan.gc.ca/en/) provides information on more than 200 native tree and shrub species, and on almost 300 insects and 200 diseases found in Canada's forests. Other useful references include OMNR (1989) and Davis and Meyer (2004) .

5.2 Common insect species that affect plantations

Several insect species affect the tree species commonly used in afforestation in southern Ontario. Table 5.1 summarizes the ones most likely to affect plantations. Many native and exotic pests can affect plantations at all stages of their development. Unchecked, they can cause severe damage and even mortality to their host trees. In smaller plantations and with smaller trees, control measures may include shaking the branches to cause the insects to drop off, or simply removing the insects or infested branches by hand and destroying them off-site. For larger plantations or trees, manual control may be impractical. In that case, several registered insecticides are available for chemical control.

Figure 5.2: Redheaded pine sawfly larvae are a serious pest of young red pine plantations. [Photo source: Larry Watkins. OMNRF]

Table 5.1: Common insects that affect coniferous and hardwood plantations in southern Ontario.

	Pines				Spruces				Larches		Eastern white cedar	Hemlock
Insects that affect conifers	Jack	Red	White	Scots	Black	White	Norway	Red	Tamarack	European		
Pine shoot beetle	X	X	X	X								
White pine weevil	X		X				X					
European pine shoot moth		X	X	X			X					
Redheaded pine sawfly	X	X		X								
European pine sawfly	X	X	X	X			X					
Yellow-headed spruce sawfly					X	X	X	X				
European spruce sawfly					X	X	X	X				
Hemlock looper						X						X
Hemlock woolly adelgid[1]												X
Larch casebearer									X	X		
Cedar leafminer											X	
Pine engraver	X	X	X	X	X	X	X	X				

	Maples			Oaks			Black walnut	Sycamore	Black cherry	Hybrid poplar	Hickories	
Insects that affect hardwoods	Sugar	Silver	Red	Red	White	Bur					Shagbark	Bitternut
Sugar maple borer	X											
Asian long-horned beetle[1]	X	X	X					X		X		
Gypsy moth	X	X	X	X	X	X	X	X	X	X	X	X
Forest tent caterpillar	X	X	X	X	X	X	X	X	X	X	X	X
Hickory bark beetle											X	X
Two-lined chestnut borer				X	X	X						

[1]These insects are not yet common, but can cause serious damage if not detected and controlled early

5.2.1 White pine weevil

Native to North America, this serious pest of white pine and Norway spruce (and sometimes jack pine and other spruces) occurs throughout the range of white pine in Ontario. Trees are usually not killed, but because the insect attacks the leader, serious stem deformities occur, especially in young, vigorously growing plantations with trees between 1 and 8 m in height. Damage is caused mainly by the larvae, which feed under the bark of the terminal shoot. This feeding causes the new shoot to wilt, then bend over and turn brown (with the result resembling a “shepherd’s crook”). At least 2 years of apical growth is destroyed, resulting in crooked, forked, or “cabbage-like” trees. This stem form is caused by lateral branches that turn upwards to replace the damaged leader. Damage can recur annually, causing a reduction in merchantable timber volume by up to 60% (NRC 2017). However, total tree mortality is low.

Several strategies can mitigate the damage caused by the insect. First, you can control the insect population, since the weevil has only one generation per year. Adults overwinter in the forest litter, and emerge in the springtime when average temperatures rise to between 2 and 4°C. They crawl up the trunk to the leader to begin feeding and mating. Females lay eggs in the upper third of the leader. The larvae hatch within 10 days, and burrow into the bark, where they feed on the inner bark. After they mature, they burrow into the centre of the stem in August and pupate. They emerge as adults and continue to feed until the temperature drops in the fall, when they seek shelter in the litter layer to overwinter and begin the life cycle again. To control the weevil:

- Monitor all young plantations as soon as they reach a height of 1 m to detect the insect’s presence. Vigorously growing plantations (where trees represent a good source of food for the weevil) and those on poor sites (where the trees are stressed and less able to resist the weevil) seem most susceptible. Weevil populations that become established in new plantations develop slowly during the first 5 years, but then expand rapidly (Coulombe et al. 2004).
- Clip, gather, and destroy damaged terminal shoots in June or July, as soon as the characteristic shepherd’s crook stem deformity becomes noticeable.
- Select one or two vigorous lateral branches near the top of the tree to become the new leader, then prune all competing branches to restore the shape of the tree. After attack by the weevil, the lateral branches on individual stems may “self-correct” or “self-prune” to restore a dominant leader and good stem form. Pruning can therefore occur at the same time as removal of infested shoots, or 1 year later. You will need to monitor these new leaders, and follow the same pruning procedures until only one dominant leader remains.
- Consider applying an insecticide that targets adult weevils when they first become active in the spring.

Second, manage the planting density in areas at risk of weevil infestations. Planting at higher initial densities (e.g., 1.5 m × 1.5 m spacing; Table 2.8) will cause early competition for light and other resources and accelerate height growth. However, achieving this high density is an expensive option and must be carefully considered to determine whether it should become part of your crop plan.

Third, consider the possibility of companion planting. If you plant white pine in combination with faster-growing species, these companions will force the white pine to accelerate its height growth, leading to improved stem form through natural pruning, or will create overstory shade that reduces height growth and makes the trees less attractive to the weevil. See Case Study #3 on "Growing white pine plantations for production of high-quality forest products" for more information.

5.2.2 Redheaded pine sawfly

This native sawfly is probably the most serious pest of young red pine plantations (see Figure 5.2). The larvae have distinctive reddish-orange heads and yellow bodies with six rows of black dorsal spots. They feed in dense colonies between July and September. The larvae feed primarily on the previous year's foliage, but may also attack new needles during heavy infestations. Complete defoliation will kill the tree. Control usually requires insecticide use.

5.2.3 Yellowheaded spruce sawfly

This native sawfly attacks all species of spruce, especially when they are growing in plantations, shelterbelts, or ornamental settings. Trees become susceptible to attack 3 to 5 years after planting, and may be re-infested annually until they are 8 m or more tall. The larvae emerge and feed in early July, starting with new foliage and then moving to older needles. Defoliation causes a growth reduction and possibly death of the top branches. The sawfly has many natural predators, including other insects, small mammals, and viruses, but these rarely control its population. Control usually requires insecticide use.

5.2.4 European pine sawfly

This exotic pest was first discovered in Ontario in 1939. Although several species of pine are susceptible to attack, Scots pine and red pine plantations experience the most severe defoliation. The larvae feed in colonies beginning in May, and consume the needles of the previous year's growth. During severe infestations, all foliage except the current-year needles may be consumed. Control usually requires insecticide use.

5.2.5 European spruce sawfly

This exotic pest was first discovered in Canada in 1922, and caused widespread damage to natural spruce stands. The larvae feed mainly on old foliage, and occasionally on new foliage. Severe defoliation causes growth reduction and sometimes mortality. Natural viruses have helped to keep its population in check, and other control measures are not usually necessary.

5.2.6 European pine shoot moth

This exotic pest was first discovered in Canada in 1925, and can now be found across Canada. The larvae feed on the buds and young shoots of a variety of pines in June, resulting in stem deformities and reduced growth, but rarely mortality. Plantations younger than 15 years seem to be most susceptible. Prompt detection of infestations is important because the insect's spread can be limited by clipping and destroying the affected shoots.

5.3 Common diseases that affect aboveground parts of trees

Several diseases affect the aboveground parts of the tree species commonly used in afforestation in southern Ontario. Table 5.2 summarizes the ones most likely to affect plantations.

Table 5.2: Common diseases that affect the leaves, needles, branches, and stems in coniferous and hardwood plantations in southern Ontario.

	Pines				Spruces				Larches		Eastern white cedar	Hemlock
Diseases that affect the leaves and needles of conifers	Jack	Red	White	Scots	Black	White	Norway	Red	Tamarack	European		
Needle blight						X						
Needle cast	X	X	X	X								
Pine needle rust	X	X		X								
Spruce needle rust					X	X	X	X				
Sooty mold	X	X	X	X								
Diplodia tip blight		X	X									
Diseases that affect the stems and branches of conifers												
Cytospora canker												
White pine blister rust			X									
Eastern gall rust	X			X								
Scleroderris canker	X	X		X								
Sirococcus shoot blight		X										
Red ring rot		X	X									

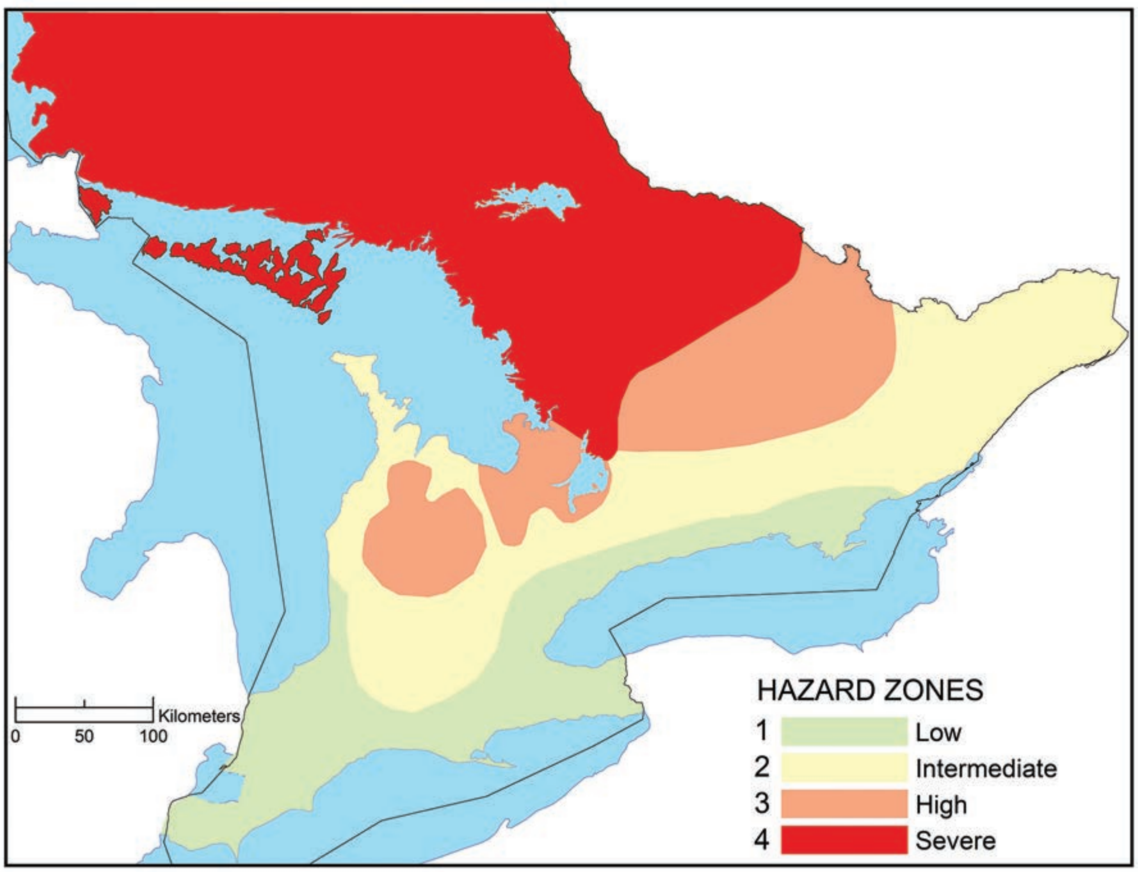
	Maples			Oaks			Black walnut	Sycamore	Black cherry	Hybrid poplar	Hickories	
Diseases that affect the leaves of hardwoods	Sugar	Silver	Red	Red	White	Bur					Shagbark	Bitternut
Leaf anthracnose	X	X	X	X	X	X	X	X	X	X	X	X
Bacterial leaf scorch			X	X	X	X		X				
Tar spot	X	X	X					X				
Diseases that affect the stems and branches of hardwoods												
Hypoxylon canker				X	X	X		X		X		
Thousand canker disease							X					
Septoria canker										X		
Sapwood streak	X	X	X				X				X	X
Verticillium wilt	X	X	X									
Oak wilt				X	X	X						
Nectria canker	X	X	X		X			X	X	X	X	X
Eutypella canker	X	X	X									
Pythium wilt									X			
Sudden oak death				X	X	X						
Hickory decline											X	X

5.3.1 White pine blister rust

This exotic disease is one of the most serious diseases of both planted and naturally regenerated white pine, and can kill trees of all ages. It was first officially reported in Ontario in 1914, but now occurs throughout the range of white pine. Like most tree-rust fungi, this parasite requires both white pine and *Ribes* species as alternative hosts at different stages of the pathogen's life cycle. Infection of pine occurs when a fungus spore from a diseased *Ribes* leaf lands on the needles in the fall, germinates, and grows into and down the branch towards the main stem. Initially, this infection kills the branch, and causes it to "flag" (become brown), which is usually the first visible symptom of infection. Eventually, the fungus reaches and invades the main stem, causing a canker to develop. The tree usually produces a heavy resin flow in an effort to isolate the infection. Eventually, the canker will girdle the stem, causing death of the tree above the point of infection.

Several strategies can mitigate the damage caused by this disease. The first is risk assessment and site evaluation. Prior to prescribing white pine for a site, you should evaluate the potential risk. Gross (1985) developed Ontario hazard zones suitable for predicting the infection risk (Fig. 5.3). These zones were based on the germination requirements of the fungal basidiospores that infect the white pine needles: temperatures between 8°C and 20°C for 48 hours, combined with free moisture (i.e., dew) on the needles.

Figure 5.3: White pine blister rust hazard zones for predicting the infection risk (Gross 1985).



Certain locations or environmental characteristics favour dew or fog formation, and should be considered when selecting a suitable planting site:

- **Topography:** Upper and middle slope positions are safest, whereas lower slope positions and flat areas, especially those adjacent to open water, are risky.
- **Aspect:** South- or southwest-facing sites are safest; all other slope aspects are risky.
- **Ground plants:** If *Ribes* is absent, the site is safer, whereas sites with *Ribes* are risky and should be avoided. Note that *Ribes* does not need to be either abundant or adjacent to the plantation site for it to host the blister rust; however, high abundance and proximity will increase the risk.
- **Canopy:** Sites with an open canopy are most risky, whereas sites with a closed or partial canopy are safest.
- **Moisture:** Dry sites (coarse to fine sands) are safest, whereas fresh to moist sites are most risky (Hodge et al. 1990).
- **Adjacent sites:** Before planting, review older adjacent plantings of white pine to assess the risk of infection at your site.

Once a plantation has been established, certain measures can decrease the risk that the fungus will become established and spread:

- **Pruning:** Monitor the plantation to detect flagging of lateral branches as soon as it occurs. Prune these branches immediately to prevent the spread of lethal cankers to the main stem. This will also modify the micro-climate around the tree to accelerate drying of moist stems during the day after a night dew or fog; this will reduce the frequency of spore germination. If monitoring and pruning of all stems is not feasible, select the desired number of crop trees and focus monitoring and pruning efforts on these trees. Section 4.5.1 provides a detailed discussion of pruning.
- **Control *Ribes*:** Eradicating both wild and domesticated *Ribes* plants can disrupt the life cycle of the fungus. However, past efforts in the 1960s and 1970s to implement this strategy were both expensive and unsuccessful. Therefore, this approach is not recommended.
- **Competition control:** Grasses and other herbaceous material surrounding young seedlings can trap cool night air and create the cooler environment required for optimal fungal infection. Controlling this competition through either manual, mechanical, or chemical means can be effective.

5.3.2 Diplodia tip blight

The fungus that causes Diplodia tip blight infects several species of pine, but particularly Austrian pine and Scots pine, and less frequently jack pine and red pine. Diplodia initially kills the tips of individual branches scattered throughout the crown. As the disease progresses, the mortality increases until 30 to 40% of the crown is affected (NRC 2017). Affected trees are then susceptible to attack by bark beetles. Large areas of plantations or naturally regenerated Scots pine have been affected in southern Ontario. Few management options are available to manage this disease. The most effective approach is to avoid planting susceptible species in areas with known infections. If you plan to replant pine species on a site that currently hosts pines, fell and burn any infected mature trees that will become a source of inoculum.

5.3.3 Scleroderris canker

This serious disease can girdle and kill jack pine and red pine in natural forests, plantations, and nurseries. Ontario has two known strains of this fungus. The North American strain infects young trees, but rarely kills trees taller than 2 m. The European strain is more virulent and can kill larger trees. The first indication of infection is a reddish-brown discoloration at the base of needles in May or June. The needles also bend downwards as the infection progresses. In summer, the needles and branch tips turn yellow to brown. The fungus then progresses along the branch and into the main stem, where it forms a canker that can kill the tree above that point. Because the fungus usually infects lower branches, pruning is an effective control measure.

5.4 Common diseases that affect the roots of plantation trees

Several diseases affect the roots of tree species commonly used in afforestation in southern Ontario. Table 5.3 summarizes the ones most likely to affect plantations.

Root diseases are sometimes called “diseases of the site” because they persist in the stumps and roots of dead or harvested trees for many years, possibly even for decades, and can transmit the disease to the new stand (Manion 1991). This problem may be less significant for former agricultural land, as there are few or no dead trees to spread the infection, but it becomes an important consideration for underplanting in coniferous plantations or when replanting the same species after a site has been harvested (see Section 4.5.2 for details). The source of infection is often apparent: dead trees with obviously decayed roots or fungal fruiting bodies on infected stumps. Both hardwoods and conifers are susceptible to root diseases, especially during their juvenile stage. For root diseases, a large food supply (i.e., roots and stumps) already colonized by the fungus provides ample energy for reproduction of the fungus. Although removal of all inoculum from a site is not possible, stump removal can reduce the potential inoculum significantly, and can thereby reduce the impact of root diseases to an acceptable level (Morrison and Mallett 1996). This technique will be most useful on easily accessible, high-productivity sites with few sources of infection.

Table 5.3: Common diseases that affect the roots of coniferous and hardwood species in plantations in southern Ontario.

	Pines				Spruces				Larches		Eastern white cedar	Hemlock
Diseases that affect the roots of conifers	**Jack**	**Red**	**White**	**Scots**	**Black**	**White**	**Norway**	**Red**	**Tamarack**	**European**		
Armillaria root rot	X	X	X	X	X	X	X	X	X	X	X	X
Heterobasidion root rot		X	X									
Tomentosus root rot					X	X	X	X				
Velvet-top fungus	X	X	X	X	X	X	X	X	X	X		X

	Maples			Oaks			Black walnut	Sycamore	Black cherry	Hybrid poplar	Hickories	
Diseases that affect the roots of hardwoods	**Sugar**	**Silver**	**Red**	**Red**	**White**	**Bur**					**Shagbark**	**Bitternut**
Armillaria root rot	X	X	X	X	X	X	X	X	X	X	X	X

5.4.1 Armillaria root rot

Armillaria root rot is caused by a number of similar species within the Armillaria genus. It can be recognized by the distinctive fruiting bodies (mushrooms) that appear in the fall as well as the "shoestring"-like black rhizomorphs that grow both under the bark of heavily infected trees and from infected roots, extending several meters into the surrounding soil. White mycelial fans are often observed growing between the wood and bark of declining trees.

Armillaria has a very wide host range. It infects nearly all conifers and hardwoods, as well as some herbaceous plants. The disease spreads through direct contact between roots and mycelium in the soil and via root grafts between infected and healthy trees, and abundant spores are produced by the fruiting bodies.

Infections in younger trees can cause swift decline and mortality, whereas the disease may begin as a butt or root rot in older trees and wait for other stress events (e.g., insect defoliation, drought) before it causes significant decline. Infected trees are susceptible to windthrow, which can create risks to workers during thinning operations. Stumps of killed or harvested trees can act as a source of inoculum for many years.

Management of Armillaria infections can be difficult, and complete eradication is unlikely once it is established. The most promising management options are reduction of the inoculum and favoring the establishment of more resistant species. Reduction of the inoculum typically means removal of stumps and may require letting a site sit fallow for some period of time. Choosing resistant species requires identification of the specific Armillaria species that is present on the site, as each species has somewhat different host preferences. For more information on the disease, see Whitney and Dumas (1994).

5.4.2 Heterobasidion root rot

This disease is also known as Annosus root rot (based on an older name for the pathogen). The fungus affects more than 150 hosts, but usually occurs on conifers. It is one of the most serious diseases in Ontario red pine plantations. The fungus produces fruiting bodies at the base of living trees and on infected stumps from previous thinning operations. In the fall, white and brown fruiting bodies form at the root collar of heavily infected trees. The fungal hyphae colonize the roots, kill them, and cause them to rot. The infection can kill young trees quickly, but can also kill larger trees after a few years of infection. Young trees exhibit symptoms such as a reduction in branch growth, chlorotic (yellowing) needles, and a "stress crop" of cones (i.e., a crop that occurs when a tree is dying and tries to reproduce one last time). Mature trees will typically show initial growth reduction, and weakened trees become increasingly susceptible to windthrow as the dead roots stop providing stability. Typically, infected trees die in groups in a circular pattern ("pockets") that results from transmission of the disease from an initially affected tree to healthy surrounding trees through root grafts.

Several strategies can mitigate the damage caused by this disease:

- **Control:** Control of the fungus is most practical during the initial infection. During thinning, freshly cut stumps can be treated with a number of registered fungicide products that prevent fungal germination and growth.
- **Careful logging:** Infection can also occur through wounds on roots and the lower stem, so minimizing damage to residual trees will reduce the frequency of infection.

5.4.3 Tomentosus root rot

This native root rot disease can be a serious threat to natural spruce stands and plantations older than 30 years, especially white spruce and Norway spruce. The fungal spores gain entry through a wound on the roots or lower tree trunk, and the infection then spreads slowly towards the main roots and large lateral roots. Once infected, these roots can infect other trees if their root systems are interconnected. Fungal fruiting bodies appear on the roots and trunk in late summer. The decay is initially characterized by a red discoloration of the wood; subsequently, pockets filled with mats of white fibers develop. This can cause the death of some trees, or weaken the roots enough to permit windthrow. This disease occurs on a wide range of sites, but is most prevalent on sites with very acidic soils (pH 4 to 5), on coarse soils with low nutrient contents and moisture-holding capacity, or where rooting depth is restricted by shallow or compacted soils (Whitney 1994).

Management can minimize losses, since the incidence of tomentosus root rot increases as the stand ages. When the typical symptom (criss-crossed windthrown stems) appears, it may be necessary to clearcut a portion of the stand, or even the entire plantation, and then establish less-susceptible species such as pines, hardwoods, or cedars on the site. However, careful planning is one of the most effective solutions: avoid planting spruces on gravelly, sandy, or silty soils, or on sites that have previously shown outbreaks of this root rot.

5.4.4 Oak wilt

This disease is a serious threat to oak, and can kill an otherwise healthy tree in a single season. Species in the red oak group (red oak, black oak, pin oak) tend to decline faster than species in the white oak group (white oak, swamp white oak, bur oak), but all oaks are susceptible. The disease spreads through root contact and insect vectors.

Potential management interventions include the removal of diseased trees, eliminating root contact through the use of vibratory plows, rock saws, or other means, and fungicide treatments for high-value trees. Some American jurisdictions recommend removal of all oak species around an infected tree, including healthy oaks, or taking advantage of natural barriers between oak stands, such as an open field or a non-oak forest.

The primary method of prevention is to minimize tree wounds that attract the sap-feeding beetles that create many new infections. Pruning of any oak species should be avoided during the beetles' active season, which runs from April to July, depending on the location and seasonal weather patterns. Wounds on high-value oaks caused by windstorms and other factors can be covered immediately with a thin layer of wound paint to reduce beetle attraction.

Oak wilt is a relatively new disease in eastern North America, so management recommendations are evolving. If you suspect that you have oak wilt on your property, contact an expert for advice.

5.4.5 Red pine pocket decline

A combination (complex) of health issues has caused unprecedented rates of decline and mortality in some of Ontario's oldest red pine plantations (i.e., >60 years). This "red pine pocket decline" has been attributed to a number of factors and causal agents:

- **Root diseases:** The presence of root diseases, including Armillaria root rot and Heterobasidion root rot. Refer to sections 5.4.1 and 5.4.2 for details.
- **Nutrient deficiency:** Unhealthy trees have a harder time resisting infections. A lack of iron is especially damaging. This can arise under alkaline soil conditions, which make iron insoluble and therefore unavailable to trees. This deficiency can be recognized by yellowing of the current year's growth, reduced overall growth, a thinning crown, and crown dieback. This deficiency is exacerbated by drought conditions. Plantations established on sites with alkaline upper (A and B) soil horizons are most likely to suffer early decline (i.e., <40 years).
- **Insects:** Bark beetles and scale insects, which may be only secondary pests, tend to attack trees that are already under stress.
- **Other predisposing site factors:** These include an alkaline soil C horizon. Red pine grows best on acidic sites, and when the roots reach soil with this higher pH, they cannot survive, effectively restricting the rooting depth.

Management options to address this issue include testing the soil pH before establishing red pine, and avoiding sites with higher pH in the upper soil horizons. Frequent monitoring of the plantation's health will let you detect and respond to problems before they become serious. See Appendix 5 for "Modified management recommendations to establish and manage red pine plantations", developed by the County of Simcoe and OMNRF.

5.5 Damaging abiotic agents

Abiotic agents are non-living factors such as climate and pollution. These factors can directly damage trees, or can weaken them and make them more susceptible to biotic agents (insects, diseases) and other abiotic agents.

5.5.1 Air pollution

Air pollution most commonly includes sulphur dioxide (SO_2), and ozone (O_3). These are emitted during combustion of fossil fuels by vehicles and industry. Because they are gases, these pollutants can be transported over long distances. SO_2 can penetrate needles and leaves, where it dissolves into the cellular water and becomes sulphuric acid, which can weaken or kill cells. Although symptoms vary between species and degrees of impact, yellowing of coniferous needles and tissue necrosis in deciduous trees often results. Ozone can accumulate at ground level, and damages living tissues by oxidation. When it combines with moisture in the atmosphere to become smog, its effects are compounded by solar radiation, which causes more ozone to form (NRC 2017). Ozone damage can cause needle discolouration, premature development of fall colouration in deciduous leaves, wilting, and premature leaf-fall. Although monitoring will reveal these symptoms, there is little you can do to prevent or mitigate these effects.

5.5.2 Salt spray

De-icing salts (primarily sodium chloride) are applied to road surfaces during the winter to provide dry, safe pavements for vehicle traffic. They are also used in urban areas to de-ice parking lots, sidewalks, and driveways. However, extensive use of salts can cause widespread damage to a wide range of conifers and hardwoods. Injury occurs when the salt dissolves in meltwater and forms a spray that can drift onto dormant stems and buds, or when dried salt deposits are carried away by wind and deposited on vegetation. Injury may also occur when excessive amounts accumulate in the soil, causing root damage. Deciduous trees mostly suffer from bud death and twig mortality, whereas conifers also suffer from extreme needle browning. Trees and plants that are less winter-hardy may be injured more severely, and may face greater susceptibility to other insects and pathogens during the growing season. One solution may be to plant salt-tolerant species adjacent to roadways to prevent salt sprays from reaching the main plantation. Tolerant species include coniferous trees such as Eastern red cedar, jack pine and tamarack and deciduous species such as red oak, white oak, cottonwood, black locust, honey locust and black cherry. Avoid planting sensitive species such as white pine, red pine, hemlock, sugar maple, and red maple. In heavy salt areas Norway spruce, white spruce, Eastern white cedar, silver maple and pin oak may also be sensitive (Johnson and Sucoff, 1999)

5.5.3 Frost

Late-spring frosts after the new growth has emerged can kill the new foliage, which remains fragile for some time. This can result in partial growth or no new growth for conifers. In contrast, hardwoods frequently form new buds that produce small leaves. Recurring late-spring frosts result in reduced internode lengths and clumping of shoots when the buds break in an ensuing normal year. Trees planted in depressions (i.e., frost pockets where cold air gathers) can remain stunted and produce multiple leaders (due to death or loss of dominance by the leader) for many years, resulting in lost growth increment, stem deformities, and even death. Avoid any likely frost pockets or plant less-susceptible species, use high-quality local seed sources that have adapted to cope with the local climate, and maintain a protective overstory that traps the day's heat during the seedling and sapling stages. Unsuitable seed sources may make the trees more likely to grow later into the fall, rendering them vulnerable to early-autumn frosts before their leaves and shoots have "hardened" in preparation for the winter. This can damage needles, shoots, and buds, leading to impaired growth in the following year.

5.5.4 Drought

Low soil moisture levels create drought that can partially kill crowns or even whole trees. All species are affected, though some (particularly pines) are better able to resist drought. Leaves of hardwoods turn brown and shrivel in mid-summer, or prematurely take on their autumn colouration at that time. Coniferous needles may turn red or brown, or trees may shed needles, and may not recover from this damage, depending on how widespread the damage is. Conifers tend to be affected from the top downwards, with current needles affected initially. Symptoms most often appear the year following a severe drought. Loss of trees to drought in a young plantation will result in a need for refill planting. Trees weakened by drought are also more susceptible to other damaging agents, such as root rots, insects, or stem diseases. Planting species that are well adapted to the soil and site conditions may help to avoid or minimize losses due to drought. (Tables 2.1 and 2.2 provide advice on species selection.)

5.5.5 Fire

Where there is a risk of fire, such as grass fires along well-travelled roads, plantations should be protected by a fire guard. These are strips of cultivated or bare soil or mown grass, usually about 3 m wide, that reduce the likelihood that a fire will spread far enough to reach the trees. For larger plantations, interior fire guards may also be helpful. The area occupied by fire guards can also provide access to the stand during future operations. Particularly for conifers, which may be more vulnerable to fire because of flammable substances in their needles and bark, eliminating flammable understory vegetation that reaches into or near the crowns or that leans against the stems, can reduce the frequency of fires and the damage they cause. Once trees begin self-pruning and become tall enough to rise above this vegetation, or develop sufficiently thick bark, the risk of fire damage will decrease. However, monitoring the stands and developing plans to work with local fire control agencies would be a wise precaution.

5.6 Damaging biotic agents

5.6.1 Deer browsing

For landowners in areas with a large deer population, browsing can be a problem; this is particularly true in stands that are adjacent to dense coniferous cover during the winter, since deer often concentrate in these "deer yards". Where this is likely to be a risk, consider planting tree species that are less prone to browsing, such as white spruce. However, if your goal is to grow high-quality white pine, annual bud capping (i.e., covering the buds with unpalatable caps) in the fall should be used until the trees reach 2 m in height. Because of the high labour requirements, this technique is most suitable for sites with small numbers of trees. However, landowners with larger numbers of trees can enlist the assistance of friends or contractors or can focus their attention on the trees with the best form. Protecting the terminal shoot of planted trees is simple. In the fall, before it snows, fold a 10 cm × 15 cm piece of medium-weight coated paper around the terminal bud cluster, leaving a hole at the top to allow for bud expansion in the spring (Fig. 5.4). The cap can be attached with three staples that hold the edges of the cap shut, but must include clusters of needles to ensure that it stays attached throughout the winter. With practice, it should be possible to attach 80 to 100 bud caps per hour. Just before bud flush in the spring, remove the caps. Although the design does allow for expansion of the terminal leader even if the cap is left on, its presence can interfere with growth (Martin Streit, OMNRF, personal communication).

Figure 5.4: Applying a "bud cap" made from coated paper to protect trees from browsing. [Photo source: Martin Streit, OMNRF)

5.6.2 Mice and voles

For young trees with thin bark, rodents such as mice and voles can damage or kill young planted trees by gnawing the bark and girdling the tree. The risk is highest when a protective cover of heavy grasses is present, since this provides shelter against predators such as hawks and owls. Minimizing the cover (e.g., by mowing) and encouraging predators (e.g., by preserving nest trees and perching trees) can reduce the severity of this problem. Where populations of these rodents are high, trapping or the use of poisoned baits may be necessary. See OMNR (1999) for more advice on protecting trees from vole damage.

5.6.3 Livestock

Livestock can also browse on new shoots and trample young trees. Fencing is the easiest solution to keep livestock out of a plantation until the trees are large enough to be safe from damage. A single-strand electric fence will work in most situations if access to electricity is available. If not, a robust wire or wooden fence will be required.

5.7 Climate Change

5.7.1 Introduction

Much has been written about the potential impact of climate change on forests including species and community adaptability and distribution, ecosystem processes and disturbances, growth rates, and seasonal timing of operations (Columbo 2008, Thompson et al 2009, Johnson et al 2009, FGCA 2017, etc.). This section provides a brief introduction with links to additional resources.

When a forest manager is making afforestation decisions they are essentially trying to predict the future. They are combining knowledge of the current environment (soils, bylaws, growth rates, markets, climate, weather, etc.) with either explicit predictions or implicit assumptions of future conditions. Any prediction of the future will be uncertain. Projected climate change increases that uncertainty and has the potential to push some conditions outside of our collective experience. This may be changes in the frequency or severity of events (freezing rain, drought, etc.) we are already familiar with, or novel conditions not yet experienced (e.g. inadequate chill periods).

To a large extent afforestation decisions are based on relatively routine and time-tested approaches and techniques that have been successful over the range of conditions experienced in the past several decades. Standing 'on the shoulders of giants' we have collectively learned what works, under what circumstances, and at least some amount of the why. The better we understand the 'why', the more transferable that knowledge will be to new circumstances, and indeed the projected changes associated with climate change will test just that. **Fundamentally sound afforestation decisions are the foundation from which a climate change response can be built.**

5.7.2 Predicting climate change

A number of resources exist to project future conditions under a changing climate (e.g. www.climatedata.ca). These can provide estimates of the climate variables most relevant to your site and proposed management activities. These might include: mean annual temperature, summer temperature, winter temperature, rainfall, snowfall, growing season length, and "degree-days".

Climate change products are typically labelled as projections, not predictions (MacCracken, 2001). Predictions tend to be of shorter duration and based on existing natural conditions, while projections are often longer term and based on assumptions of future human related activities such as socioeconomic and technical developments. Because these assumptions may not be fulfilled, climate projections are subject to a high degree of uncertainty (UNITAR, 2015).

When considering the projected future conditions for your area it is important to not confuse the high resolution of climate data products with high accuracy. Due to the uncertainty inherent in predicting the future, and particularly in translating global climate models into locally relevant results (e.g. Pielke 2011), adaptation strategies that work under a wide range of future conditions are preferable over planning for a single specific future (e.g. Wilby and Desai 2010).

5.7.3 Predicting impacts

Determining the likelihood of a particular climate impact requires a combination of expert knowledge and scientific information. As such, landowners and forest managers are encouraged to engage a knowledgeable professional to help guide them to appropriate sources.

Conducting a vulnerability assessment, even if rudimentary and informal, can help inform how you deploy the limited resources that are available to you to address the climate related impacts your plantation may encounter (maladaptation, extreme events, pests, etc.). A number of guides and case studies are available to adopt or modify based on your needs. These include Gleeson et al. (2011), Edwards et al. (2015), and Swanston et al (2016).

5.7.4 Managing risk

A simple listing of the vulnerabilities can be overwhelming. Indeed, if one were to list the vulnerabilities even without considering climate change you may wonder why anyone would take on an afforestation project at all. To help make sense of the potentially long list of vulnerabilities it is helpful to think about risk.

Risk is the intersection of impact and probability. What will happen if a vulnerability materializes (impact), and how likely is that to happen (probability)? Using a combination of expert opinion, model projections, and empirical information you can categorize the impact and probability associated with each vulnerability. The possible combinations coming out of this exercise range from low impact / low likelihood to high impact / high likelihood.

Characterizing risk in this way does not tell you what to do but rather provides a useful framing of the problem to begin talking about solutions and where to focus efforts. It is not possible to mitigate all risk as some will be technologically or economically infeasible. For other risks the mitigation action may come with it's own impacts, potentially greater than the initial risk. It is the responsibility of the landowner and forest manager to determine what risks are acceptable, what risks need to be addressed through an adaptation action, and the opportunity cost of doing so.

5.7.5 Adaptation (addressing impacts)

Healthy trees are more resilient than stressed or unhealthy trees, so any measure that will promote the health of your plantation will increase its resilience in a changing climate.

In some jurisdictions, mixing local seed with seed from a different climate zone is being recommended (FGCA 2017). The data products that accompany Ontario's Seed Transfer Policy (MNRF in prep) provide a useful perspective on appropriate seed sources for your planting site.

There are several resources that can be drawn upon to better understand what adaptation might look like. Chapter 3 of Swanston et al (2016) for example offers 36 adaptation approaches organized under 10 strategies. Case studies 2, 7, and 8, in chapter 6 of this afforestation guide fit well with Swanston et al's strategy 3 (reduce the risk and long-term impacts of severe disturbance), strategy 7 (reduce the impact of biological stressors), and strategy 5 (maintain and enhance species and structural diversity) respectively.

Given the wide variety of things that could be done, it is beyond the scope of this document to provide specific recommendations for what should be done. It is worth repeating the introductory caution from Swanston et al (2016):

> *The adaptation strategies and approaches do not… make recommendations or set guidelines for management decisions. It is up to the land manager to decide how this information is used…A combination of location-specific factors and manager expertise is needed to inform the selection of any strategy or approach (box 9, pg 29).*

5.7.6 Mitigation (addressing cause)

Afforestation projects can contribute to climate change mitigation by sequestering carbon from the atmosphere (wood fibre, litter, soil, etc.). Several factors affect the amount of carbon absorbed and stored by a forest including age, species mix, silvicultural treatments, and local climate. Various third-party systems have been developed to register and verify carbon credits. The precise calculus for each system can be complex (defining baselines, storage in long-lived products, leakage, etc.) and may influence management options. Forest managers and landowners interested in obtaining carbon credits for their afforestation efforts are encouraged to carefully research the details of each system.

5.7.7 Monitoring

Developing a monitoring plan to understand and respond to the condition of your plantation has always been important (e.g. section 2.12). With the potential impacts of climate change, particularly when a "wait and see" approach to adaptation has been selected, monitoring becomes even more critical. For example catching a forest pest problem early (e.g. invasive species), may be the difference between having some options and having no options. In addition to monitoring for basic plantation performance (e.g. growth rates), and scheduling of subsequent treatments (e.g. competition control and thinning) monitoring should be tailored to the specific climate vulnerabilities identified for your plantation.

Engaging a knowledgeable professional can expand your informal monitoring network to help you make predictions about the future performance of your own – substituting time for space. A knowledgeable professional can not only provide regional context for what other landowners are experiencing, but can provide early feedback on the success of any adaptation strategies employed.

Chapter 6
Case studies

Case Study # 1

Agricultural Field Restoration using Direct Seeding and Ground Cover at the Upper Big Creek Block (Nature Conservancy of Canada)

Author: Paul K. Gagnon, Long Point Region Conservation Authority

Introduction

- **Landscape Context –** The site is located in Southwestern Ontario, in the Carolinian Zone, on the Norfolk Sand Plain adjacent to Big Creek Valley and the Big Creek Bend (Significant Natural Area). The Carolinian Zone (Site Region 7E) has more endangered and rare species than any other life zone in Canada, and has the greatest diversity of wildlife and plants including species not found anywhere else in Canada. Forest cover in the Carolinian Zone has been reduced from 80% to 11.3%. The Norfolk Sand plain is situated in the heart of Carolinian Canada, and presently has the highest level of natural cover in the Carolinian life zone. Originally settled in the late 1700's, the light-textured soils could not support regular cropping. As the original humus layer became exhausted, agricultural productivity declined and wind erosion increased. In the early 1900's a program of reforestation began and the St. Williams tree nursery was established to supply the planting stock. The area is now a mixed landscaped of farms, natural forests, and maturing plantations.
- **Site Location -** Lots 13, 14, & 15, Concession 8, Former Township of North Walsingham, Norfolk County (538089, 4728351 UTM zone 17N). The property is owned and managed by the Nature Conservancy of Canada, and is known locally as the "Upper Big Creek Block" (see Figure 1).
- **Stand and Site Conditions –** 47 Ha (116 acres). The fields described in this case study were in corn production in 2012, and are outlined in red in Figure 1.

Figure 1: Site map. The property is open to the public, and is accessible off of the 8th Concession Road. The areas outlined in red show the fields that were restored. [Photo source: Land Information Ontario]

Forest Management Objectives

The objectives of the restoration project are:

- to restore the agricultural fields to the historical sand plain forest habitat;
- expand the Big Creek valley forest complex;
- enhance the ecological quality of the existing woodland systems; and
- to increase wetland habitat.

Methods

The restoration project took place in a sequence of operations. First, the entire site was disked in the spring of 2013 using farm equipment to incorporate the corn stubble into the soil, and to make the site suitable for the direct seeding of native trees, grasses and forbs. The site also had four smaller areas of former wetland that had been drained to support agriculture. The wetland areas were restored by excavating them at the same time that the rest of the site was prepared for planting. Following this site preparation, the large woody seeds were then planted using a two-row nut planter (see figure 2). There is 2 meters between each planter, and about 3 to 4 meters between each pass. Random species of seeds / nuts were planted 0.6 m apart within the row. One nut was planted in each spot. The planter made two passes over the field in a diamond angle (corner to corner of field) resulting in both densely seeded and open areas. The target seeding rate is 22 kg per ha, which equals 6,600 nuts/ha (based on an average of 300 nuts/kg) (personal communication Mary Gartshore, ecological restoration consultant). The direct seeding operation was implemented by St. Williams Nursery and Ecology Center. This operation was tendered, and required supplying and planting the seeds. As per the tender specifications, all seeds were to be sourced from seed zone 37. Seeds were to be dormancy tested to confirm viability, and it was the contractor’s responsibility to ensure the seeds were handled/treated/stored properly prior to planting. The cost/ha for supply and plant was $1,439.88 (plus tax). A wide variety of native tree species were planted, including hickories (bitternut, pignut and shagbark), oaks (black, white, bur and dwarf chinquapin), black cherry, black gum and red cedar. Native shrubs included hawthorns, dogwoods, winged sumac and spicebush.

After the large woody seeds were planted, a mix of seeds of native ground cover (grasses & forbs) were broadcast over the entire site by St. Williams Nursey and Ecology Center using a Truax Wildflower Seeder and packed with a spool packer. This was followed by the hand-planting of a number of native trees and shrubs in the lower areas surrounding the excavated wetlands. The medium-sized seeds of trees (i.e. dogwoods, hawthorns and witch-hazel)and wild flowers were sown by hand in the fall of 2013. Weather during the summer of 2013 was slightly cooler than normal with close to normal precipitation, which was beneficial for germination and growth of the various species, especially on the dry sandy areas (personal communication Craig Jacques, LPRCA).

Summary of native plant species seeded.

Type	Number of Species
Grasses	4
Wild Flowers (bi-annuals and perennials)	44
Trees	13
Shrubs	16
Vines	3

Note: White Millet was used as a filler in the seed mix, to help thin out the seed so that broadcast seeding would be effective, and to minimize clumping of the seed as it was sown.

Total seed (kg) for 47 ha

Graminoid	12.22
Herbaceous	25.62
Large woody seed	972.9
Small woody Seed	28.06

Bare-root tree seedlings planted in clusters in the low areas (2 Ha) where it was too wet for the farm machinery. Planted at 2.1 to 2.7 m row spacing

White Pine	500
Red Oak	1000
White Oak	1020
Black Oak	800
Black Cherry	400
Trembling Aspen	100
Largetooth Aspen	200
American Hazel	50
Total	4070

Figure 2: Direct seeding the large woody seeds. Random species of seeds / nuts were planted 0.6 m apart within the rows, which were 2 m apart. One nut was planted in each spot

Results and Monitoring

The site was monitored using the Stars Reforestation – Survival Survey assessment method in the fall of 2013 and 2014 to determine the success of the direct seeding and planting of the trees species. A total of 22 assessment plots were established. The survey plots were marked with 1 by 1" wooden stakes, and GPS spots taken. Results are as follows:

Species	Number		Percent	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Red Oak	222	96	12	18
Eastern Cottonwood	1400	369	78	68
Bur Oak	111	21	6	1
Bitternut Hickory	45	3	3	<1
White Oak	6	45	<1	8
White Ash	1		<1	
Black Oak	4		<1	
Largetooth Aspen	3		<1	
American White Elm		1		<1
White Birch		2		<1
Silver Maple		4		<1
White Pine		2		<1
Black walnut		1		<1

Eastern Cottonwood seed was not planted, but this species regenerated naturally from mature trees surrounding the site, and made up the majority of the stems in the sample plots (see Figure 3). Red oak and black oak in the first few years after sprouting can be difficult to distinguish apart. Red oak and black oak were seeded at the highest volume (235 kg/ha and 376 kg/ha respectively). White ash, largetooth aspen, American white elm, white birch, silver maple, white pine, and black walnut were not seeded, and are all natural regeneration from the surrounding forests.

Figure 3: Naturally seeded Eastern Cottonwoods (on the right) next to a direct seeded oak (on the left). Photo taken March, 2017. Herbaceous species seen in this photo include brown-eyed Susan, round-headed bushclover, and riverbank rye.

During the assessments it was noted that the areas planted with tree seedlings had poor survival and the seedlings appeared to be stunted and burned. It was determined that the corn crop in 2012 had been treated with Atrazine and with the light soils and rains, the Atrazine had leached down to the low areas where the seedlings had been planted. The Atrazine didn't appear to have impacted the direct seeded areas on the higher ground.

During the survival surveys there was no evidence of excessive nut predation, or girdling of the seedlings.

Ground Cover

In year one, out of the 18 species of ground cover observed in the sample plots, only four (4) of the species were planted. In year two, out of the 11 species of ground cover observed, eight (8) species were planted.

Year 1	Year 2
36% open ground	8% open ground
34% Millet	29% open ground
5% Lamb's Quarters	29% Horseweed
5% Ragweed	26% Brown Eyed Susan
4% Brown Eyed Susan	
4% Pigweed	
4% Barnyard Grass	

During a site visit on March 9, 2017, the following ground cover species were observed: Round-headed bushclover, Virginia mountain mint, grey goldenrod, Indian grass, little bluestem, Canada wild rye, showy tick-trefoil, wormwood, wild bergamot, and brown-eyed Susan (see Figure 4). All of these species were planted.

Figure 4: The Upper Big Creek Block (NCC). Photo taken in March, 2017 showing the success of the ground cover seeding.

Conclusions/Recommendations

- Oaks, and to a lesser degree hickories, appear to germinate well in the first few years following seeding.
- When a seed source for eastern cottonwood and to a lesser degree trembling aspen is in the area, they don't need to be included in the plantings as they will populate the areas through natural seed dispersal.
- Direct seeding along with the planting of seedlings that don't appear to germinate in the first few years (black cherry, black gum, red cedar), and the addition of seedlings such as white and yellow birch, largetooth aspen and rooted cuttings of pin cherry and sassafras may help replicate nature succession and also improve biodiversity.
- With proper site preparation, common annuals and bi-annuals initially dominate the ground cover. As the site matures, the annuals and bi-annuals are replaced by the seeded perennials and the amount of bare ground decreases.

Case Study #2

Ice Storm Demonstrates the Value of Past Plantation Management

Author: Eric Boysen, NewLeaf Forest Services

Introduction and Background

The climate of southern Ontario is changing. One of the most noticeable indicators include more extreme weather events such as summer drought (summer 2016), ice storms (Eastern Ontario 1998, Toronto, 2012, Dufferin County 2016), and wind events such as tornados and downbursts.

Over the years, private landowners in Ontario have established conifer plantations on former agricultural lands, which themselves were cleared of forests in the 1800's, for a variety of management objectives, including forest products, site protection and restoration, wildlife habitat and aesthetics (see Figure 1).

Few of these plantations were established specifically to mitigate the impacts of climate change, but plantations established since the early 2000's may be primarily managed to sequester carbon to mitigate these climate change effects. Given that most conifer plantations are planted with final rotation objectives of between 80 and 100 years, it is necessary to manage these stands throughout their life to increase their resilience to overcome climate and other natural challenges (see Figure 2).

This case study examines the impacts of the 1998 ice storm in eastern Ontario, which tested the resilience of these plantations of various ages, under various management regimes. The response to this storm, and the lessons learned, can help future forest managers build resilience to such calamities into their normal management activities.

Figure 1: Early photograph of the Larose Forest east of Ottawa, with conifers planted on a fragile, blowsand site. [Photo source: Ontario Ministry of Natural Resources and Forestry archives]

Figure 2: A mature well-managed red pine plantation in the Larose Forest. This stand is in the same general area as the historical photograph shown in Figure 1.

Site Location – While private land conifer plantations have occurred throughout Ontario, the focus of this case study will be on Eastern Ontario during the 1998 ice storm. Because of the wide spread damage, no specific stands will be profiled, but more general observations and impacts

Landscape Context – The land base of Eastern Ontario is approximately 15,000 km2 and inhabited by over a million people. Approximately 88 percent of the productive forest cover is privately owned, with many parcels being less than 40 hectares. Over 6,500 landowners manage their woodlots as business ventures to local wood-using facilities. Local ice storms (average 20 mm of ice accumulation) occur with return times of 20 to 100 years compared to other types of natural disturbances such as windstorms and fire, which have return times of 100 to 1000 years. Large-scale ice storms such as that of 1998 may, however, have return times of up to 500 years.

From January 5 to 10, 1998, many of these woodlots were exposed to close to 100mm of freezing rain, combined with winds up to 35 kph. This ice storm was unprecedented not only in the amount of ice deposited, but also in duration and geographic extent (from western Ontario into Quebec, New England States, New Brunswick and Nova Scotia). This resulted in much damage to all types of Ontario forests, including 194,361 ha of light damage; 291,147 ha of moderate damage; 114,017 ha of moderate-to-severe damage; and 5,129 ha of severe damage (Barkley and McVey, 2001). See Figure 3 for a map of the generalised forest damage assessment. All forest types were affected, but this case study will focus on pine plantations. Most of these pine plantations were established during the Woodlands Improvement Act programs (1966 to 1993), making them between 5 and 30 years old. Older plantations existed mainly in the Agreement Forests which could be as old as 60 years. According to the 1980 Forest Resource Inventory, there were 7,933 hectares of red pine plantations on Crown, private and former Agreement Forest lands, with an estimated gross volume of over 725,000 m3 (EOMF, 1994).

Given the unprecedented nature of the ice storm and the resulting damage, forest managers needed to respond in many ways, including assessing the damage (at a stand and landscape level); developing site / stand appropriate prescriptions to either salvage the damaged materials or to help the stand recover; and through various regional assistance and scientific research programs. The economic impact of the storm was enormous; total losses for red pine plantations have been estimated to be between $21 and $32 million across the region (Heigh, et al, 2003).

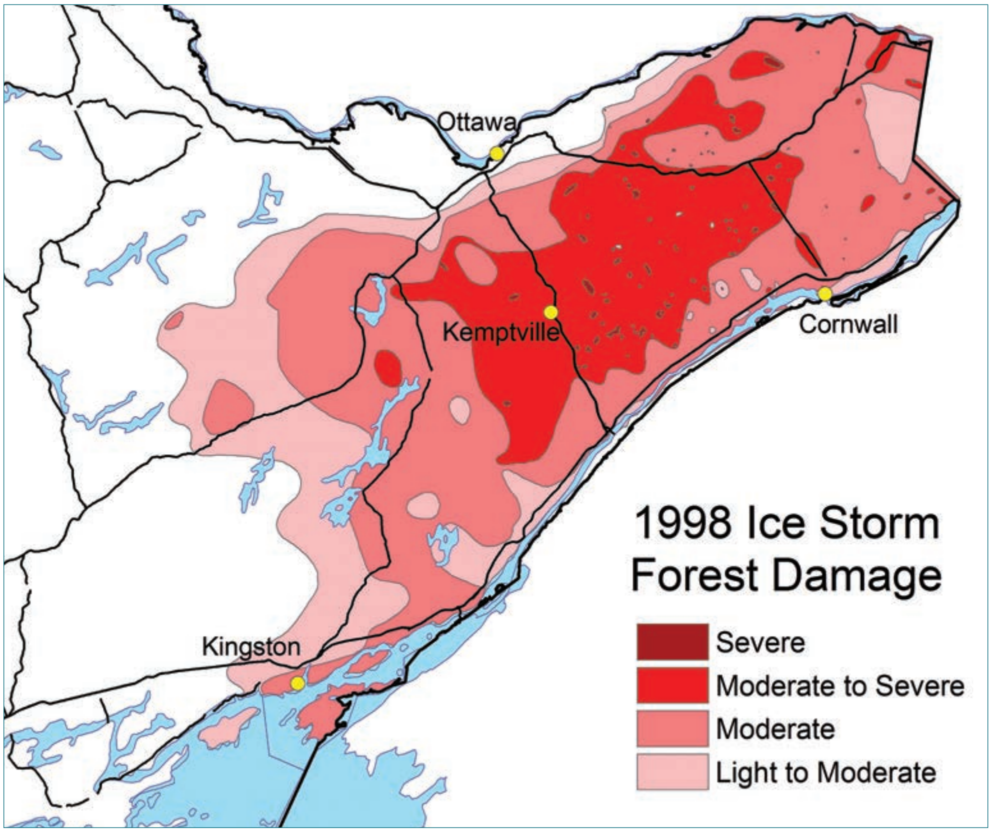


Figure 3: Map of Aerial Survey of Ice Damaged forests in Eastern Ontario, 1998. [Source: OMNRF]

Stand and Site Conditions – variable, ranging from young, pre-commercial stands, to over-stocked unmanaged stands, to well managed stands. Many plantations were established at spacings ranging from 1.8 x 1.8 m to 2.4 x 2.1 m. Refilling to ensure full stocking was a common practice within 2 or 3 years of establishment.

Until the early 1990's, there was a limited market for smaller diameter thinnings of red pine. While some landowners undertook timely pre-commercial thinnings to ensure the health and continued growth of their plantations, many others did not because of the costs involved. However, since the 1990's a more robust market for red pine has developed for first and subsequent thinnings, making it more likely that these plantations can, and will be, well managed.

Species Involved – a variety of conifer species have been established on old field sites (afforestation), including white, red and jack pine, white and Norway spruce, tamarack and other larches, and eastern white cedar depending upon soil depth, drainage and texture. At the local level, the physical characteristics of the site (soil texture, drainage, access, field size), and the objectives of the landowner often dictated which species was planted. At the regional level, little consideration was been given to concepts of sustainable regional wood supply, or the relative economics of plantation size or location.

Forest Management Objectives

Red pine is a preferred species for afforestation given that it can withstand the harsh, nutrient-poor conditions of old field sites, has quick juvenile growth, and is relatively insect / disease free. (see Figure 4). There is a ready forest product market for materials such as fencing, decking (both treated with wood preservatives) , utility poles and dimensional logs for home construction. While red pine

Figure 4: A 30 year old red pine plantation following first row-removal thinning.

plantations are often described as "ecological deserts" because of their uniformity, they can provide habitat for many species of birds and mammals throughout their rotation (Kristensen, 1996).

It is important to restore the site before you can restore the forest. Eventually, soil organic materials build up, and a forest micro-climate is established which can favour the natural regeneration of native hardwoods species. As plantations age, forest managers are challenged with shifting management objectives from managing pine, to managing succession (see Figure 5).

Figure 5: Natural regeneration in the understory of a mature red pine plantation.

Methods: Prescriptions and Implementation

Following the ice storm, a detailed site level and regional assessment of the damage was undertaken. Damage ranged from minor crown breakage, to bent-over juvenile stems, through to snapped and toppled stems, to complete destruction (see Figures 6 & 7). The prescription depended on the extent of the damage, and included:

- Salvage moderately and severely damaged stems as soon as possible to avoid deterioration of wood quality due to decay, stain and wood-boring insects
- Promote the recovery of partially damaged plantations
- Protect the integrity of the site (ground vegetation, soil organic matter)
- Preserving wildlife habitat and biodiversity
- Re-plant heavily damaged plantations following salvage operation, or promote the development of native hardwoods if advanced regeneration existed

Figure 6: The author standing in an example of damage in an unthinned, 30 year old plantation

Figure 7: Aerial view of a plantation bent over and snapped by the weight of the ice and snow.

Research and monitoring

There was a significant investment in forest assessment, forest recovery and forest science following the ice storm of 1998. Programs were funded under the Canada-Ontario Agreement for the Ice Storm Economic Recovery Assistance Program, in addition to contributions from local, provincial and federal government agencies. The results of the science effort can be found in the Forestry Chronicle, 75 (4), 77(1) and 77 (4).

The recommendations from this initial research and management response included:

- Recovery operations initially focused on heavily damaged stands and stems. Lightly damaged crowns were left to recover apical dominance and crown volume, and could be removed in subsequent thinning operations (Van Dyke, 1999).
- Salvage within one year of damage before onset of decay, stain and insect damage (Hopkin et al, 2001)
- Following salvage operation, re-plant the site with conifers if necessary. If sufficient natural regeneration exists on the site, promote the growth and development of native species. Be especially cautious about the potential proliferation of weeds (mullein, raspberry) and invasive plants (buckthorn, dog-strangling vine).
- An initial plantation spacing of 2.4m x 2.1m (8’ x 7’) is ideal as it will delay need for first thinning until about age 20 (mean DBH of 20 cms), and promote healthier crowns

Results and Lessons Learned

While the severity and extent of the damage caused by the 1998 ice storm in Eastern Ontario is considered unprecedented, there are several observations and lessons learned that are applicable to all conifer plantations across Ontario. These include:

- The damage in pine plantations is dependant upon the size of the tree. Seedlings and small polewood bend, while polewood and larger trees tend to break either at mid crown or just below the crown (Van Dyke, 1999)
- The 1998 ice storm caused varying levels of tree and stand damage, including crown loss, and uprooting and bending of whole trees. Damage was highly variable, ranging from 0% to 71%. Density of studied stands averaged 1344 stems/ha, and an average of 385 stems/ha were killed outright by the storm. In addition, the storm damaged but left standing and average of 90 stems/ha with >25% crown loss, and left 39 stems/ha with severe crown damage of >50% crown loss (Ryall &Smith, 2005)
- White pine was damaged less than red pine. Scots pine and jack pine suffered greater losses
- Crown damage in red pine stands declined with increasing mean stand DBH and stand age (larger diameter trees were damaged less by ice accumulation than smaller diameter trees)
- Studies found a strong positive relationship between tree damage and stand density – which supports the strategy of timely and frequent thinnings to manage for increased tree resistance (Ryall & Smith, 2005)
- Overstocked or dense plantations suffer more severe damage than more widely spaced plantations with trees with sturdier boles and well developed canopies (Van Dyke, 1999)
- Avoid growing tall, weak, small diameter trees, as these are very susceptible to stem breakage. Consider clearcutting areas too spindly to respond favourably to thinning (Meating et al. 2000)
- Thin plantations from below to release dominant trees. Retain trees with symmetrical, balanced crowns (Meating et al. 2000)
- Thinned, or less dense stands are more resistant than unthinned stands, but stands that were thinned just prior to the event were more vulnerable than adjacent unmanaged stands. Timing is everything!
- It is nearly impossible to predict such natural calamities, therefore it is nearly impossible to correctly time the thinnings. The best advice is to follow standard silvicultural practices including a few light thinnings during early stages of growth to maintain a healthy live crown ratio.

References

Barkley, B. & G. McVey. 2001. The role and response of the Eastern Ontario Model Forest to the 1998 ice storm. Forestry Chronicle. 77(4) 603-604.

Eastern Ontario Model Forest. 1994. Managing and marketing red pine plantations in Eastern Ontario. Kemptville, ON. File Report #1.

Heigh, J., Fox, G., McKenney, D., & Rollins, K. 2003. The economic impact of the 1998 ice storm on eastern Ontario woodlots: case studies of red pine and white cedar. For. Chron. 79: 31-46.

Hopkin, A., Greifenhagen, S. & Holland, J. 2001. Decay, stains and beetles in ice-storm-damaged forests: A review. Forestry Chronicle. 77(4) 605-611.

Kristensen, D. 1996. An assessment of the songbird habitat quality provided by red pine plantations in Eastern Ontario. Kemptville, ON. EOMF Information Report # 25

Meating, J., Van Dyke, O., Boyd, A., & Wright, K. 2000. Management of ice storm damaged woodlots and plantations. Ontario Ministry of Natural Resources. Brockville, ON. SCSS Technical Report #117.

Ryall, K.L & Smith S.M. 2005. Patterns of damage and mortality of red pine plantations following a major ice storm. Can. J. Forest Research. 35: 487-493

Van Dyke, O. 1999. A literature review of ice storm impacts on forests in Eastern North America. Ontario Ministry of Natural Resources. Brockville, ON., SCSS Technical Report #112.

Case Study #3

Growing white pine plantations for the production of high quality forest products

Authors: Steven Hunter (United Counties of Prescott and Russell) and Martin Streit (OMNRF)

Figure 1: White pine dominated mixed conifer (tamarack, white spruce) plantation thinning.

Introduction and Background

Since the late 1920's, millions of white pine have been planted in pure and mixed plantations on abandoned agricultural lands across southern Ontario (Figure 1). It has long been recognized that, when grown in open conditions, white pine can be heavily impacted by white pine weevil (Figure 2). Repeated attack of the leader by weevil can result in a drastic reduction in the value of the future forest products.

Figure 2: Planted white pine heavily affected by white pine weevil in a white spruce dominated mixed plantation on a sandy site with poor drainage.

Observations of plantations in Larose Forest (east of Ottawa) established between 1928 - 1960 have shed some light on site conditions, species combinations, row arrangement and proportion of white pine in mixed plantations that may result in lower incidences of white pine weevil and higher value white pine forest products. The impacts of initial planting density (spacing) were also reviewed, although most plantations at Larose Forest were established at a consistent spacing of 1.8 m X 1.8 m (6 ft X 6 ft).

Historic and current observations suggest that white pine weevil was present and a management challenge throughout the establishment era of the Larose Forest. The variable quality of the plantations provides interesting insights into cultural practices which may have contributed to higher quality white pine.

Silviculture records are not consistent, but generally indicate a commitment to intensive management of all the plantations. Treatments such as leader clipping, pruning, and improvement cutting were widely applied and have influenced the quality of all the white pine plantations throughout Larose.

Site Location

The subject of this case study is the United Counties of Prescott and Russell County Forest (also known as the Larose Forest) which is located approximately 50 km east of Ottawa.

Landscape Context

Eastern Ontario is a heavily disturbed landscape with generally small patches of second growth forest surrounded by agricultural lands and small communities. Larose Forest is roughly 10,800 ha and is composed of 4,800 ha of conifer plantation, 4,200 ha of second growth hardwoods and 1,800 ha wetland habitat.

Site Conditions

The majority of the soils are deep, very fine sands on various drainage regimes. Survey records from the 1800's suggest that the area that is now Larose Forest was primarily white pine dominated forest.

Management History

Larose Forest was established in 1928 through the Agreement Forest program that was administered by the Department of Lands and Forests (now Ministry of Natural Resources and Forestry). Under the management of the Department of Lands and Forests, lands (typically failed farmlands) were acquired and plantations were established and managed in an effort to stabilize soils and to provide a "useful crop." Significant effort was invested in the establishment and management of the plantations. Records of that management are available, although there are some gaps.

Commercial thinning, uniform and group shelterwood and clearcut with seedtrees are common silvicultural systems used to manage white pine dominated, mixed conifer plantations of Larose Forest. Selection thinning is typically used in plantations where there is sufficient stocking of sawlog quality white pine. Shelterwood is used where there is insufficient stocking to support a commercial thinning operation and/or where the average white pine quality is poor and future forest products are predicted to be poor. Clearcut with seedtrees is used where there is insufficient stocking in white pine and other shelterwood species to support the shelterwood silvicultural system.

Methods

A list of stands was generated that included plantations composed of at least 30% white pine (as of 2014) where the white pine component was of superior quality (i.e. high sawlog component, few forked tops due to weevil damage, low incidence of blister rust). Plantation mixes (species and arrangement) and management records for these plantations were compared in an effort to determine common elements that led to the current state of the plantation. The goal being to provide some guidance for "open grown" plantations specific to initial plantation mixes and arrangement as well as management regimes would have a higher likelihood of resulting in a stand dominated by high quality white pine at maturity.

Species Mixes and Arrangement

Several species have been mixed with white pine in plantations to act as a nurse crop for white pine. Ideally, the nurse crop would provide shelter from the weevil for the first 20+ years until the white pine are >6 m tall, after which the nurse crop could be targeted for removal in thinning treatments. The most common species mixed in white pine plantations in Larose Forest include red pine, white spruce and tamarack. Other species that have been used include Norway spruce, European larch, jack pine and various hardwoods. Intolerant species like poplar, grey birch and red maple were common invaders on the newly planted sites which also had influence on white pine stem quality.

1. Red Pine

Red pine was most commonly mixed with white pine on very fine sandy soils with good drainage. The best examples of white pine / red pine mixes are where white pine makes up between 30-60 % of the original planting (i.e. 5-7 rows red pine:3-5 rows white pine). Better than average results were also observed where the white pine was planted in groups; i.e. three continuous rows or small patches of white pine. Plantations that had more than 60% white pine at establishment resulted in higher instances of weevil damage.

Example: Compartment 256c was planted on an old field in 1935. Soils are very fine sands with good drainage (Figure 3). Spacing was 1.5 m x 1.5 m and species composition was Pr6Pw3Pj1. Row arrangement was variable but typical arrangement was 1-2 row Pw:1-3 rows Pr or Pj. The stand has been thinned twice (1960 and 1970). Thinning focused on the removal of jack & red pine and hardwoods with some lower quality white pine. By 1980 the species composition was reported to be Pr5Pw4Pj1. This plantation contains the highest quality white pine in Larose Forest.

Figure 3: Compartment 256c: White, red and jack pine planted in 1935.

As of 2014, the stand characteristics were as follows:

- Species composition = Pw 70, Pr 30
- Density = 560 stems/ha
- Basal area range = 30 m^2/ha – 54 m^2/ha
- Average basal area = 42 m^2/ha
- Basal area distribution: poles = 6 m^2/ha, small sawlog = 9 m^2/ha, medium sawlog = 15 m^2/ha , large sawlog = 12 m^2/ha
- Quadratic Mean Diameter = 32 cm
- Average height = 22 m
- Top height = 29 m
- GMV = 415 m^3

2. White Spruce

White spruce was the primary species mixed with white pine on Larose Forest. It was used in numerous combinations on a variety of drainage regimes, typically on moderate to poorly drained, very fine sandy soils. Despite the many examples of white spruce / white pine mixes there are very few instances that resulted in high quality white pine. In most cases, white pine outgrew white spruce resulting in suppression and mortality in the white spruce while the white pine was heavily affected by weevil (Figure 4). Some of the few examples of white spruce acting as a nurse crop for white pine are instances where white pine was introduced or enhanced via fill planting 5-10 years after the original establishment of the plantation.

Figure 4: An example of white pine – white spruce mixed plantation.

3. Tamarack

Tamarack has been mixed with white pine, typically on imperfect to poorly drained, very fine sandy soils. On these types of soils tamarack grows very quickly and can reach a height of 5 metres within 5 years on suitable sites. Although tamarack outgrows white pine it has a thin crown which allows diffuse light through the canopy allowing good white pine growth despite being overtopped. There are few examples where tamarack was the only species mixed with white pine; i.e. it was often mixed with white spruce, Norway spruce, red pine, other larch species. Examples that exist suggest that the best results are where white pine makes up between 40 - 60% of the original planting (i.e. 1-2 rows Pw:1 row Ta).

Example: Compartment 246g was planted on an old field in 1955. Soils are very fine sands with imperfect drainage. Trees were planted at 1.8 m x 1.8 m spacing with alternating rows of white pine and either tamarack or white spruce. The resulting species composition was Pw5Ta3Sw2. Pruning to 12’ occurred in 1972. By 1980 the species composition was reported to be Pw6Ta3Sw1 (Figure 5).

As of 2014, the stand characteristics were as follows:

- Species composition = Pw 90, Ta 10
- Density = 709 stems/ha
- Basal area range = 32 m^2/ha to 52 m^2/ha
- Average basal area = 38 m^2/ha
- Basal area distribution: poles = 9 m^2/ha, small sawlog = 16 m^2/ha, medium sawlog = 10 m^2/ha , large sawlog = 3 m^2/ha
- Quadratic Mean Diameter = 28 cm

- Average height = 20.25 m
- Top height = 23.75 m
- GMV = 317 m^3

Figure 5: Compartment 246g: White pine – tamarack – white spruce planted in 1957.

4. White Pine and inadvertent intolerant hardwoods

There are a number of examples where white pine was planted in pure stands in the Larose Forest where intolerant hardwoods (poplar, red maple and/ or grey birch) became established and overtopped the plantation, creating an unplanned nurse crop. White pine sporadically regenerates naturally under these forest conditions in Larose Forest.

Example: Compartment 95c was planted in an old field in 1935. Soils are very fine sands with variable drainage due to rolling topography. By 1960 the species composition was reported as Po6 Pw3 Ms1. In 1962 much (but not all) of the poplar and soft maple and the lower quality white pine was removed. Crop tree white pine were pruned. The current composition is Pw8 Po1 Ms1. Although total stocking is lower than many of the white plantations, white pine quality is very good (Figure 6).

As of 2014, the stand characteristics were as follows:

- Species composition = Pw 80, Po 10, Mr10
- Density = 563 stems/ha
- Basal area range = 32 m^2/ha to 52 m^2/ha
- Average basal area = 34 m^2/ha
- Basal area distribution: poles = 7 m^2/ha, small sawlog = m^2/ha, medium sawlog = 11 m^2/ha , large sawlog = 10 m^2/ha
- Quadratic Mean Diameter = 29 cm

- Average height = 20.5 m
- Top height = 26.25 m
- GMV = 307 m³

Figure 6: Compartment 95c: White pine planted 1935 overtopped by poplar and red maple.

Observations on Initial Planting Density (Spacing)

Historically most Larose Forest plantations were established at high density (1.8 X 1.8 m spacing) which is equivalent to 3,086 stems/hectare. A few examples were established at 1.5 X 1.5 m spacing which is equivalent to 4,444 stems/ha.

Example: Compartment 124e was established as a pure white pine plantation at 1.5 m by 1.5 m spacing in 1928. The plantation had repeated non-commercial and commercial thinnings to remove defective stems and release higher quality crop trees. Crop trees were also pruned. There is a growth and yield plot in the stand, and the tallest plantation-grown white pine in Ontario (36.3m) has been measured here. The stand also has a well-developed understory of red maple, sugar maple and yellow birch (Figure 7).

Figure 7: Compartment 124e: 100% white pine planted in 1928.

Results and Lessons Learned

The stands we observed with good quality white pine typically had experienced a moderate to high degree of tree competition during the period of greatest weevil susceptibility (height under 6 m). This competition can generally be described as two types:

Lesson 1 - Lateral Competition

Lateral competition from adjacent trees does not prevent weevil infestation, but helps the damaged tree to recover by forcing vertical height growth of the remaining lateral branches in subsequent years. When coupled with corrective leader pruning and improvement cutting, weevil damage can be substantially mitigated.

The creation of lateral competition through very high initial density planting (1.5 by 1.5 m) became widely adopted in the later days of the WIA program on sites where weevil damage was anticipated because of an existing population of white pine in the local area. However it is rarely used now due to the high initial establishment costs. Tight spacing requires a commitment to improvement cutting after the plantation exceeds the 6 m height which allows the manager to remove defective stems and space the remaining higher quality stems. This treatment is labour intensive because markets for the material are usually non-existent. It can be cost and time-prohibitive on larger plantations but is still an effective option for developing quality white pine in smaller plantations.

Lesson 2 - Overhead Competition

Overhead competition helps to prevent weevil damage by slowing white pine growth, which results in smaller white pine leaders which are less prone to infestation. This emulates the condition in nature where white and red pine become established after fire and develop under an intolerant hardwood canopy. The selection of the species to grow with white pine and the pattern with which to establish it depend on the site and growth habit of the species established with the white pine. Typically the species chosen is one which is suited to the site, has rapid early growth and crown density which allows partial light to penetrate to the subordinate white pine. In Larose forest tamarack (Figure 8), inadvertent intolerant hardwoods, and red pine appear to have provided the best results as nurse crops. Suggested planting patterns to emulate these plantations are alternate row white pine-tamarack on imperfectly drained sites, white pine with every third row hybrid poplar clone DN 74 (Figure 9) on better drained loam and clay loams soils, and 3 continuous rows or small groups of white pine with 2-3 rows of red pine on better drained fine sandy soils. More red pine rows are suggested on sites better suited to red pine.

Based on the examples found on the very fine sands of Larose Forest, the use of white spruce as a nurse crop for white pine is not recommended. It is speculated that on sites to which white spruce are better adapted, it may be a viable option. There were no examples within Larose Forest to test this theory.

Consideration needs to be given to the options for removal of the nurse crop once the white pine has developed past 6 meters in height. In some instances the faster growing trees may start to die naturally (e.g. hybrid poplar) and release the white pine. In other situations a removal (commercial or non-commercial depending on markets) may be needed. Removal of a nurse crop is easier when it has been established in pure rows.

Figure 8: White Pine-Tamarack Alternate Row Planted 2011 (Leeds County)

Figure 9: Two rows Pw-One Row Hybrid Planted 2011 (Leeds County)

Key Messages

- Companion species must be selected based upon their suitability to the site being planted.
- White spruce is not a suitable companion species when the target is to grow quality white pine, especially on moist-wet sands.
- Consider access and future thinning when determining row spacing and species arrangement. It is recommended that companion species be planted in pure rows and rows should be at least 1.8 m apart to accommodate access for harvesting equipment.
- Follow-up is essential to ensure overhead competition with white pine is not excessive. Tending will most likely be required in the first 10 years to manage overhead competition.
- First thinning should target the removal of the companion species and can occur after the white pine has reached 6 m in height. This usually occurs around 25 years of age.
- Regular thinning (i.e. 10-15 years) is recommended to manage lateral competition, to remove poor quality white pine and to promote rapid growth.

Case Study #4

The Agroforestry Option: When Complete Afforestation is not Possible or Desirable

Authors: Andrew M. Gordon, R.P.F. and Naresh V. Thevathasan, P.Ag., School of Environmental Sciences, University of Guelph

Introduction

In 1987, a long-term tree-based intercropping research project was initiated on a 30-ha field at the University of Guelph Agroforestry Research Station, Ontario, Canada (43◦32’28’’ N latitude, 80◦12’32’’W longitude – to the east of Victoria Road and the University of Guelph Arboretum). Ten tree species, namely silver maple, hazelnut, white ash, black walnut, Norway spruce, hybrid poplar (DN), red oak, black locust, willow and eastern white cedar were planted and annually intercropped with corn, soybean and winter wheat or barley. Tree rows were spaced at 12.5m or 15m apart with within-row spacings of 3 m or 6 m. The soil type is sandy loam (Typic Hapludalf). Crops were planted between the tree rows every year according to local ‘standard’ cultural practices (see Figure 1).

Figure 1: The University of Guelph Agroforestry Research Station, Guelph, Ontario. [Photo source: N. Thevathasan, University of Guelph]

Establishment and Management

There are several factors to take into consideration when establishing and managing an intercropping scenario:

1. Corn is the best establishment crop. If possible, keep corn as the companion crop for a minimum of 2 years and possibly 3 years. After that, a standard corn-beans-wheat rotation can be followed. The corn does not tend to compete for water with newly planted trees unlike winter wheat (see Figure 2). In addition, corn will protect newly planted trees from scorching winds in dry conditions.

Figure 2: Top: One-year growth of walnut, when winter wheat was the companion crop. Bottom: One-year growth of walnut, when corn was the companion crop. Winter wheat draws down moisture levels and causes height growth loss in trees, while corn grows in response to the amount of available water. These same results were found for all tree species used. [Photo sources: (top) A. M. Gordon, University of Guelph; (bottom) P. A. Williams, Williams and Associates]

2. In southern Ontario, orientate the tree rows in a SE to NW direction. This ensures sun in the early morning, and protection from baking temperatures in the afternoon if the companion crop is corn.
3. Understand the leave strip or area. This is the area occupied by the trees. Initially, on a 110 tree per hectare planting, the leave area will occupy 10% of the area. In other words, 10% of agricultural production will be lost. If trees are not regularly pruned, the leave area will grow rapidly, and side branches will prevent agricultural equipment from accessing the area. A regularly (every 2-3 years) pruned intercropping establishment will develop tree boles of considerable value, depending upon the species, and will usually boast a leave area of 12-15% (see Figures 3 and 4).

Economically, since approximately 15% of agricultural production is lost annually, the value of the trees when harvested in 60+ years must offset the annual lost income.

There is no need to control weed species in the leave row. We did so initially with both chemical and physical means, but a subsequent study showed that it was not necessary. The leave strip became a highly diverse habitat for small mammals, which fed energy up the food chain to raptors, happy to roost in the 3rd dimension provided by maturing trees.

Herbicide spraying in the alley crops should be done on windless days. If this is not possible, small trees can be protected with a makeshift structure made of poly and wood poles, carried by a student and placed over the tree in front of the advancing sprayer.

Figure 3: The student is standing on the leave area and has her hand on a 2-year old black walnut. At a planting of 110 trees per hectare, the leave area starts out at 10%. If trees are not pruned on a regular basis, the leave area will rapidly grow to 15% or more, decreasing overall agricultural yields. [Photo source: A.M. Gordon, University of Guelph]

Major Findings

Some of the major findings are presented here, and are supported by approximately 20 M.Sc. and Ph.D. projects.

1. Crop yields: Although as indicated above, overall crop production was reduced by about 15%, the 'per area' yield was not different between production units in the alleys when compared to the same crops in a non-intercropped (monocropped situation). This was true for soybeans and winter wheat; corn, on the other hand is a C4 plant and can't tolerate as much shade. We noticed yield losses in corn (in addition to those attributed to the leave strip) of about 10%, especially close to the tree rows. On the other hand, in drought years, our soybean yields under trees were greater than those in monocropped situation – it was found that the shade produced by the trees lowered evapotranspiration in the soybean plants, allowing them to mature.

2. Economics: A Net Present Value(NPV) approach is necessary to evaluate the economics of a system wherein one component delivers an annual product and another one does not mature for decades. We conducted an NPV analysis based on low quality wood products (i.e. pallets) being produced from harvested trees in 50 years. This was not enough to offset annual losses of crop production and it would actually cost a farmer about $44 per hectare for the 'privilege' of intercropping. Our study was conducted when interest rates were at 7%. The $44 cost to the farmer disappeared when the analysis was conducted at the lower interest rates found today. The $44 cost also disappeared if the tree component produced any sort of annual product such as a nut, or maple syrup. If any environmental benefits were invoked and valued (i.e. less erosion, less nutrient loss, more biodiversity, carbon sequestered, etc.) the $44 cost also disappeared and the intercropped system became very profitable. This is the framework within which southern Ontario will be functioning over the next century and it therefore bodes well for intercropping as an alternative land-use food production system.

3. Enhanced 'beneficial' insect diversity: Studies suggested that herbivorous (to the crop) insects were less prevalent in intercropped systems compared to monocropped systems, and that beneficial insects (those that preyed on the herbivores) were more prevalent in intercropping. This would imply that less pesticides would need to be used in an intercropping scenario (not only counting the leave strip, but the actual amount applied per unit area of cropped land), yielding both environmental and economic benefits.

4. Increased earthworm populations: Earthworm populations were enhanced in the intercropped system compared to a monocrop system. Per square metre, the monocropped system rarely had more than 2 earthworms (to 15 cm depth) compared to between 30 and 75 in the intercropped planting. Earthworms tend to be beneficial in most agroecosystems (however, not necessarily beneficial for forests) for their aeration contributions. Some researchers have found evidence that enhanced earthworm populations increase N_2O emissions, which is not good from a GHG perspective. We investigated this but found no evidence on our site for this phenomenon.

5. Enhanced animal/bird diversity: Anecdotally, we found great evidence of a multitude of animal populations (e.g. fox, vole, mole, rabbit, mice) utilizing the leave strip in the intercropped planting. They were often fodder for raptor populations. Bird species diversity and use was greater in the intercropped area than monocropped areas, and use of intercropped areas by birds increased over time as trees aged and increased in structural diversity (i.e.cavities were formed).

6. The carbon budget of the intercropped planting was vastly superior to that of a monocropped agricultural field, as one would expect. The ‘transient’ carbon trapped in the trees themselves was impressive, but even more valuable was the increase in soil carbon as a result of litterfall inputs to the crop alleys. In the first 7 years of tree growth alone, carbon levels increased by a solid 1% next to the tree rows. As the trees aged, and crowns got bigger and taller, litter was deposited further into the alleys, increasing soil carbon content there as well.

7. Reduced N losses to receiving waters by 50%: Nitrate fertilizers are applied to agricultural crops in southern Ontario usually at rates greater than plants can utilize. This results in excessive nitrate slipping by the roots of the shallow rooted crop systems. In a tree-based intercropping system, the tree roots exist below the root zone of the crop plants and under the so-called ‘safety net hypothesis’ capture deep-moving nitrate that would be normally lost from the system. This N is converted to organic N and released into the crop alleys as litterfall. This would imply that farmers who intercrop could lessen N fertilizer applications, saving money and reducing GHG emissions since N- fertilizer production is so energy intensive.

8. Enhanced mycorrhizal communities: The community structure of mycorrhizal communities was changed and enhanced with intercropping. However, additional studies need to be conducted to examine this in more detail and to ferret out the ecological advantage that this may or may not provide to crops grown in an intercropped scenario.

In summary, 30 years of intercropping research at the University of Guelph has demonstrated that this system is productive biologically and economically, and that many environmental benefits will manifest themselves on land subject to intercropping. It is a viable option for farmers interested in increasing tree cover in agricultural areas while at the same time maintaining land in agricultural production.

Figure 4: An ash – winter wheat intercropping, age 13 at the University of Guelph. Ash is no longer recommended as a good intercropping tree species because of the invasive emerald ash borer. [Photo source: A. M. Gordon]

Further Reading

Rivest, D., Olivier, A. & Gordon, A. M.. 2010. Hardwood intercropping systems: Combining wood and agricultural production while delivering environmental services. Agriculture and Agrifood Canada Pub. No. 11208E. p. 11.

Thevathasan, N. V. & Gordon, A. M.. 2004. Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. Agrofor. Syst. 61:257-268.

Gordon, A. M. & Williams, P. A. 1991. Intercropping of valuable hardwood tree species and agricultural crops in southern Ontario. For. Chron. 67:200-208.

Case Study #5

Cover Crops for Afforestation

Author: John Enright, Upper Thames River Conservation Authority

Introduction

The cover crops described in this case study are an appropriate site preparation treatment for any site that will be planted with bareroot stock. The main purpose of establishing a cover crop is to prevent or control the amount and type of competing vegetation that will invade the site. It is most often used on sites that have recently been in agricultural crop production. This case study will show the techniques and results on two different sites that were originally in either corn production, or bean production. Both sites are located in Perth East Township, Perth County, Ontario. For more detailed discussion on the use of cover crops, refer to Section 3.1.3, and Table 3.2 in the Guide.

Regardless of the original agricultural crop, there are a number of common observations based on our experience in southwestern Ontario, including:

- A cover crop is just another form of site preparation
- Generally used when a site is going from row crops such as corn or beans (including soy, white or kidney beans) to trees
- Normally involves both a nurse crop (eg. wheat/barley) in the first season, and a longer-term cover crop (eg. Dutch white clover)
- Nurse crop can be established in the fall (i.e. wheat), or in the spring (i.e barley) prior to tree planting
- Once established, the cover crop will require mowing between tree rows for the first 2-3 years
- Landowner involvement is critical for the best success.

Cover crop benefits

- Reduced weed pressure (between tree rows) because you control the type of herbaceous materials establishing on the site
- Improves ease and cost of future maintenance
- Improved micro-climate in years of drought
- Increased ability to fix nitrogen in the soil
- Reduced soil erosion

Cover crop disadvantages

- May attract deer, which can then cause damage to the trees

A closer look at two common prescriptions for cover crop establishment:

Site previously in corn production

- Chop corn stalks after the corn has been harvested (Nov./Dec.). A rotary mower is normally used. This is an operation that most engaged landowners can undertake.
- Plant the cover crop. There are two options:

    1. Frost seed a barley/Dutch white clover mix in March when the site is still frozen, just prior to the spring tree planting, or

    2. Use a no-till seed drill to seed a barley/Dutch white clover mix, about two weeks prior to tree planting (April)

The following picture sequence (figures 1 to 7) will show the various treatments to establish and maintain the cover crop, and the results of using Option 2.

Figure 1: A mix of hardwood and conifer bareroot seedlings machine-planted into corn ground. Simazine is being applied in bands during the same operation. If you look closely you can see evidence of the emerging cover crop (barley/Dutch white clover) hich was seed-drilled in two weeks earlier.

Figure 2: Site one month after planting. The band application of simazine has controlled the cover crop within the planting strip, and the barley has established well between the rows. Inset picture shows close up of Dutch white clover emerging below the barley.

Figure 3: Site three months after planting. Note the triazine-resistant weeds such as lamb's quarters within the planting strip. These weeds will not suppress the seedlings and if anything will provide some shelter during periods of extreme heat and drought. Without a cover crop the entire field would be covered in weeds such as lamb's quarters.

Figure 4: Site five months after planting. Note the site has been mowed once in mid-summer and the Dutch white clover is now well established. The annual weeds within the tree rows are starting to die back making the seedlings visible again.

Figure 5: The same site 6 months after planting. Note that the site has been mowed for the second time in early November in preparation for winter. If hardwoods have been planted this is important as it reduces rodent cover and potential for winter girdling. The site is now ready for a second application of Simazine in either a late fall or early the following spring.

Figure 6: The site three years after planting. Note that the landowner continues to mow the cover crop twice a growing season, the Dutch white clover is still present, and the trees are free-to-grow.

Figure 7: The site 6 years after planting. Note the bur oak in back ground approaching 6 metres in height.

Site previously in bean production

Unlike the example of sites in corn production, there is no need to mow the site following the harvest of various types of beans, because the stubble and debris is minimal, and won't interfere with subsequent site treatment. There are three options to establish a cover crop, including:

1. After bean harvest, seed winter wheat as a nurse crop in Sept./Oct., and then frost seed Dutch white clover as a cover crop in March, or
2. Frost seed a barley/Dutch white clover mix in March, or
3. Using a no-till seed drill, seed a barley/Dutch white clover mix in April, two weeks prior to tree planting

The following picture sequence (figures 8 to 12) will show the results of following Option 1.

Figure 8: Machine planting into winter wheat under seeded to Dutch white clover. Band application of simazine being applied in the rows of planted trees in the same operation.

Figure 9: Site one month after planting - Band application of simazine has controlled the cover crop within the planting strip (left). Close up of Dutch white clover emerging below barley (right)

Figure 10: Site two months after planting. Note the site has been mowed once to reduce any weeds, and the Dutch white clover is starting to establish.

Figure 11: Site five months after planting. Note annual weeds and grasses within the planting rows are starting to die down. The site is now ready for either a second application of simazine in either late fall or early the following spring.

Figure 12: Site 4 years after planting. Note how the Dutch white clover continues to persist with mowing twice a year in mid-summer and late fall. The trees are now free-to-grow.

Case Study # 6

Red Pine Afforestation Crop Plan

Authors: Murray Woods (Canadian Wood Fibre Centre, CFS), and Margaret Penner (Forest Analysis Ltd.)

Introduction

In this case study, a land manager wants to establish a stand of red pine on abandoned agricultural land with the objective of producing high-quality forest timber products over the life of the stand. Some key information is required and decisions need to be made. These include:

- Determine the site quality
- Choose initial stand planting density
- Choose whether or not to plan for thinning treatments

Density Management Diagrams (DMDs) are tools that permit comparing crop plans to determine which scenario may meet the land manager's objective. These modeled estimates, including timing of thinnings and projected growth, are based on remeasurements of sample plots established throughout Ontario. The relationships observed on these sample plots are used to develop the DMDs. Growth rates of individual stands may vary slightly from the predictions. It is important that the land manager continue to monitor the stand's development over time and adjust DMD model projections as necessary.

Site index (SI) is the site productivity measure most often used in forestry. SI is appropriate for stands when most trees are the same species and age. SI is based on stand height and age. Afforestation usually occurs on land that has been cleared of trees for many years and stand height and age are not available. Another option for determining site quality is to base it on the present substrate conditions. Taylor and Jones (1986) linked dominant soil texture and depth to mottling to the productivity measure, SI, by species (Appendix 1). For this case study, the site is assumed to have a sandy texture with depth to mottles from 80-100 cm. Both red and white pine have a "Very Good" assessment with no cautions. Red pine was selected for this case study. The SI class for red pine is greater than 23 m. For this case study the SI is assumed to be 24 m (meaning the dominant stand height is expected to be 24 m at 50 years of age).

Table 1: The Species suitability from Appendix 1 for planted conifers on sandy soils in site region 6E with depth to mottles of 80 – 100 cm.

Species	Productivity assessment	SI (m)	Caution on productivity assessment
Le	Very Good	≥ 25.0	Subjective extrapolation, no data collected
Pr	Very Good	≥ 23.0	None
Pw	Very Good	≥ 26.0	None
Sn	Very Good	≥ 27.0	Insufficient data for proper site class prediction
Sw	Good	24.0 - 25.9	None

Initial planting density should be objective driven. If the land manager wishes to establish a level of forest cover that encourages ingrowth of natural regeneration, a low planting density 1000 – 1200 stems/ha may meet that objective. If the land manager wishes to grow quality timber products, higher densities are recommended. Trees growing at lower densities (wider spacing between trees) tend to have larger crowns with heavier branches. The resulting large knots limit the potential of the tree for both products and value. Pruning can be used to reduce knots and improve wood quality.

This case study compares DMD scenarios where a high-value timber product is desired. Four scenarios are compared. The survival rate of the planted seedlings is assumed to be 85%. For scenarios with thinnings, the initial thinning involves a removing a row of trees and some thinning of smaller stems within residual rows to achieve a 33% reduction in basal area. This is the “Access thinning with selection” of section 4.2.4.

Scenario 1 – Target a DBHq of 16 cm at time of first thinning. The first thinning is a row thinning with selection and the next two thinnings thin from below within the “maximum stand growth area” of the DMD.

Scenario 2 – Same establishment as scenario 1 but no thinnings.

Scenario 3 – Same establishment and first thinning as scenario 1. The second and third thinnings remove 30% of the basal area, from below, when the stand reaches the upper boundary of the “maximum stand growth area”.

Scenario 4 – Plant at 1,500 stems/ha with 85% survival. The first thinning is an access with selection thinning. The second thinning removes 30% of the basal area, from below, when the stand reaches the upper boundary of the “maximum stand growth area”.

DMDs are structured to emulate thinning from below (removal of small stems). They do not represent row thinnings. However, almost all first entries into planted stands require access. For the purpose of this case study, the DMD is mis-used for the first “access with selection” thinning.

Recalculating the post thinning condition is recommended in order to realign stand projections

Scenario 1- Target a DBHq of 16 cm at time of first thinning – maintain the stand within the maximum stand growth area.

The DMD can be used to determine the appropriate planting density to achieve a DBHq of 16 cm at the time of first thinning. Allowance must be made for the expected planting mortality and if that mortality is going to be refilled immediately. Here, the survival rate is assumed to be 85% meaning 85% of the planted trees are expected to survive to the time of first thinning. An assumption for modeling is that these are equally spaced individuals. This is not likely the case and another reason the land manager must monitor the developing stand over time and readjust DMD model assumptions.

To maintain optimum growth, the stand should be thinned just prior to the point where competition for resources will result in mortality of some stems. This threshold on the DMD is known as the *Mortality Initiation Line* (MIL) or lower self-thinning line (Figure 4.9). It is the upper limit of the *Zone of Optimum Density Management* and the lower limit of the *Zone of Imminent Competition and Mortality* (ZICM). For a given density, this threshold indicates when a thinning is necessary to prevent mortality.

The objective is DBHq = 16 cm at the time of first thinning. This corresponds to Point B on Figure 1. A vertical line is drawn from Point B to the x-axis (Point A) indicating a survival density of 1,968 stems/ha. Given a survival rate of 85%, this correspondes to a planning density of 1,968 stems/ha x (1/0.85) = 2,315 stems/ha. At point B, the average stand DBHq is 16 cm (solid linear isolines with units on left in cm). The corresponding top height of the stand would be 15.2 m (dashed curved isolines labeled on the right) and a mean tree GTV is 0.13 m^3/ha (y-axis).

The age of the stand at the first thinning can be estimated using the stand top height at the time of thinning and SI. Based on the case study site information, a SI of 24 m was assumed. The stand top height at point (B) is 15.2 m. Using the red pine SI chart at the top right of the Figure 1, a top height of 15.2 m on the SI 24 curve occurs at a breast height age of 27 years. To convert breast height age to total age for red pine an average adjustment factor of 5 years to reach breast height is assumed. Therefore, a thinning is scheduled when the stand reaches (27 + 5) = 32 years of age.

The basal area (BA) for point (B) is estimated as:

$$BA = (DBHq^2 \times 0.00007854) \times Density$$

$$= (16^2 \times 0.00007854) \times 1968 = 39.6\ m^2/ha$$

The Gross Total Volume (GTV) is estimated as the mean tree GTV multiplied by Density:

$$GTV = \text{mean tree GTV} \times Density$$

$$= 0.13 \times 1968 = 255.8\ m^3/ha$$

First thinning - 1 in 4 Row Removal and Light Thinning from Below

Often the first stand entry includes a row thinning to create access. A typical reduction in basal area for a first thinning is about 33% of the stand basal area. Removing every 4th row reduces the basal area by approximately 25% (as average sized trees are removed). The remaining 8% reduction in basal area is achieved by removing smaller, lower quality trees from the remaining rows. A simplistic approach is used on the DMD to approximate a row thinning. As a row thinning (plus a few smaller trees from within residual rows) generally does not affect the average stand DBHq, the stand moves along the DBHq isoline to a point where 33% of the basal area is removed (point B to point C). The calculations are as follows.

1. Calculate the basal area to be removed for a 33% reduction

   BA to be thinned (BA_t) = Pre-Thinning basal area x 0.33

   = 39.6 x 0.33 = 13.1 m^2/ha

2. Calculate the density of stems to be removed given the basal area to be thinned and the average DBHq

Density to be thinned= BA_t / ($DBHq^2$ x 0.00007854)

= 13.1 / (16^2 x 0.00007854)

= 649 stems/ha

Since average trees are being removed, the number of trees to be removed can also be calculated as the pre-thinning density multiplied by the removal

Density to be thinned (BA_t) = Density x 0.33

= 1968 x 0.33

= 649 stems/ha

3. Post thinning Density (point (C))

Pre-Thinning Density – Post Thinning Density

= 1968 – 649 stems

= 1318

4. Volume removed during thinning

Density to be thinned x mean tree GTV at point (B)

= 649 x 0.13 = 84.4 m^3/ha

No stand mortality is expected to occur and the stand will track vertically along a density line of 1,318 stems/cm to point (D). This is the point at which, if the stand is not thinned, mortality is likely.

Thinning 2: Thinning from Below – within the maximum stand growth zone

Thinning from below means that the smaller trees will be removed, increasing the light and space for the residual trees. A DMD is designed to handle this type of thinning operation. The post thinning density is determined by following the arc of the top height isoline to where it intersects the Maximum stand production initiation line (the beginning of the maximum stand growth zone) indicated by point (E). The stand moves along the arc of the top height isoline because thinning from below does not change the stand top height– but does increase the DBHq.

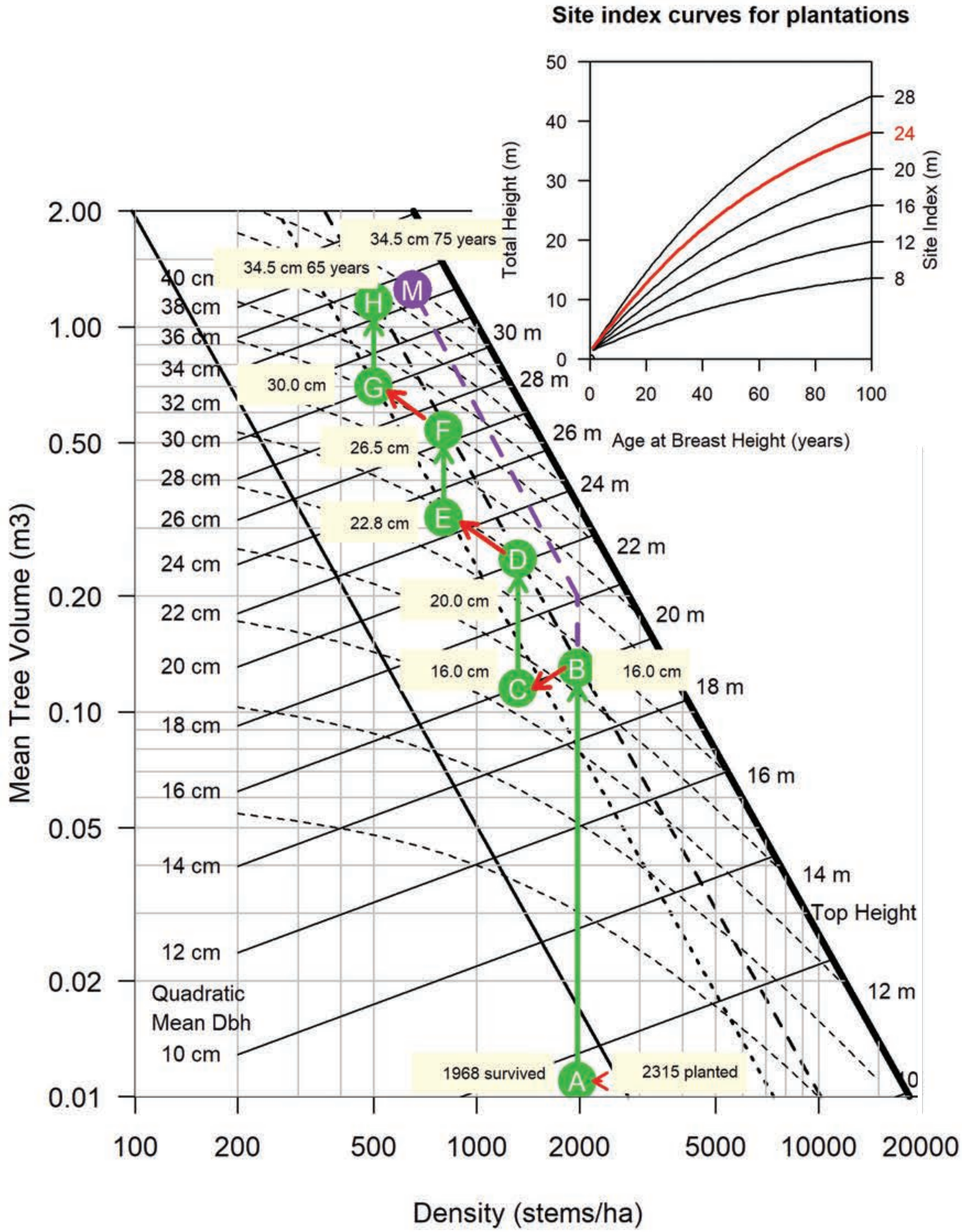


Figure 1: Scenarios 1 and 2 are plotted on the DMD.

Pre-Thinning Stand parameters Point (D)

Density: 1318 stems
Top Height: 17.8m
DBHq: 20.0 cm
Mean tree GTV = 0.25 m^3

Calculate: Age (using the top height and SI 24 curve): (34 + 5) = 39 yrs
BA = (20^2 x 0.00007854) x 1318 = 41.4 m^2/ha
GTV = 0.25 x 1318 = 329.5 m^3/ha

Post-Thinning Stand parameters Point (E)

Density: 800 stems
Top Height: 17.8m
DBHq: 22.8 cm
Mean tree GTV = 0.32 m^3

Calculate: Age: (34 + 5) = 39 yrs
BA = (22.8^2 x 0.00007854) x 800 = 32.7 m^2/ha
GTV = 0.32 x 800 = 256.0 m^3/ha

Calculating Values removed from thinning – thinning from below

When thinning from below, the quantities removed are determined by calculating the difference between the Pre- Thinned stand parameters and the Post-Thinned stand parameters.

Thinned Basal Area = 41.4 – 32.7 = 8.7m^2 (21% removal)
Thinned GTV = 329.5 - 256.0 = 73.5 m^3/ha
Thinned Density = 1318 – 800 = 518 stems/ha[1]

Once again, no mortality is expected to occur following thinning and the stand will track vertically along a density line of 800 stems to point (F). Using the DMD, the stand parameters at that time are:

Density: 800 stems
DBHq: 26.5cm
Top Height: 22.0m
Mean tree GTV = 0.54 m^3
Age (using the top height and SI 24 curve) = (45 + 5) = 50 yrs
BA: 44.1 m^2/ha
GTV: 432 m^3/ha

[1]Because the thinning is from below, the density estimate is an approximation as smaller trees than the average are likely being removed.

It takes approximately 11 years for the thinned stand to reach point (F) when another thinning is warranted to minimize mortality. Another thinning from below (from point (F) to point (G)) can be simulated with the DMD. The post-thinning stand condition is found by moving from along the arc of the 22 m top height isoline until it intersects the 0.40 RD line (indicated by point (G)

The post-thinning parameters at point (G) are

Density: 500 stems
Top Height: 22.0m
DBHq: 30.0 cm
Mean tree GTV = 0.70 m^3

Calculate: Age: 50 yrs
BA = 35 m^2/ha
GTV = 350.0 m^3/ha

Table 2: Scenario 1 is summarized.

Label		Density (stems/ha)	DBHq (cm)	Top Ht (m)	Age (yrs)	Basal Area (m^2/ha)	Mean tree GTV (m^3/tree)	GTV (m^3/ha)	% removed
A	Planting	1968							
B	Grow To Mortality Line	1968	16.0	15.2	32	39.6	0.13	255.8	
	Thinning removal	**649**				**13.1**		**84.4**	**33**
C	Post Row Thinning	1318	16.0	15.2	32	26.5	0.13	171.4	
D	Grow To Mortality Line	1318	20.0	17.8	39	41.4	0.25	329.5	
	Thinning removal	**518**				**8.7**		**73.5**	**21**
E	Post Thin from Below	800	22.8	17.8	39	32.7	0.32	256.0	
F	Grow To Mortality Line	800	26.5	22.0	50	44.1	0.54	432.0	
	Thinning removal	**300**				**8.8**		**82.0**	**20**
G	Post Thin from Below	500	30.0	22.0	50	35.3	0.70	350.0	
H	Grow To Mortality Line	500	34.5	27	65	46.7	1.16	580.0	
	Total Production							819.9	

Scenario # 2 – Same establishment as Scenario 1 - no thinning

Scenario 2 has the same establishment density as scenario 1 but is not thinned. Scenario 2 is illustrated in Figure 1 and summarized in Table 3.

Table 3: Scenario 2 is summarized.

Label		Density (stems/ ha)	DBHq (cm)	Top Ht (m)	Age (yrs)	Basal Area (m2/ha)	Mean tree GTV (m3/ tree)	GTV (m3/ ha)
A	Planting	1968						
	Total Production to a Total age of 65 years	800	31.0	27.0	65	60.4	0.85	680.0
M	Total Production to a DBHq of 34.5 cm	650	34.5	29.5	75	60.8	1.25	812.5

Scenario #3 – Same establishment as Scenario 1 – three thinnings with at least 30% removal

This scenario has the same establishment and first thinning as Scenario 1. The second and third thinnings remove 30% of the basal area and occur when the stand reaches the mortality initiation line. The scenario is illustrated in Figure 2 and summarized in Table 4.

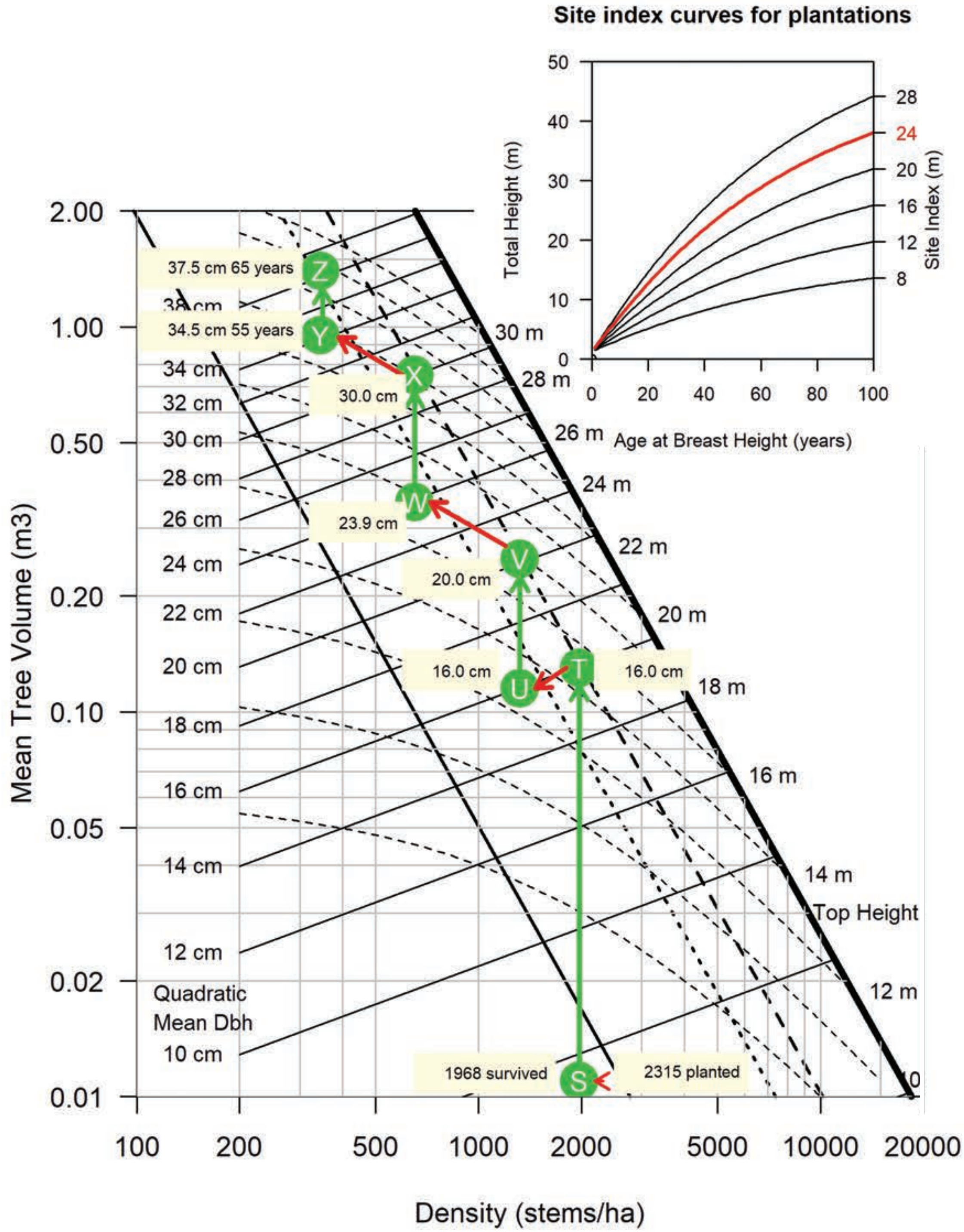


Figure 2: Scenario 3 is plotted on the DMD.

Table 4: Scenario 3 is summarized.

Label		Density (stems/ ha)	DBHq (cm)	Top Ht (m)	Age (yrs)	Basal Area (m2/ ha)	Mean tree GTV (m3/ tree)	GTV (m3/ ha)	% removed
S	Planting	1968							
T	Grow To Mortality Line	1968	16.0	15.2	32	39.6	0.13	255.8	
	Thinning removal	**~649**				**13.1**		**84.4**	**33**
U	Post Row Thinning	1318	16.0	15.2	32	26.5	0.13	171.4	
V	Grow To Mortality Line	1318	20.0	17.8	39	41.4	0.25	329.5	
	Thinning removal	**~668**				**12.2**		**102.0**	**30**
W	Post Thin from Below	650	23.9	17.8	39	29.2	0.35	227.5	
X	Grow To Mortality Line	650	30.0	24.0	55	45.9	0.75	487.5	
	Thinning removal	**~305**				**13.7**		**146.0**	**30**
Y	Post Thin from Below	345	34.5	24.0	55	32.3	0.99	341.6	
Z	Grow To 65 years	345	37.5	27	65	38.1	1.40	483.0	
	Total Production to a DBHq of 34.5 cm				55			673.9	
	Total Production to a Total age of 65 years				65			815.4	

Scenario #4 – Same as Scenario 3 but planted at 1500 stems (with an 85% survival rate)

In scenario 4, the planting density is 1,500 stems/ha with 85% survival. The first thinning is an access with selection thinning to reduce BA by 33%. The second thinning removes 30% of the basal area, from below, when the stand reaches the upper boundary of the “maximum stand growth area”.

Scenario 4 is illustrated in Figure 3 and summarized in table 5.

Table 5: Scenario 4 is summarized.

Label		Density (stems/ ha)	DBHq (cm)	Top Ht (m)	Age (yrs)	Basal Area (m2/ ha)	Mean tree GTV (m3/ tree)	GTV (m3/ ha)	% removed
1		1275							
2	Grow To Mortality Line	1275	20.7	18	39	42.9	0.27	341.7	
	Thinning removal	**~421**				**14.2**		**113.6**	**33**
3	Post Row Thinning	854	20.7		39	28.7	0.27	228.9	
4	Grow To Mortality Line	854	26.0	21.5	47	45.4	0.50	427.1	
	Thinning removal	**~404**				**13.5**		**125.6**	**30**
5	Post Thin from Below	450	30.0	21.5	47	31.8	0.67	301.5	
6	Grow to 34.5 cm	450	34.5	26.0	63	42.1	1.13	508.5	
	Total Production to a DBHq of 34.5cm							747.7	

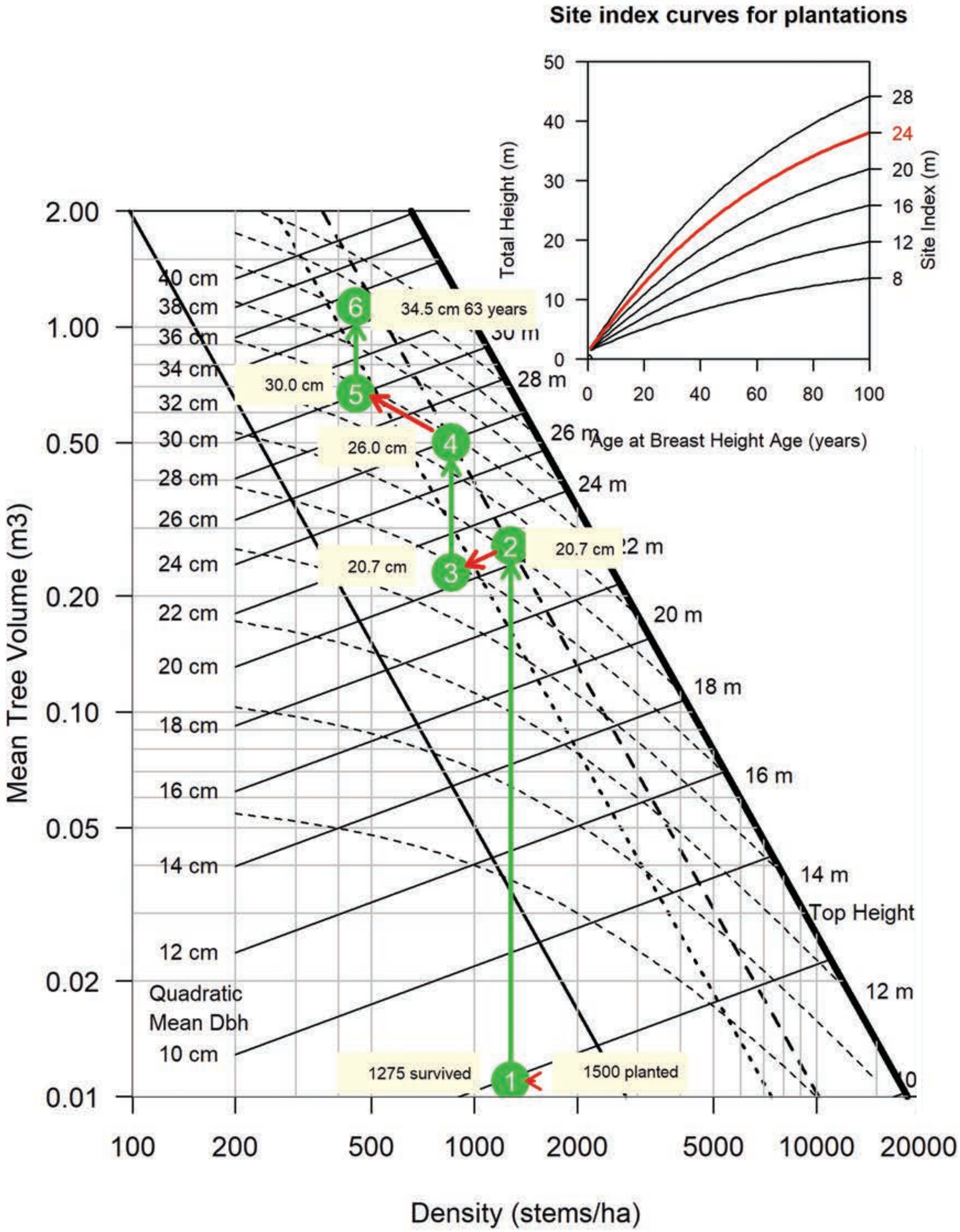


Figure 3: Scenario 4 is plotted on the DMD.

Many considerations go into deciding which scenario to implement. A higher planting density may reduce ingress of other vegetation but may require thinning to achieve merchantable products in a shorter time period. Thinnings provide intermediate revenue and the opportunity to remove poorer quality stems and concentrate growth on higher quality stems. The profitability of intermediate thinnings depends on the piece size and the area of the plantations. It may be difficult to find a logging contractor to harvest small trees on small areas.

Scenarios 1 and 3 provide good total volume production and good quality (Table 6).

Table 6: The scenarios are compared at age 65. The piece size evaluation is at age 65. The piece sizes associated with thinnings are much smaller than those associated with the final harvest. The better the quality and the larger the pieces, the higher the product value.

	Planting		GTV (m^3/ha)			DBHq			
Scenario	density (stems/ha)	Thinning	Final Harvest	thinned	Total production	(cm)	Production	Quality	Piece size
1	2315	Max growth	580	240	820	34.5	Good	Good	Mid
2	2315	None	680	0	680	31	Lower	Good	Smaller
3	2315	30%	483	332	815	37.5	Good	Good	Larger
4	1500	30%	509	238	747	34.5	Medium	Lower	Mid

Additional resources

Ontario Woodlot Association - Ontario Woodland Notes:

Management techniques for conifer plantations – Part I – Density Management Diagrams.

> https://www.ontariowoodlot.com/publications-and-links/owa-publications/woodland-notes/management-techniques-for-conifer-plantations-part-i

Management techniques for conifer plantations – Part II – Using a Density Management Diagram.

> https://www.ontariowoodlot.com/publications-and-links/owa-publications/woodland-notes/management-techniques-for-conifer-plantations-part-ii

Management techniques for conifer plantations – Part III – Crop Planning – Predicting Future Harvests.

> https://www.ontariowoodlot.com/publications-and-links/owa-publications/woodland-notes/management-techniques-for-conifer-plantations-part-iii

Case Study #7

Managing Buckthorn & Manitoba Maple in the Understory of Coniferous Plantations to Promote Succession to Native Species

Author: Chris Gynan M.Sc.F., R.P.F.,Silv-Econ, Ltd

Introduction and Background

European buckthorn (*Rhamnus cathartica*) is a common understory shrub in mature conifer plantations in southern Ontario. The species is very long lived, often as old as the overstory trees themselves. It grows tall (5 to 10 m) and casts a heavy shade. It is a prolific species and can consumes growing space which would otherwise be utilized by preferred natural tree regeneration to replace the overstory as it matures or is thinned through silvicultural management.

Site Location

This case study presents an overview of a successful control treatment applied to management buckthorn in a mature 0.62 hectare (ha) Scots pine plantation located adjacent to the Town Hall in the Town of Aurora (100 John West Way).

Landscape Context

The property is situated within the river valley of the East Holland River, about 1.5 km north of the Oak Ridges Moraine. The valley area immediately adjacent to the woodlot serves a recreational corridor and contains the Aurora Community Arboretum (ACA). Also found in this valley system is the Town's Vandorf Woodlot, Sheppard Bush and a number of Town parks. Remnants of one of the earliest sawmills in York Region (the Lloyd sawmill 1800 circa) can be found approximately 1 km south of the woodlot, although not within the arboretum, in the river valley where a pedestrian trail crosses the river (Lloyd 1995).

The East Holland River is one of the most populated and polluted river systems in the Lake Simcoe Watershed, and is one of the highest contributors of phosphorus entering Lake Simcoe (LSRCA 2012). The river drains an area approximately 243 square kilometers and joins with the West Holland River just north of Bradford to eventually enter Lake Simcoe at Cooks Bay (LSRCA 2000). The greatest threats to this system are believed to be loss of forest cover, and excessive nutrient runoff from sources such as urban storm water ponds and from agricultural fields.

The woodlot is presently isolated from other forest areas in the river valley. Through the efforts of the Aurora Community Arboretum, tree cover in the valley adjacent to the plantation will increase significantly in the coming decades and together with the Scots pine plantation will serve as a forest corridor that connects major woodlots and facilitates natural movement of plants and animals across the landscape. Wildlife that rely on such linkages include migratory forest birds, deer, fox, and coyotes among many other species. Connectivity is critical to the heath of forest ecosystems at the landscape level. Connectivity facilitates inter-breeding of wildlife and plants between isolated woodlots and promotes genetic diversity which ensures their adaptation to the worlds changing environment.

A search of the province's Natural Heritage Information Centre (NHIC) database was performed to determine if any "Species-at-risk" have been observed in the geographic area surrounding the property. No species have been documented within 1 km of the woodlot. Rare species generally occur in small populations and are often very difficult to locate. Observations of Butternut (*Juglans cinera*) have been made in the Holland River Valley south of Wellington Street. Butternut is an endangered species; none were observed growing in the Scot pine plantation. As a result of its small size and lack of species diversity, the woodlot likely does not provide critical habitat for Speciesat-risk which are known to be in this part of the watershed.

Stand and Site Conditions

The woodlot was planted with Scots pine seedlings in 1944 circa, likely by the Department of Lands and Forests (now the Ministry of Natural Resources and Forestry) as part of the Agreement Forest Program at that time. Such plantations typically were established in areas not suitable for agriculture; in this case a result of the steep topography. When mature, these stands will provide shelter and suitable growing conditions for native forest vegetation. The woodlot never received any silvicultural treatment since it was planted. Soil conditions are well drained, silty clay loam. As a result of the sloping topography, surface soils often become very dry during the growing season.

Species Involved

The overstory Scots pine trees were in good condition, exhibiting healthy foliage and good trunk growth (diameters are increasing between 2 and 4 mm annually). The inventory is described in Table 1. The understory was dominated by European buckthorn and to a lesser extent Manitoba maple (see Table 2). These two undesirable species impact the sustainability of the forest by preventing establishment of native tree and shrub regeneration. This jeopardizes the ability of the forest to naturally restore its tree cover should it be impacted by weather events, insects and disease or even human impacts (see Figure 1).

Table 1: Overstory inventory estimate.

Species	Average diameter at breast height (cm)	Density Estimates	
		Tree density (stems/ha)	Basal area (m^2/ha)
Scots pine (*Pinus sylvestris*)	27	917	55.0
Manitoba maple (*Acer negundo*)	9	267	1.8
Black cherry (*Prunus serotina*)	40	2	0.5
Standing dead trees	16	67	1.3
Total		**1,253**	**58.6**

Table 2: Tree regeneration estimate.

Species	Density/ha
European buckthorn	5,167
Black cherry	67
Manitoba maple	
European Mountain ash	83
Total	**5,800**

Figure 1: 70-year-old scots pine plantation with a profuse understory of buckthorn and Manitoba maple. Many of the buckthorn and maple specimens exceed 50 years in age.

Forest Management Objectives

The main objective for the woodlot is to maintain a thriving canopy of Scots pine and other conifers which provides shade, wildlife habitat and beautification to the surrounding landscape while ensuring the stand has the ability to sustain these functions as it responds to future storm events, and other natural disturbances.

Methods: Prescriptions and Implementation

Two key short-term activities were implemented to achieve the management objective for the woodlot:

1) reduce the density and proliferation of buckthorn and Manitoba maple species from the understory; and

2) implement tree and shrub plantings to ensure the growing space previously occupied by invasive species is quickly captured by desired vegetation. These plantings will serve as the future growing stock to replace overstory trees as they naturally senesce or are thinned from the plantation in future years.

Garlon™ RTU (Trylcopyr) herbicide was selected as the chemical control method because this pesticide can be applied with a hand spray bottle, has little to no drift, and only requires the use of a small amount of pesticide, thereby minimizing unwanted exposure to the operator and to the environment. Treatment was applied on June 26, 2015. The weather conditions were sunny, dry and warm. All buckthorn and Manitoba maple saplings smaller than 5 cm DBH were sprayed at their base with a band of herbicide 10-20 cm tall which completely surrounded the stem (Figure 2). Larger stems of were girdled with two parallel cuts to the stem near the ground which where were subsequently treated with herbicide (Figure 3). Stems located near trail were cut to the ground and herbicide sprayed to cover the entire cambium of the stem. All other stems were left standing to die and eventually fall over naturally.

Figure 2: Garlon™ RTU being applied to a buckthorn sapling.

This treatment was followed by the planting of 100 deciduous trees and shrubs of a variety of native species (e.g., sugar maple, bur oak, ironwood, American elderberry, American basswood and serviceberry among others) on September 16, 2015 throughout the treated area at a spacing of 5-10 m (Figure 4). This was then supplemented with 650 seedlings of white pine, and white cedar planted on April 29, 2016 at approximately 3-meter spacing (Figure 5).

The work required six people to implement the girdling, cutting and herbicide application and tree planting required 3 people. Total cost for each activity was approximately $5,000 (or $7,500/ha).

Figure 3: Example of how the large buckthorn specimens were girdled.

Figure 4: 2-gallon potted sugar maple planted on September 16, 2015.

Figure 5: Bareroot white cedar and white pine planted on April 29, 2016.

Figure 6: All treated buckthorn and Manitoba maple are stems (shown above with brown leaves) were killed within 1 month following treatment with Garlon™ RTU. The green leaved tree on the left is a thriving black cherry.

Research and follow-up monitoring

Monitoring of the forest's response to this treatment is on-going. Post treatment inspections have shown the application of Garlon™ RTU to be highly effective with mortality in all treated stems by the end of July within 1 month of treatment (Figure 6). First year survival of trees and shrubs was high. Herbivory by rabbits and some vandalism tended to be the main causes of tree damage.

Results and Lessons Learned

The two treatments implemented to help achieve the objective for the Scots pine plantation were highly effective; Garlon™ RTU eliminated the heavy shade cast by buckthorn and Manitoba maple; and tree and shrub planting introduced new species and trees to the understory which would not otherwise have developed. As the same time, a variety of native and naturalized herbaceous plants have grown into the understory to further introduce diversity to the woodlot.

The following silvicultural tasks will be continued requirements over the next 5 to 10 years to promote growth of established tree regeneration,

- Managing buckthorn regeneration where it significantly competes for sunlight. For seedlings, this can be achieved by hand pulling.
- Supplemental tree planting to fill gaps as they may occur.
- Monitoring and possible control of other unwanted plants which may proliferate and impact desired successional processes.
- Periodic felling of Scots pine may be required to maintain growth and vigor of planted seedlings and saplings so they develop with good form. The pine overstory is expected to dominate the site for many more years.

References

Lloyd, R.D. 1995. Pride, Prejudice and Politics. A History of the Lloyd Family in Wales, Pennsylvania and Ontario. Part III (a) The Ontario Years. Toronto.

LSRCA. 2012. East Holland River Project: 2007 – 2012. Final Report. 10p.

LSRCA. 2000. State of the Watershed Report. East Holland River Subwatershed. 129p.

Case Study #8

Variable Density Thinning: Increasing diversity and resilience in red pine plantations

Authors: Ken Elliott, R.P.F. OMNRF; Dr. Bill Parker, OMNRF-OFRI; Steve Williams, R.P.F. OMNRF (retired)

Supporting partners: St. Williams Conservation Reserve Community Council; Bird Studies Canada; Guelph U.; U. of Waterloo; McMaster U., Trent U.; U. of Toronto.

Introduction and Background

In southern Ontario there are tens of thousands of hectares of red pine plantations established to protect blowsands during the early part of the last century. As these stands have matured, concerns about their uniformity and incidences of decline have left land managers looking for ways to diversify and move them towards a more "natural" condition.

This study began in 2011 as an MNRF collaboration between district forester Steve Williams (retired) of Aylmer District, Ontario Forest Research Institute (OFRI) scientist Dr. Bill Parker and Sr. Program Advisor Ken Elliott. Researchers continue to work with Aylmer District staff, as well as the Community Council for the St. Williams Conservation Reserve, to ensure the work matches the goals of the area's management plan (see Figure 1).

Figure 1: An aerial overview of the Variable Density Thinning trial, Block A, following the initial canopy treatments.

Site Location: The Turkey Point Tract of the St. Williams Conservation Reserve (SWCR) in Norfolk County, Ontario, Canada (42°42'20.455"N, 80°21'17.086"W)

Landscape Context: The two stands used in this trial are located within the large forested Turkey Point Tract of the SWCR. The SWCR is one of the largest blocks of forest in the Carolinian Life Zone (Site Region 7E) of extreme southern Ontario and is recognized regionally, provincially, and nationally for its exceptional biological diversity and natural heritage values. The combined diversity of oak savanna, Carolinian forests, maturing conifer plantations and wetland habitats support one of the highest remaining concentrations of species-at-risk in Ontario and Canada. The SWCR is also internationally recognized as a natural heritage area within and adjacent to the Long Point World Biosphere Reserve, a United Nations Education, Scientific and Cultural Heritage Site.

Site Conditions: The two stands comprising 21 ha of gently rolling deep very fine dry sands were planted in 1941 (Block A) and 1943 (Block B). Records show that one stand was thinned in 1982 and the other in 1987. This was likely a second thinning however there is no recorded date for this previous treatment. Prior to the most recent thinning, the stand had 100% crown closure with approximately 576 stems/ha and a basal area of 37.7 m^2/ha.

Species: Red pine was the main species planted, however there is the odd maturing white pine, black oak and black cherry in the overstory and surrounding hedgerows. The understory is mostly comprised of young and advanced red maple, white pine, black oak, black cherry and sassafras.

Forest Management Objectives

The objective is provide the conditions to allow for a transition to mixed natural forest with primarily Carolinian upland dry to dry-fresh mixed forest (ELC FOM1 or FOD1 communities) with legacy mature red pine trees in clumps and as individual super canopy trees overtopping the younger mixed forest. As compared to traditional uniform thinning, the patch mosaic created by a combination of skips (no vegetation management), gaps (removal of all or most trees) and traditional vegetation management (single tree – based even-aged thinning) in red pine should improve species diversity, ecological complexity and biological diversity, and importantly, enhance the natural succession and restoration of these plantations to native forest types. Since biodiversity is positively related to the capacity of forest vegetation to resist and recover from environmental stresses, it is expected that VDT will improve the capacity of the stand to weather the increasing frequency and magnitude of stresses associated with future climate change.

Wildlife trees – trees with stick nests (some with buffers) or cavities or mast producers were retained; dead standing trees (snags) were also retained where it was safe (especially in control blocks and aggregate retention patches).

Stubs – 80 artificially created snags were made by using the mechanical harvester to cut trees off at 3 to 4 m above the ground. We identified 4 to 6 trees lower quality trees for this stubbing cut per treatment block (see Figure 2).

Figure 2: A mature red pine was cut at a height of 3 to 4 m by the mechanical harvester to create a "stub", which will emulate a snag in a natural stand. This provides structural diversity to the stand.

Biodiversity, Climate Change and Resilience: It is expected that the increase in heterogeneity across the site will increase the opportunities for various species of plants, insects, wildlife, soil micro-organisms etc. to colonize and utilize the site, including the eastern hognose snake and eastern whippoorwill. Resilience through diversity should allow the site to respond better to changes in climate and other threats.

Recreational Uses: The Conservation Reserve and surrounding set of public lands are popular with hikers, birders and trail users of all sorts including small motorized vehicles. The Conservation Council in consultation with MNRF maintains a designated trail system which does cross this site and has been proven to be a compatible use.

Methods

In February 2014, the stand was thinned a third time using variable retention harvesting (VRH) or variable density (VDT) thinning. The stand was originally planted in a grid pattern, and was then divided into 21 blocks of approximately 1 hectare (0.89 ha average) in size and each block was randomly subjected to one of five treatments for a total of four replicates of each treatment (See Figure 3). The five treatments were as follows: dispersed retention (i.e. uniformly spaced) at 55% crown closure (approximately 240 trees remaining in each block with 6 m spacing between trees), dispersed retention at 33% crown closure (approximately 145 trees remaining in each block with 7.5 m spacing between trees), aggregated retention at 55% crown closure (set of 4 circular patches per block, See Figure 5), aggregated retention at 33% crown closure and control blocks with no cutting or removal of trees.

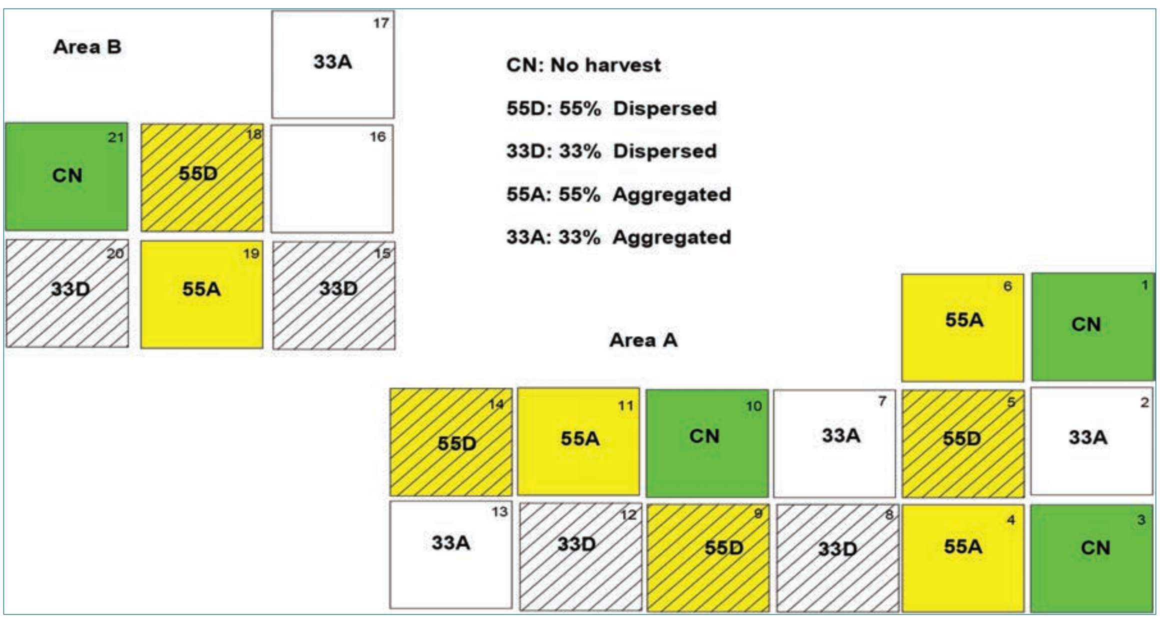


Figure 3: Variable density thinning treatment assignment to 21 blocks in study areas A and B. Block 16 was thinned at 55D but not used in the experiment.

Prescriptions and Implementation

Preliminary data was collected in the fall of 2011 to characterize stand structure and composition and provide the necessary data to design and implement a VDT trial at the SWCR. Through a review of this data, a few site visits by the project team, and consultation with the scientific literature and other experts, the project team was able to finalize a prescription package in March, 2013.

In this application of the VDT approach, crown closure was chosen as the measure to be used in adjusting the variability of the stand structure. As well, reasonably different conditions within each of the five treatment types was a target. The residual crown closure targets 55% (regeneration cut) and 33% (first removal cut) were chosen to loosely match existing direction for pine shelterwood system in Ontario today (see Figure 4).

Figure 4: Photos taken from the ground looking up into the canopy following treatment. Photo on the left shows a crown closure of 55%, and the one on the right shows a crown closure of 33%.

The dispersed/thinning prescription and marking are standard approaches that were familiar to the project team. The methods designed to accommodate the aggregate approach were developed through some iterative on the ground testing and measuring. It was basically a geometry exercise using 4 circles of two sizes designed to get the right crown area per block (Figure 5). Implementation required some adjustments to the location and shape of retained patches in order to accommodate existing mortality areas.

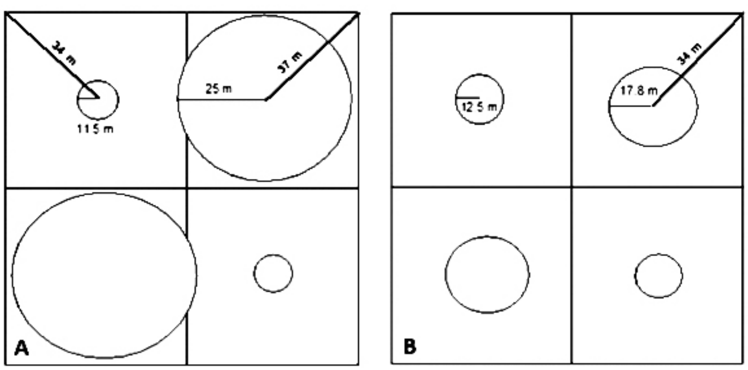


Figure 5: Diagram of aggregated retention in blocks with (A) 55% retention and (B) 33% retention. Blocks were divided into four quadrants (average length 51m, average width 42m) and each block had two quadrants with large retention patches and two with small patches. Equal sized patches occurred along the diagonal of each block. In 55% retention blocks, large 25 m radius patches were centered 37m from the corner on a 45° angle while small 11.5 m radius patches were centered 34m from the corner. All patches (large – 17.8 m radius, small – 12.5m radius) in the 33% retention blocks were centered 34m from the corner.

The completely randomized experimental design will enable a quantitative assessment of VDT effects on understory vegetation, etc., greatly increasing the value of monitoring for thinning effects. As well, the random assignment of the 5 treatments will create a heterogeneous canopy structure across the entire study area, consistent with the objectives of VDT as an ecological forestry approach.

Tree marking: Through the winter of 2012-2013, the project leaders identified all the aggregate retention patches using blue paint on the perimeter trees. The mark-and-tally tree marking was conducted by a contractor in April 2013. All trees for removal were marked with orange and tallied for volume calculations by block. In conjunction with the marking, a stick nest survey was conducted in order to mark trees and buffers for any nests requiring this consideration.

Wildlife trees: Standing dead trees provide valuable habitat features for wildlife feeding and nest cavities. 'Snags" (dead trees) and cavity trees are in relatively short supply in managed stands such as this and through harvesting the operators fell many of the existing "snags" and "chicots" (dead tree or limb that may endanger a worker) for safety reasons. The felled snag trees are left on the ground as a source of downed woody material to enhance habitat and stand complexity. To accommodate the loss of natural snags, an experiment was implemented to create new snags through "stubbing". A "stub" *is defined as a live tree that has been cut (and killed) well above the normal stump height (i.e.,3-5 m)*.

A total of 85 trees in the trial area were identified for stubbing, five trees per harvested block plus 1 additional tree in blocks where natural snag numbers were low (80 stubs were left following harvesting). Trees were selected from trees previously identified for removal, and further marked as a stub tree with an "S" and a consecutive number. A GPS coordinate, dbh and notes on tree condition were taken on each stub tree.

Harvest operations: A tender was put out for the harvest and the successful bid awarded in September 2013. The harvesting occurred in February 2014 under the support and careful eye of the Aylmer District MNRF and the SWCR Community Council. The operator was able to carefully work around identified seed trees, wildlife trees and residual hardwood regeneration patches and conduct the stubbing needed after some adjustments were made to make these trees easier to identify.

Financial Considerations: Managed red pine stands of this age provide a fantastic opportunity for "self-supporting restoration". The operations were conducted with significant revenue generation and with easy operating conditions for the contractor. The stubbing requirement was a first for the operator and he was not charged for stubbed tree tops that he could utilize. This was agreed to as a reasonable compromise on the time needed to work slowly and carefully in retaining these stubs.

Research and monitoring: This trial at the SWCR is the first research application of VDT in Ontario, and the first experiment anywhere to evaluate VDT as a method to restore red pine plantations to native forest types. As such, a strong research component to the monitoring and assessment of VDT on various ecosystem components is essential. Given the innovative nature of this study, the experiment provides a unique opportunity for local Universities and government agencies to become involved in a significant collaborative research project. As the VDT trial evolved, the project team was able to interest researchers from Bird Studies Canada, U. Guelph, U. Waterloo, McMaster U., Trent U. and U. of Toronto to join the research team and to lend their respective expertise to monitoring VDT responses of understory vegetation, bird populations, cavity users, nutrient cycling, mycorrhizae, insects, tree growth, carbon sequestration, soil respiration and soil invertebrates.

Figure 6a. Left Photo: September 4th, 2014 photo of Dr. Bill Parker taking hemispherical photo of Block 15 which is a replication of the 33% dispersed crown closure treatment - a uniform thinning pattern. Right Photo: September 4th, 2014 photo of morning sunlight shinning into an uncut Control block from an opening in an adjacent block with 33% canopy retention in aggregate patches.

Results and Lessons Learned

Although it is still early in the life of this experiment, it is already quite evident that 5 distinct structural conditions have been created out of what used to be a single high canopy layer. Light, moisture and other environmental variables are more diverse now and in response we can see that the understory vegetation and wildlife are beginning to utilize the new niches that have been created. Monitoring of the stubs has shown an immediate response by bark beetles and wood borers which in turn has created a food source for woodpeckers. The increase in light and growing space across many of the treatments is allowing for increased growth on both the residual trees and the advanced regeneration. New seedlings have become established and birds adapted to canopy gaps and more open habitats have become interested in the site.

Appendices

Appendix 1 - Species Suitability and Productivity

The choice of species depends on many factors, including the site (mainly the soils and climate) and the objectives of forest management. On productive sites, several species may grow well; on poor sites, even the most suitable species may grow poorly. Thus, landowners may want to select species with a higher growth rate or species that will not grow as well, but that will survive and protect the site. Growth rates and fibre production are strongly correlated with the site index, and extensive fieldwork was conducted in southern Ontario in an effort to link the site index to soil properties for each species. Taylor and Jones (1986a,b) measured trees across a range of soil textures and depths to mottling (an indicator of drainage) to determine the site index range. Their results are summarized here. The original source is Taylor & Jones (1986a) and updated as Taylor & Jones (1986b). The tables also appear in Appendix D of the southern Ontario Silviculture Guide. There are minor differences between all three publications. Taylor & Jones 1986b is used here.

Table 7.1.1: An example of productivity data from Table 7.1.2. This example shows the predicted productivity of coniferous species as a function of soil texture, depth to mottles (a proxy for drainage), and site region. It has been modified slightly to illustrate the formatting conventions. The productivity rating is followed, in brackets, by the range of site index values. This example is for gravelly sandy soils with a depth to mottles > 150 cm in site region 6E.

Species	**Depth to mottles > 150 cm**	
European larch	*(Poor) (19.0 - 20.9)*	Italics indicate subjective extrapolation of site class, no data collected
Red pine	**Mod (19.0 - 20.9)/Poor r (17.0 - 18.9)**	“r” indicates site class when a root restricting layer occurs within the top 60 cm of the soil, e.g. a sandy soil overlying a clay
White pine	**V Poor (< 19.9)**	white cells with data indicate poor or very poor productivity
Norway spruce	**Mod*c (23.0 - 24.9)**	green cells indicate moderate to very good productivity
Scots pine	n.a.	n.a. indicates no data
White spruce	**Good* (24.0 - 25.9)/V Poor*c (< 19.9)**	asterisk indicates insufficient data for proper site class prediction “c” indicates site class when free carbonates are within the top 50 cm of the soil

Table 7.1.2: The predicted productivity is given by site region, species, soil texture (see Table 2.1) and depth to distinct mottles.

The SI range associated with the productivity rating varies by species. The productivity rating is followed, in brackets, by the site index range.

Ratings in brackets, with grey, italic font indicates subjective extrapolation of site class – no data collected.

n.a. indicates no data.

Green cells indicate Moderate to Very Good productivity.

White cells indicate Poor or Very Poor productivity.

"*" indicates insufficient data for proper site class prediction

"c" indicates site class when free carbonates are within the top 50 cm of the soil

"r" indicates site class when a root restricting layer occurs within the top 60 cm of the soil, e.g., a sandy soil overlying a clay.

Species code	Species
Le	European larch
Pr	Red pine
Pw	White pine
Sn	Norway spruce
Sw	White spruce
Aw	White ash
Bd	Basswood
Be	Beech
Bu	Butternut
Cb	Black cherry
Mh	Hard (sugar) maple
Mr	Soft (red) maple
Ms	Silver maple
Or	Red oak
Ow	White oak
Wb	Black walnut

Spp	Depth to mottling						
	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
	SITE REGION 6E						
	Very Gravelly						
Le	**V Poor* (< 18.9)**	**Mod* (21.0 - 22.9)**	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pr	**Mod (19.0 - 20.9)/V Poor c (< 16.9)**	**Mod (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*
Pw	**Poor* (20.0 - 21.9)/V Poor c (< 19.9)**	**Good* (24.0 - 25.9)**	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*
Sn	*(V Poor) (< 20.9)*	*(Poor) (21.0 - 22.9)*	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*	*(V Poor) (< 20.9)*	*(V Poor) (< 20.9)*
Sw	**V Poor (< 19.9)**	*(Poor) (20.0 - 21.9)*	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Aw	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Bd	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Be	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cb	**Poor (18.0 - 19.9)**	*(Mod) (20.0 - 21.9)*	*(Mod) (20.0 - 21.9)*	*(Mod) (20.0 - 21.9)*	n.a.	n.a.	n.a.
Mh	**Poor (16.0 - 17.9)**	*(Mod) (18.0 - 19.9)*	*(Mod) (18.0 - 19.9)*	*(Mod) (18.0 - 19.9)*	**Poor (16.0 - 17.9)**	n.a.	n.a.
Mr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	**Poor* (18.0 - 19.9)**	**Good* (22.0 - 23.9)**	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.	n.a.
	Gravelly Sandy						
Le	*(Poor) (19.0 - 20.9)*	*(Good) (23.0 - 24.9)*	*(Good) (23.0 - 24.9)*	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*
Pr	**Mod (19.0 - 20.9)/ Poor c (17.0 - 18.9)**	**Mod* (19.0 - 20.9)**	**Mod* (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*
Pw	**V Poor (< 19.9)**	*(Mod) (22.0 - 23.9)*	**Mod (22.0 - 23.9)**	*(Good) (24.0 - 25.9)*	**Poor (20.0 - 21.9)**	**V Poor* (< 19.9)**	*(V Poor) (< 19.9)*
Sn	**Mod*c (23.0 - 24.9)**	**Good*c (25.0 - 26.9)**	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*	**V Poor* (< 20.9)**	*(V Poor) (< 20.9)*
Sw	**Good* (24.0 - 25.9)/V Poor*c (< 19.9)**	*(Mod) (22.0 - 23.9)*	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)/(V Poor)c (< 19.9)*	*(Poor) (20.0 - 21.9)*	**V Poor* (< 19.9)**	*(V Poor) (< 19.9)*
Aw	**Mod* (21.0 - 22.9)**	*(Good) (23.0 - 24.9)*	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Bd	*(Poor) (17.0 - 18.9)*	**Mod* (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	n.a.	n.a.
Be	**Poor* (16.0 - 17.9)**	*(Mod) (18.0 - 19.9)*	*(Poor) (16.0 - 17.9)*	*(V Poor) (< 15.9)*	*(V Poor) (< 15.9)*	n.a.	n.a.
Cb	*(Mod) (20.0 - 21.9)*	**Good (22.0 - 23.9)**	*(Mod) (20.0 - 21.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.	n.a.

Spp	Depth to mottling > 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Mh	**Mod (18.0 - 19.9)**	*(Good) (20.0 - 21.9)*	*(Poor) (16.0 - 17.9)*	*(Poor) (16.0 - 17.9)*	*(V Poor) (< 15.9)*	n.a.	n.a.
Mr	*(Mod) (20.0 - 21.9)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	**Poor (18.0 - 19.9)**	*(Good) (22.0 - 23.9)*	*(Good) (22.0 - 23.9)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.
	Sandy						
Le	**Mod (21.0 - 22.9)**	**Good (23.0 - 24.9)**	*(V Good) (≥ 25.0)*	**V Good (≥ 25.0)**	*(Good) (23.0 - 24.9)*	*(Mod) (21.0 - 22.9)*	*(V Poor) (< 18.9)*
Pr	**Mod (19.0 - 20.9)**	**Good (21.0 - 22.9)**	**V Good (≥ 23.0)**	**V Good (≥ 23.0)/Mod r (19.0 - 20.9)**	**Good (21.0 - 22.9)**	**Mod (19.0 - 20.9)**	**Poor (17.0 - 18.9)**
Pw	**Poor (20.0 - 21.9)**	**Good (24.0 - 25.9)**	**V Good (≥ 26.0)**	**Good (24.0 - 25.9)**	**Mod (22.0 - 23.9)**	**Poor* (20.0 - 21.9)**	**V Poor (< 19.9)**
Sn	**Poor (21.0 - 22.9)**	**V Good (≥ 27.0)**	**V Good* (≥ 27.0)**	*(Good) (25.0 - 26.9)*	**Poor (21.0 - 22.9)**	*(Poor) (21.0 - 22.9)*	*(V Poor) (< 20.9)*
Sw	**Mod (22.0 - 23.9)/V Poor*c (< 19.9)**	**Mod (22.0 - 23.9)**	**Good (24.0 - 25.9)**	**V Good (≥ 26.0)**	**Mod (22.0 - 23.9)**	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*
Aw	**Good (23.0 - 24.9)**	*(Mod) (21.0 - 22.9)*	*(Good) (23.0 - 24.9)*	*(Mod) (21.0 - 22.9)*	**Mod (21.0 - 22.9)**	**Poor (19.0 - 20.9)**	n.a.
Bd	**Poor*cr (17.0 - 18.9)**	**Good* (21.0 - 22.9)**	**Mod* (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	n.a.
Be	**Poor* (16.0 - 17.9)**	**Good* (20.0 - 21.9)**	*(Mod) (18.0 - 19.9)*	*(Poor) (16.0 - 17.9)*	*(Poor) (16.0 - 17.9)*	n.a.	n.a.
Cb	**Poor* (18.0 - 19.9)**	*(Mod) (20.0 - 21.9)*	**Good* (22.0 - 23.9)**	**V Good (≥ 24.0)**	**Mod (20.0 - 21.9)**	*(Poor) (18.0 - 19.9)*	n.a.
Mh	**Mod (18.0 - 19.9)**	**V Good (≥ 22.0)**	**Mod (18.0 - 19.9)**	**Poor* (16.0 - 17.9)**	**Poor* (16.0 - 17.9)**	n.a.	n.a.
Mr	**Mod* (20.0 - 21.9)**	*(V Good) (≥ 24.0)*	**Good (22.0 - 23.9)**	**Mod* (20.0 - 21.9)**	**Poor* (18.0 - 19.9)**	**Poor* (18.0 - 19.9)**	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	*(Mod) (20.0 - 21.9)*	**Mod* (20.0 - 21.9)**	*(Poor) (18.0 - 19.9)*
Or	**Poor (18.0 - 19.9)**	**Good* (22.0 - 23.9)**	*(V Good) (≥ 24.0)*	**V Good (≥ 24.0)**	**Mod (20.0 - 21.9)**	*(Poor) (18.0 - 19.9)*	n.a.
	Gravelly Loamy						
Le	**Mod* (21.0 - 22.9)**	*(Good) (23.0 - 24.9)*	**Mod* (21.0 - 22.9)**	**Poor* (19.0 - 20.9)**	**Poor* (19.0 - 20.9)**	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*
Pr	**Mod (19.0 - 20.9)**	*(Mod) (19.0 - 20.9)*	*(Good) (21.0 - 22.9)*	*(Mod) (19.0 - 20.9)*	**Mod (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*
Pw	**Mod (22.0 - 23.9)/V Poor c (< 19.9)**	**Good (24.0 - 25.9)**	*(V Good) (≥ 26.0)*	*(Mod) (22.0 - 23.9)*	**Poor (20.0 - 21.9)**	**V Poor (< 19.9)**	*(V Poor) (< 19.9)*
Sn	**Mod (23.0 - 24.9)**	**V Good* (≥ 27.0)**	**V Good* (≥ 27.0)**	**Good (25.0 - 26.9)/ Poor*cr (21.0 - 22.9)**	**Mod* (23.0 - 24.9)**	**Mod (23.0 - 24.9)**	**V Poor*cr (< 20.9)**
Sw	*(Mod) (22.0 - 23.9)*	**Good* (24.0 - 25.9)**	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)/V Poor cr (< 19.9)*	**V Poor (< 19.9)**	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Aw	**Mod (21.0 - 22.9)**	**V Good (≥ 25.0)**	*(Good) (23.0 - 24.9)*	**Good* (23.0 - 24.9)**	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	n.a.

	Depth to mottling						
Spp	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Bd	**Poor* (17.0 - 18.9)**	*(Good) (21.0 - 22.9)*	*(Mod) (19.0 - 20.9)*	**Poor* (17.0 - 18.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	n.a.
Be	*(Poor) (16.0 - 17.9)*	*(Mod) (18.0 - 19.9)*	*(Mod) (18.0 - 19.9)*	*(Mod) (18.0 - 19.9)*	*(Poor) (16.0 - 17.9)*	n.a.	n.a.
Cb	**Poor (18.0 - 19.9)**	**Good* (22.0 - 23.9)**	*(Good) (22.0 - 23.9)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.
Mh	**Mod (18.0 - 19.9)**	**Mod* (18.0 - 19.9)**	*(Mod) (18.0 - 19.9)*	**Good (20.0 - 21.9)**	*(Poor) (16.0 - 17.9)*	*(V Poor) (< 15.9)*	n.a.
Mr	*(Mod) (20.0 - 21.9)*	*(Good) (22.0 - 23.9)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	*(Poor) (18.0 - 19.9)*	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	*(Poor) (18.0 - 19.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*
Or	*(Mod) (20.0 - 21.9)*	*(Good) (22.0 - 23.9)*	*(V Good) (≥ 24.0)*	**Good* (22.0 - 23.9)**	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	n.a.
	Coarse Loamy						
Le	**Mod (21.0 - 22.9)**	**V Good* (≥ 25.0)**	**V Good* (≥ 25.0)**	**Good (23.0 - 24.9)**	**Good (23.0 - 24.9)**	**Poor (19.0 - 20.9)**	*(V Poor) (< 18.9)*
Pr	**V Good (≥ 23.0)/V Poor cr (< 16.9)**	*(V Good) (≥ 23.0)/(V Poor) c (< 16.9)*	**Good (21.0 - 22.9)/V Poor r (< 16.9)**	**V Good (≥ 23.0)/V Poor c (< 16.9)**	**Mod (19.0 - 20.9)**	**Mod* (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*
Pw	**Mod (22.0 - 23.9)/V Poor c (< 19.9)**	**V Good (≥ 26.0)/V Poor* c (< 19.9)**	**Good (24.0 - 25.9)**	**Good (24.0 - 25.9)**	**Mod (22.0 - 23.9)**	**Mod (22.0 - 23.9)/V Poor c (< 19.9)**	**Poor (20.0 - 21.9)/V Poor*c (< 19.9)**
Sn	**Good (25.0 - 26.9)**	**V Good (≥ 27.0)**	**V Good* (≥ 27.0)**	**Good* (25.0 - 26.9)**	**Mod (23.0 - 24.9)**	**Good (25.0 - 26.9)**	**Mod (23.0 - 24.9)**
Sw	**Mod (22.0 - 23.9)**	**Good (24.0 - 25.9)**	*(V Good) (≥ 26.0)*	**Mod (22.0 - 23.9)**	**Mod (22.0 - 23.9)/V Poor cr (< 19.9)**	**Poor (20.0 - 21.9)**	**V Poor (< 19.9)**
Aw	**Mod (21.0 - 22.9)**	**V Good (≥ 25.0)**	**Good* (23.0 - 24.9)**	**Mod (21.0 - 22.9)**	**Mod (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*	n.a.
Bd	**Poor (17.0 - 18.9)**	**V Good (≥ 23.0)**	*(V Good) (≥ 23.0)*	**Poor* (17.0 - 18.9)**	**Mod (19.0 - 20.9)**	**V Poor* (< 16.9)**	n.a.
Be	**Mod (18.0 - 19.9)**	**Mod (18.0 - 19.9)**	*(V Good) (≥ 22.0)*	*(Good) (20.0 - 21.9)*	**Good* (20.0 - 21.9)**	n.a.	n.a.
Cb	**Mod (20.0 - 21.9)**	**V Good (≥ 24.0)**	*(V Good) (≥ 24.0)*	**Mod* (20.0 - 21.9)**	**Good* (22.0 - 23.9)**	**Mod* (20.0 - 21.9)**	n.a.
Mh	**Mod (18.0 - 19.9)**	**V Good (≥ 22.0)**	**Good (20.0 - 21.9)**	**Good (20.0 - 21.9)**	**Mod (18.0 - 19.9)**	*(V Poor) (< 15.9)*	n.a.
Mr	*(Mod) (20.0 - 21.9)*	*(V Good) (≥ 24.0)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	**Mod* (20.0 - 21.9)**	**Poor* (18.0 - 19.9)**	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	**Mod* (20.0 - 21.9)**	**Mod (20.0 - 21.9)**	**Poor* (18.0 - 19.9)**
Or	**Mod (20.0 - 21.9)**	**V Good* (≥ 24.0)**	**V Good (≥ 24.0)**	**Mod* (20.0 - 21.9)**	**Mod* (20.0 - 21.9)**	**Poor* (18.0 - 19.9)**	*(V Poor) (< 17.9)*
	Silty						
Le	**V Good (≥ 25.0)**	*(V Good) (≥ 25.0)*	*(Good) (23.0 - 24.9)*	*(Mod) (21.0 - 22.9)*	**Poor (19.0 - 20.9)**	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*
Pr	**Good (21.0 - 22.9)**	**Mod (19.0 - 20.9)/ Poor cr (17.0 - 18.9)**	**V Good (≥ 23.0)**	**Good (21.0 - 22.9)/V Poor r (< 16.9)**	**Good (21.0 - 22.9)/V Poor r (< 16.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*
Pw	**Mod (22.0 - 23.9)**	*(Good) (24.0 - 25.9)*	**Mod* (22.0 - 23.9)**	**Mod* (22.0 - 23.9)**	**Mod (22.0 - 23.9)/V Poor cr (< 19.9)**	**Poor* (20.0 - 21.9)**	**V Poor (< 19.9)**

	Depth to mottling						
Spp	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Sn	**Mod* (23.0 - 24.9)**	*(V Good) (≥ 27.0)*	*(V Good) (≥ 27.0)*	**Mod* (23.0 - 24.9)**	**Good (25.0 - 26.9)**	**Good* (25.0 - 26.9)**	*(Poor) (21.0 - 22.9)*
Sw	**V Good (≥ 26.0)**	**Good* (24.0 - 25.9)**	*(V Good) (≥ 26.0)*	**Mod (22.0 - 23.9)**	**Mod (22.0 - 23.9)**	**Poor (20.0 - 21.9)**	*(Poor) (20.0 - 21.9)*
Aw	**Good* (23.0 - 24.9)**	*(V Good) (≥ 25.0)*	*(V Good) (≥ 25.0)*	*(Mod) (21.0 - 22.9)*	**Poor* (19.0 - 20.9)**	*(V Poor) (< 18.9)*	n.a.
Bd	**Poor* (17.0 - 18.9)**	*(Mod) (19.0 - 20.9)*	*(Good) (21.0 - 22.9)*	*(Mod) (19.0 - 20.9)*	*(Mod) (19.0 - 20.9)*	**Mod* (19.0 - 20.9)**	n.a.
Be	**Poor* (16.0 - 17.9)**	*(Mod) (18.0 - 19.9)*	*(V Good) (≥ 22.0)*	*(Good) (20.0 - 21.9)*	*(Mod) (18.0 - 19.9)*	n.a.	n.a.
Cb	**Mod* (20.0 - 21.9)**	*(V Good) (≥ 24.0)*	**V Good* (≥ 24.0)**	*(Mod) (20.0 - 21.9)*	**Poor* (18.0 - 19.9)**	*(V Poor) (< 17.9)*	n.a.
Mh	**Mod (18.0 - 19.9)**	**V Good (≥ 22.0)**	**Good (20.0 - 21.9)**	**Good (20.0 - 21.9)**	**Mod (18.0 - 19.9)**	*(V Poor) (< 15.9)*	n.a.
Mr	*(Good) (22.0 - 23.9)*	*(V Good) (≥ 24.0)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	*(V Poor) (< 17.9)*	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	*(Mod) (20.0 - 21.9)*	*(V Good) (≥ 24.0)*	*(Good) (22.0 - 23.9)*
Or	*(Mod) (20.0 - 21.9)*	*(V Good) (≥ 24.0)*	*(V Good) (≥ 24.0)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	*(V Poor) (< 17.9)*
	Fine Loamy						
Le	**Poor* (19.0 - 20.9)**	*(Mod) (21.0 - 22.9)*	*(Good) (23.0 - 24.9)*	**Mod* (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pr	**V Good* (≥ 23.0)**	*(Mod) (19.0 - 20.9)*	**Good* (21.0 - 22.9)**	**Good (21.0 - 22.9)**	**Good (21.0 - 22.9)**	**Poor* (17.0 - 18.9)**	*(V Poor) (< 16.9)*
Pw	**Poor (20.0 - 21.9)**	**Good* (24.0 - 25.9)/V Poor cr (< 19.9)**	*(Good) (24.0 - 25.9)*	**Poor* (20.0 - 21.9)**	**Mod (22.0 - 23.9)/V Poor cr (< 19.9)**	**V Poor (< 19.9)**	*(Poor) (20.0 - 21.9)*
Sn	**Mod (23.0 - 24.9)**	*(V Good) (≥ 27.0)*	*(Good) (25.0 - 26.9)*	*(Good) (25.0 - 26.9)*	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	*(V Poor) (< 20.9)*
Sw	**Poor (20.0 - 21.9)**	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*	**V Poor (< 19.9)**	**Poor (20.0 - 21.9)**	**Mod (22.0 - 23.9)**	**Poor (20.0 - 21.9)**
Aw	**Mod (21.0 - 22.9)**	**V Good* (≥ 25.0)**	**Mod* (21.0 - 22.9)**	**Mod* (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*	**V Poor* (< 18.9)**	n.a.
Bd	*(Poor) (17.0 - 18.9)*	**Mod (19.0 - 20.9)**	**Mod (19.0 - 20.9)**	**Poor* (17.0 - 18.9)**	**Poor* (17.0 - 18.9)**	**V Poor* (< 16.9)**	n.a.
Be	*(Poor) (16.0 - 17.9)*	*(Mod) (18.0 - 19.9)*	*(Good) (20.0 - 21.9)*	*(Good) (20.0 - 21.9)*	**Good* (20.0 - 21.9)**	n.a.	n.a.
Cb	**Good (22.0 - 23.9)**	**Good* (22.0 - 23.9)**	**Poor* (18.0 - 19.9)**	**Mod* (20.0 - 21.9)**	**Poor* (18.0 - 19.9)**	n.a.	n.a.
Mh	**Good (20.0 - 21.9)**	**V Good (≥ 22.0)**	**Good* (20.0 - 21.9)**	**Mod (18.0 - 19.9)**	**Mod (18.0 - 19.9)**	*(V Poor) (< 15.9)*	n.a.
Mr	**V Good* (≥ 24.0)**	*(V Good) (≥ 24.0)*	*(Good) (22.0 - 23.9)*	*(Mod) (20.0 - 21.9)*	**V Poor* (< 17.9)**	*(V Poor) (< 17.9)*	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	**Mod (20.0 - 21.9)**	*(Mod) (20.0 - 21.9)*
Or	*(Mod) (20.0 - 21.9)*	*(Good) (22.0 - 23.9)*	**Mod* (20.0 - 21.9)**	*(Mod) (20.0 - 21.9)*	*(Poor) (18.0 - 19.9)*	*(V Poor) (< 17.9)*	n.a.
	Clayey						
Le	n.a.	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pr	n.a.	*(V Poor) (< 16.9)*	**Mod* (19.0 - 20.9)**	**Poor* (17.0 - 18.9)**	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*

	Depth to mottling						
Spp	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Pw	n.a.	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)/V Poor cr (< 19.9)*	*(Poor) (20.0 - 21.9)*	*(Poor) (20.0 - 21.9)*	**Poor (20.0 - 21.9)**	*(V Poor) (< 19.9)*
Sn	n.a.	*(Mod) (23.0 - 24.9)*	*(Good) (25.0 - 26.9)*	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	**Poor (21.0 - 22.9)**	*(V Poor) (< 20.9)*
Sw	n.a.	**V Poor (< 19.9)**	*(Mod) (22.0 - 23.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*	**V Poor (< 19.9)**	*(V Poor) (< 19.9)*
Aw	n.a.	**Poor* (19.0 - 20.9)**	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	n.a.
Bd	n.a.	*(Poor) (17.0 - 18.9)*	**Poor* (17.0 - 18.9)**	*(Poor) (17.0 - 18.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	n.a.
Be	n.a.	*(Mod) (18.0 - 19.9)*	*(Mod) (18.0 - 19.9)*	*(Good) (20.0 - 21.9)*	n.a.	n.a.	n.a.
Cb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mh	n.a.	**Poor* (16.0 - 17.9)**	**Good (20.0 - 21.9)**	*(Poor) (16.0 - 17.9)*	*(V Poor) (< 15.9)*	n.a.	n.a.
Mr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	**V Good (≥ 24.0)**	**Mod (20.0 - 21.9)**
Or	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Shallow						
Le	n.a.	n.a.	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pr	n.a.	n.a.	**Good (21.0 - 22.9)**	*(Mod) (19.0 - 20.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*	*(V Poor) (< 16.9)*
Pw	n.a.	n.a.	**Poor (20.0 - 21.9)**	*(Mod) (22.0 - 23.9)*	**V Good (≥ 26.0)**	*(Mod) (22.0 - 23.9)*	**V Poor (< 19.9)**
Sn	n.a.	n.a.	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*	*(Mod) (23.0 - 24.9)*	*(V Poor) (< 20.9)*	*(V Poor) (< 20.9)*
Sw	n.a.	n.a.	*(Poor) (20.0 - 21.9)*	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Aw	n.a.	n.a.	**V Poor (< 18.9)**	**Mod* (21.0 - 22.9)**	**Poor* (19.0 - 20.9)**	n.a.	n.a.
Bd	n.a.	n.a.	**Mod* (19.0 - 20.9)**	*(Poor) (17.0 - 18.9)*	**Poor* (17.0 - 18.9)**	*(V Poor) (< 16.9)*	n.a.
Be	n.a.	n.a.	**V Poor* (< 15.9)**	*(V Poor) (< 15.9)*	*(V Poor) (< 15.9)*	n.a.	n.a.
Cb	n.a.	n.a.	**Poor* (18.0 - 19.9)**	**Mod (20.0 - 21.9)**	*(V Poor) (< 17.9)*	n.a.	n.a.
Mh	n.a.	n.a.	**Mod (18.0 - 19.9)**	**Mod (18.0 - 19.9)**	**V Poor (< 15.9)**	n.a.	n.a.
Mr	n.a.	n.a.	**Poor* (18.0 - 19.9)**	*(Poor) (18.0 - 19.9)*	*(Mod) (20.0 - 21.9)*	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	n.a.	n.a.	*(V Poor) (< 17.9)*	*(Poor) (18.0 - 19.9)*	n.a.	n.a.	n.a.

Spp	Depth to mottling > 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
				SITE REGION 7E			
	Very Gravelly						
Le	*(Poor) (20.0 - 21.9)*	**Good* (24.0 - 25.9)**	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Pr	**V Poor* (< 18.9)**	**Mod* (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pw	**V Poor* (< 21.9)**	*(Poor) (22.0 - 23.9)*	*(Mod) (24.0 - 25.9)*	*(Mod) (24.0 - 25.9)*	*(Poor) (22.0 - 23.9)*	*(V Poor) (< 21.9)*	*(V Poor) (< 21.9)*
Sn	*(Poor) (23.0 - 24.9)*	*(Good) (27.0 - 28.9)*	*(Good) (27.0 - 28.9)*	*(Mod) (25.0 - 26.9)*	*(Poor) (23.0 - 24.9)*	*(V Poor) (< 22.9)*	*(V Poor) (< 22.9)*
Sw	*(V Poor) (< 20.9)*	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*	*(Poor) (21.0 - 22.9)*	*(V Poor) (< 20.9)*	*(V Poor) (< 20.9)*
Aw	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Bd	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Be	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Bu	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mh	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	*(V Poor) (< 19.9)*	*(Poor) (20.0 - 21.9)*	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*	n.a.	n.a.	n.a.
Ow	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Wb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Gravelly Sandy						
Le	*(Poor) (20.0 - 21.9)*	*(Good) (24.0 - 25.9)*	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Pr	*(V Poor) (< 18.9)*	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Mod) (21.0 - 22.9)*	*(Poor) (19.0 - 20.9)*	*(V Poor) (< 18.9)*
Pw	*(Poor) (22.0 - 23.9)*	*(Poor) (22.0 - 23.9)*	*(Good) (26.0 - 27.9)*	*(Mod) (24.0 - 25.9)*	*(Mod) (24.0 - 25.9)*	*(Poor) (22.0 - 23.9)*	*(V Poor) (< 21.9)*
Sn	*(Mod) (25.0 - 26.9)*	*(Good) (27.0 - 28.9)*	*(Good) (27.0 - 28.9)*	*(Mod) (25.0 - 26.9)*	*(Mod) (25.0 - 26.9)*	*(Poor) (23.0 - 24.9)*	*(V Poor) (< 22.9)*
Sw	*(Poor) (21.0 - 22.9)*	*(Mod) (23.0 - 24.9)*	*(Good) (25.0 - 26.9)*	*(Mod) (23.0 - 24.9)*	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*	*(V Poor) (< 20.9)*
Aw	**Poor* (22.0 - 23.9)**	*(Mod) (24.0 - 25.9)*	*(Mod) (24.0 - 25.9)*	*(Good) (26.0 - 27.9)*	*(Poor) (22.0 - 23.9)*	n.a.	n.a.
Bd	n.a.	n.a.	*(Poor) (21.0 - 22.9)*	*(Poor) (21.0 - 22.9)*	*(Poor) (21.0 - 22.9)*	**V Poor* (< 20.9)**	n.a.
Be	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Bu	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Spp	Depth to mottling > 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Cb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mh	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mr	Poor* (20.0 - 21.9)	(Mod) (22.0 - 23.9)	(Mod) (22.0 - 23.9)	(Mod) (22.0 - 23.9)	(Poor) (20.0 - 21.9)	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	(Poor) (20.0 - 21.9)	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	(Good) (24.0 - 25.9)	(Mod) (22.0 - 23.9)	(Mod) (22.0 - 23.9)	n.a.
Ow	n.a.	n.a.	(V Poor) (< 16.9)	(Poor) (17.0 - 18.9)	(Poor) (17.0 - 18.9)	Poor* (17.0 - 18.9)	(Mod) (19.0 - 20.9)
Wb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sandy						
Le	Poor* (20.0 - 21.9)	(V Good) (≥ 26.0)	Good (24.0 - 25.9)	Mod (22.0 - 23.9)	Good (24.0 - 25.9)	(Poor) (20.0 - 21.9)	(V Poor) (< 19.9)
Pr	Poor (19.0 - 20.9)	Good (23.0 - 24.9)	V Good (≥ 25.0)	Good (23.0 - 24.9)	Good (23.0 - 24.9)	Mod (21.0 - 22.9)	(Poor) (19.0 - 20.9)
Pw	Poor (22.0 - 23.9)	Poor (22.0 - 23.9)	V Good (≥ 28.0)	Mod (24.0 - 25.9)	Mod (24.0 - 25.9)	Poor (22.0 - 23.9)	(V Poor) (< 21.9)
Sn	Good (27.0 - 28.9)	(V Good) (≥ 29.0)	(V Good) (≥ 29.0)	Good (27.0 - 28.9)	Good (27.0 - 28.9)	(Mod) (25.0 - 26.9)	(Poor) (23.0 - 24.9)
Sw	Mod (23.0 - 24.9)	Good (25.0 - 26.9)	V Good (≥ 27.0)	Mod (23.0 - 24.9)	Good (25.0 - 26.9)	Mod (23.0 - 24.9)	(Poor) (21.0 - 22.9)
Aw	Poor* (22.0 - 23.9)	Mod* (24.0 - 25.9)	(Good) (26.0 - 27.9)	V Good* (≥ 28.0)	Mod* (24.0 - 25.9)	(V Poor) (< 21.9)	n.a.
Bd	n.a.	(Poor) (21.0 - 22.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	Mod* (23.0 - 24.9)	n.a.
Be	(Poor) (19.0 - 20.9)	Mod* (21.0 - 22.9)	Good* (23.0 - 24.9)	Good* (23.0 - 24.9)	V Poor* (< 18.9)	n.a.	n.a.
Bu	n.a.	n.a.	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	Poor* (21.0 - 22.9)	(V Poor) (< 20.9)	n.a.
Cb	(Poor) (21.0 - 22.9)	(Mod) (23.0 - 24.9)	V Good* (≥ 27.0)	Good* (25.0 - 26.9)	Mod (23.0 - 24.9)	Mod* (23.0 - 24.9)	n.a.
Mh	Mod* (22.0 - 23.9)	Good* (24.0 - 25.9)	Good (24.0 - 25.9)/ Mod (22.0 - 23.9)	Poor (20.0 - 21.9)	(V Poor) (< 19.9)	n.a.	n.a.
Mr	(Poor) (20.0 - 21.9)	(Good) (24.0 - 25.9)	Mod* (22.0 - 23.9)	Good* (24.0 - 25.9)	Poor* (20.0 - 21.9)	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	Mod* (24.0 - 25.9)	Good (26.0 - 27.9)	Mod (24.0 - 25.9)	(Poor) (22.0 - 23.9)
Or	(Mod) (22.0 - 23.9)	Good* (24.0 - 25.9)	V Good* (≥ 26.0)	V Good (≥ 26.0)	Good* (24.0 - 25.9)	Good (24.0 - 25.9)	(Poor) (20.0 - 21.9)
Ow	n.a.	n.a.	(Poor) (17.0 - 18.9)	(Poor) (17.0 - 18.9)	(Mod) (19.0 - 20.9)	Good (21.0 - 22.9)	V Good* (≥ 23.0)
Wb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Gravelly Loamy						
Le	Mod* (22.0 - 23.9)	(Good) (24.0 - 25.9)	(V Good) (≥ 26.0)	(Good) (24.0 - 25.9)	Mod (22.0 - 23.9)	(Poor) (20.0 - 21.9)	(V Poor) (< 19.9)
Pr	V Poor (< 18.9)	(Mod) (21.0 - 22.9)	V Good* (≥ 25.0)	Good (23.0 - 24.9)	(Mod) (21.0 - 22.9)	(Poor) (19.0 - 20.9)	(V Poor) (< 18.9)

Spp	Depth to mottling						
	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Pw	V Poor c (< 21.9)	(Mod) (24.0 - 25.9)/(V Poor) c (< 21.9)	(Good) (26.0 - 27.9)	(Mod) (24.0 - 25.9)	(Mod) (24.0 - 25.9)	(Poor) (22.0 - 23.9)	(V Poor) (< 21.9)
Sn	Mod (25.0 - 26.9)	(Good) (27.0 - 28.9)	(V Good) (≥ 29.0)	(Good) (27.0 - 28.9)	(Mod) (25.0 - 26.9)	(Mod) (25.0 - 26.9)	(Poor) (23.0 - 24.9)
Sw	Good (25.0 - 26.9)	(Good) (25.0 - 26.9)	(V Good) (≥ 27.0)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Poor) (21.0 - 22.9)
Aw	Poor* (22.0 - 23.9)	(Mod) (24.0 - 25.9)	(Good) (26.0 - 27.9)	(Good) (26.0 - 27.9)	(Mod) (24.0 - 25.9)	(Poor) (22.0 - 23.9)	n.a.
Bd	n.a.	Mod* (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Poor) (21.0 - 22.9)	(Poor) (21.0 - 22.9)	n.a.
Be	(Poor) (19.0 - 20.9)	(Mod) (21.0 - 22.9)	(Mod) (21.0 - 22.9)	(Good) (23.0 - 24.9)	(Poor) (19.0 - 20.9)	n.a.	n.a.
Bu	Poor* (21.0 - 22.9)	(Mod) (23.0 - 24.9)	(Good) (25.0 - 26.9)	(Good) (25.0 - 26.9)	(Mod) (23.0 - 24.9)	(Poor) (21.0 - 22.9)	n.a.
Cb	(Poor) (21.0 - 22.9)	(Good) (25.0 - 26.9)	(Good) (25.0 - 26.9)	(Good) (25.0 - 26.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	n.a.
Mh	Poor (20.0 - 21.9)	(Good) (24.0 - 25.9)	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	(V Poor) (< 19.9)	(V Poor) (< 19.9)	n.a.
Mr	V Poor* (< 19.9)	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	(Good) (24.0 - 25.9)	(Mod) (22.0 - 23.9)	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	(Poor) (22.0 - 23.9)	(Good) (26.0 - 27.9)	(Good) (26.0 - 27.9)	(Mod) (24.0 - 25.9)
Or	Good* (24.0 - 25.9)	(Good) (24.0 - 25.9)	(Good) (24.0 - 25.9)	(V Good) (≥ 26.0)	(Good) (24.0 - 25.9)	(Mod) (22.0 - 23.9)	(Poor) (20.0 - 21.9)
Ow	n.a.	(V Poor) (< 16.9)	(Poor) (17.0 - 18.9)	(Poor) (17.0 - 18.9)	(Mod) (19.0 - 20.9)	(Good) (21.0 - 22.9)	(Good) (21.0 - 22.9)
Wb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Coarse Loamy						
Le	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	(V Good) (≥ 26.0)	Good* (24.0 - 25.9)	Poor (20.0 - 21.9)	Poor* (20.0 - 21.9)	(V Poor) (< 19.9)
Pr	Good (23.0 - 24.9)/ Poor c (19.0 - 20.9)	Good* (23.0 - 24.9)	Good (23.0 - 24.9)	Good (23.0 - 24.9)	Mod (21.0 - 22.9)	Mod (21.0 - 22.9)	(V Poor) (< 18.9)
Pw	Mod (24.0 - 25.9)/(V Poor) c (< 21.9)	Good* (26.0 - 27.9)	Good* (26.0 - 27.9)	Mod (24.0 - 25.9)	Mod (24.0 - 25.9)	Mod (24.0 - 25.9)	(Poor) (22.0 - 23.9)
Sn	Mod (25.0 - 26.9)	(V Good) (≥ 29.0)	Good* (27.0 - 28.9)	(V Good) (≥ 29.0)	Good (27.0 - 28.9)	Poor (23.0 - 24.9)	Poor (23.0 - 24.9)
Sw	Mod (23.0 - 24.9)	Mod (23.0 - 24.9)	Good* (25.0 - 26.9)	Poor (21.0 - 22.9)	Mod (23.0 - 24.9)	Mod (23.0 - 24.9)	(Poor) (21.0 - 22.9)
Aw	Mod (24.0 - 25.9)	Good (26.0 - 27.9)	V Good (≥ 28.0)	Good* (26.0 - 27.9)	Mod (24.0 - 25.9)	Mod (24.0 - 25.9)	(Poor) (22.0 - 23.9)
Bd	Mod (23.0 - 24.9)	V Good (≥ 27.0)	(Good) (25.0 - 26.9)	Mod* (23.0 - 24.9)	Mod (23.0 - 24.9)	Poor* (21.0 - 22.9)	n.a.
Be	Mod (21.0 - 22.9)	(Mod) (21.0 - 22.9)	Poor* (19.0 - 20.9)	Good (23.0 - 24.9)	Mod (21.0 - 22.9)	Poor* (19.0 - 20.9)	(V Poor) (< 18.9)
Bu	Mod (23.0 - 24.9)	V Good* (≥ 27.0)	Good* (25.0 - 26.9)	Good (25.0 - 26.9)	Mod (23.0 - 24.9)	Poor* (21.0 - 22.9)	(V Poor) (< 20.9)
Cb	Mod (23.0 - 24.9)	Good* (25.0 - 26.9)	V Good* (≥ 27.0)	Good (25.0 - 26.9)	Good (25.0 - 26.9)	Mod* (23.0 - 24.9)	n.a.
Mh	Mod (22.0 - 23.9)	Good (24.0 - 25.9)	V Good (≥ 26.0)	Mod (22.0 - 23.9)	Mod (22.0 - 23.9)	Mod (22.0 - 23.9)	n.a.
Mr	Mod* (22.0 - 23.9)	Mod* (22.0 - 23.9)	(Good) (24.0 - 25.9)	Good (24.0 - 25.9)	Good* (24.0 - 25.9)	Good (24.0 - 25.9)	n.a.

Spp	Depth to mottling						
	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Ms	n.a.	n.a.	n.a.	**Mod* (24.0 - 25.9)**	**V Good (≥ 28.0)**	**V Good (≥ 28.0)**	*(Mod) (24.0 - 25.9)*
Or	**Good (24.0 - 25.9)**	*(Good) (24.0 - 25.9)*	**Mod* (22.0 - 23.9)**	**V Good (≥ 26.0)**	**Good (24.0 - 25.9)**	**Mod (22.0 - 23.9)**	*(Poor) (20.0 - 21.9)*
Ow	n.a.	*(Poor) (17.0 - 18.9)*	*(Mod) (19.0 - 20.9)*	**Mod* (19.0 - 20.9)**	*(Good) (21.0 - 22.9)*	**V Good* (≥ 23.0)**	*(Good) (21.0 - 22.9)*
Wb	**Poor* (21.0 - 22.9)**	**V Good* (≥ 27.0)**	*(V Good) (≥ 27.0)*	*(Good) (25.0 - 26.9)*	**Good* (25.0 - 26.9)**	**Poor* (21.0 - 22.9)**	*(V Poor) (< 20.9)*
	Silty						
Le	*(Mod) (22.0 - 23.9)*	*(V Good) (≥ 26.0)*	*(V Good) (≥ 26.0)*	*(Good) (24.0 - 25.9)*	**Good (24.0 - 25.9)**	**Good* (24.0 - 25.9)**	**Mod (22.0 - 23.9)**
Pr	**Good (23.0 - 24.9)/ Poor r (19.0 - 20.9)**	*(Good) (23.0 - 24.9)/ (Poor) (19.0 - 20.9)*	**Good* (23.0 - 24.9)/ Poor* r (19.0 - 20.9)**	**V Good (≥ 25.0)**	**Good* (23.0 - 24.9)**	**Mod* (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*
Pw	**Mod* (24.0 - 25.9)**	*(V Good) (≥ 28.0)*	**Good* (26.0 - 27.9)**	**Mod (24.0 - 25.9)**	**Mod (24.0 - 25.9)**	**Mod (24.0 - 25.9)**	*(Poor) (22.0 - 23.9)*
Sn	**Good (27.0 - 28.9)**	*(V Good) (≥ 29.0)*	*(V Good) (≥ 29.0)*	**Mod (25.0 - 26.9)**	**Mod (25.0 - 26.9)**	*(Poor) (23.0 - 24.9)*	*(Poor) (23.0 - 24.9)*
Sw	**Mod* (23.0 - 24.9)**	*(Good) (25.0 - 26.9)*	*(V Good) (≥ 27.0)*	**Mod (23.0 - 24.9)**	**Poor (21.0 - 22.9)**	**Poor (21.0 - 22.9)**	*(Poor) (21.0 - 22.9)*
Aw	**Mod* (24.0 - 25.9)**	*(V Good) (≥ 28.0)*	**Good (26.0 - 27.9)**	**Mod* (24.0 - 25.9)**	**Mod (24.0 - 25.9)**	*(Poor) (22.0 - 23.9)*	**V Poor* (< 21.9)**
Bd	*(Mod) (23.0 - 24.9)*	*(V Good) (≥ 27.0)*	**V Good* (≥ 27.0)**	*(Good) (25.0 - 26.9)*	**Mod* (23.0 - 24.9)**	**Mod* (23.0 - 24.9)**	n.a.
Be	*(Poor) (19.0 - 20.9)*	*(Mod) (21.0 - 22.9)*	*(Good) (23.0 - 24.9)*	**V Good* (≥ 25.0)**	**Good* (23.0 - 24.9)**	**Good (23.0 - 24.9)**	*(Poor) (19.0 - 20.9)*
Bu	*(Mod) (23.0 - 24.9)*	*(V Good) (≥ 27.0)*	**Good* (25.0 - 26.9)**	*(Good) (25.0 - 26.9)*	**Good (25.0 - 26.9)**	*(Mod) (23.0 - 24.9)*	*(Poor) (21.0 - 22.9)*
Cb	**Good* (25.0 - 26.9)**	*(V Good) (≥ 27.0)*	**Good* (25.0 - 26.9)**	**Mod* (23.0 - 24.9)**	**Poor* (21.0 - 22.9)**	*(Poor) (21.0 - 22.9)*	n.a.
Mh	**Good (24.0 - 25.9)**	**V Good (≥ 26.0)**	*(V Good) (≥ 26.0)*	**Good* (24.0 - 25.9)**	**Good* (24.0 - 25.9)**	**Mod* (22.0 - 23.9)**	n.a.
Mr	*(Mod) (22.0 - 23.9)*	*(V Good) (≥ 26.0)*	*(V Good) (≥ 26.0)*	*(Good) (24.0 - 25.9)*	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*
Ms	n.a.	n.a.		n.a.	*(Good) (26.0 - 27.9)*	**V Good* (≥ 28.0)**	*(Mod) (24.0 - 25.9)*
Or	**Good (24.0 - 25.9)**	*(V Good) (≥ 26.0)*	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)*	**Good* (24.0 - 25.9)**	**V Good* (≥ 26.0)**	**Poor (20.0 - 21.9)**
Ow	n.a.	*(Poor) (17.0 - 18.9)*	*(Good) (21.0 - 22.9)*	**Mod* (19.0 - 20.9)**	*(Good) (21.0 - 22.9)*	**V Good* (≥ 23.0)**	*(Mod) (19.0 - 20.9)*
Wb	*(Mod) (23.0 - 24.9)*	*(Good) (25.0 - 26.9)*	*(V Good) (≥ 27.0)*	*(V Good) (≥ 27.0)*	**V Good* (≥ 27.0)**	*(Good) (25.0 - 26.9)*	*(Poor) (21.0 - 22.9)*
	Fine Loamy						
Le	*(Mod) (22.0 - 23.9)*	*(Good) (24.0 - 25.9)*	*(Mod) (22.0 - 23.9)*	*(Mod) (22.0 - 23.9)*	*(Poor) (20.0 - 21.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*
Pr	**Good (23.0 - 24.9)**	*(Good) (23.0 - 24.9)*	**Mod* (21.0 - 22.9)**	*(Mod) (21.0 - 22.9)*	**Mod (21.0 - 22.9)**	**Mod (21.0 - 22.9)**	*(Poor) (19.0 - 20.9)*
Pw	**Poor (22.0 - 23.9)**	*(Good) (26.0 - 27.9)*	*(Good) (26.0 - 27.9)*	**Mod* (24.0 - 25.9)**	**Mod (24.0 - 25.9)**	**Poor* (22.0 - 23.9)**	*(V Poor) (< 21.9)*
Sn	**Poor* (23.0 - 24.9)**	*(Good) (27.0 - 28.9)*	*(V Good) (≥ 29.0)*	**Mod* (25.0 - 26.9)**	*(Mod) (25.0 - 26.9)*	**V Poor* (< 22.9)**	*(V Poor) (< 22.9)*

	Depth to mottling						
Spp	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Sw	Poor* (21.0 - 22.9)	(Good) (25.0 - 26.9)	(V Good) (≥ 27.0)	(Good) (25.0 - 26.9)	Mod (23.0 - 24.9)	Poor* (21.0 - 22.9)	(Poor) (21.0 - 22.9)
Aw	Poor* (22.0 - 23.9)	Mod* (24.0 - 25.9)	(Good) (26.0 - 27.9)	V Good (≥ 28.0)	V Good (≥ 28.0)	Mod (24.0 - 25.9)	Good* (26.0 - 27.9)
Bd	Mod* (23.0 - 24.9)	(Good) (25.0 - 26.9)	(Good) (25.0 - 26.9)	Mod* (23.0 - 24.9)	Mod (23.0 - 24.9)	Mod (23.0 - 24.9)	n.a.
Be	Poor (19.0 - 20.9)	(Mod) (21.0 - 22.9)	(Mod) (21.0 - 22.9)	(Good) (23.0 - 24.9)	Mod* (21.0 - 22.9)	(Poor) (19.0 - 20.9)	V Poor* (< 18.9)
Bu	Mod* (23.0 - 24.9)	Mod* (23.0 - 24.9)	Good* (25.0 - 26.9)	V Good* (≥ 27.0)	(Mod) (23.0 - 24.9)	(Poor) (21.0 - 22.9)	n.a.
Cb	V Poor* (< 20.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	Poor* (21.0 - 22.9)	V Poor* (< 20.9)	n.a.
Mh	Mod (22.0 - 23.9)	(Good) (24.0 - 25.9)	Mod* (22.0 - 23.9)	Good* (24.0 - 25.9)	Good (24.0 - 25.9)	Mod (22.0 - 23.9)	Poor (20.0 - 21.9)
Mr	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	(V Good) (≥ 26.0)	(Mod) (22.0 - 23.9)	(Good) (24.0 - 25.9)	Mod* (22.0 - 23.9)	Mod* (22.0 - 23.9)
Ms	n.a.	n.a.	n.a.	n.a.	Mod (24.0 - 25.9)	Good (26.0 - 27.9)	V Poor* (< 21.9)
Or	Mod* (22.0 - 23.9)	(Mod) (22.0 - 23.9)	Mod* (22.0 - 23.9)	Good* (24.0 - 25.9)	Good (24.0 - 25.9)	Good (24.0 - 25.9)	Good (24.0 - 25.9)
Ow	n.a.	n.a.	(Mod) (19.0 - 20.9)	Good (21.0 - 22.9)	V Good (≥ 23.0)	Mod* (19.0 - 20.9)	(Poor) (17.0 - 18.9)
Wb	Poor* (21.0 - 22.9)	(Good) (25.0 - 26.9)	(V Good) (≥ 27.0)	Good* (25.0 - 26.9)	Mod* (23.0 - 24.9)	Poor* (21.0 - 22.9)	V Poor* (< 20.9)
	Clayey						
Le	n.a.	(Mod) (22.0 - 23.9)	(Mod) (22.0 - 23.9)	(Poor) (20.0 - 21.9)	(Poor) (20.0 - 21.9)	(V Poor) (< 19.9)	(V Poor) (< 19.9)
Pr	n.a.	(Mod) (21.0 - 22.9)	(Mod) (21.0 - 22.9)	(Poor) (19.0 - 20.9)	(V Poor) (< 18.9)	V Poor (< 18.9)	(V Poor) (< 18.9)
Pw	n.a.	(Mod) (24.0 - 25.9)	(Good) (26.0 - 27.9)	(Mod) (24.0 - 25.9)	(Mod) (24.0 - 25.9)	Mod (24.0 - 25.9)	(Poor) (22.0 - 23.9)
Sn	n.a.	(Mod) (25.0 - 26.9)	(Good) (27.0 - 28.9)	(Good) (27.0 - 28.9)	(Mod) (25.0 - 26.9)	Poor* (23.0 - 24.9)	V Poor (< 22.9)
Sw	n.a.	(Poor) (21.0 - 22.9)	(Mod) (23.0 - 24.9)	(Good) (25.0 - 26.9)	Good* (25.0 - 26.9)	(Mod) (23.0 - 24.9)	(Poor) (21.0 - 22.9)
Aw	n.a.	Mod* (24.0 - 25.9)	(Good) (26.0 - 27.9)	(Good) (26.0 - 27.9)	Mod (24.0 - 25.9)	Mod (24.0 - 25.9)	Good (26.0 - 27.9)
Bd	n.a.	n.a.	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	(Mod) (23.0 - 24.9)	Mod* (23.0 - 24.9)	n.a.
Be	n.a.	Poor* (19.0 - 20.9)	(Mod) (21.0 - 22.9)	(Mod) (21.0 - 22.9)	Poor* (19.0 - 20.9)	n.a.	n.a.
Bu	n.a.	Poor* (21.0 - 22.9)	(Good) (25.0 - 26.9)	(Mod) (23.0 - 24.9)	Mod (23.0 - 24.9)	Poor* (21.0 - 22.9)	(V Poor) (< 20.9)
Cb	n.a.	n.a.	n.a.	(Mod) (23.0 - 24.9)	Poor* (21.0 - 22.9)	Poor (21.0 - 22.9)	n.a.
Mh	n.a.	Good* (24.0 - 25.9)	V Good* (≥ 26.0)	Good* (24.0 - 25.9)	Good* (24.0 - 25.9)	Mod (22.0 - 23.9)	Poor* (20.0 - 21.9)
Mr	n.a.	Good* (24.0 - 25.9)	(Good) (24.0 - 25.9)	(Mod) (22.0 - 23.9)	(Mod) (22.0 - 23.9)	Mod (22.0 - 23.9)	Poor* (20.0 - 21.9)
Ms	n.a.	n.a.	n.a.	n.a.	Poor* (22.0 - 23.9)	Good (26.0 - 27.9)	Mod (24.0 - 25.9)
Or	n.a.	Mod* (22.0 - 23.9)	(Mod) (22.0 - 23.9)	Mod* (22.0 - 23.9)	Mod (22.0 - 23.9)	Good (24.0 - 25.9)	Mod (22.0 - 23.9)
Ow	n.a.	n.a.	(V Poor) (< 16.9)	Mod* (19.0 - 20.9)	Good (21.0 - 22.9)	Good (21.0 - 22.9)	Poor* (17.0 - 18.9)

	Depth to mottling						
Spp	> 150 cm	100 – 150 cm	80 – 100 cm	50 – 80 cm	30 – 50 cm	15 – 30 cm	< 15 cm
Wb	n.a.	**V Good* (≥ 27.0)**	*(Good) (25.0 - 26.9)*	*(Good) (25.0 - 26.9)*	**Good* (25.0 - 26.9)**	**Mod (23.0 - 24.9)**	**Poor* (21.0 - 22.9)**
	Shallow						
Le	n.a.	n.a.	**V Poor* (< 19.9)**	*(Poor) (20.0 - 21.9)*	*(Poor) (20.0 - 21.9)*	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Pr	n.a.	n.a.	**Poor* (19.0 - 20.9)**	**Poor* (19.0 - 20.9)**	**Mod (21.0 - 22.9)**	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*
Pw	n.a.	n.a.	**Poor* (22.0 - 23.9)**	**Mod (24.0 - 25.9)**	**Good* (26.0 - 27.9)**	**Poor (22.0 - 23.9)**	*(V Poor) (< 21.9)*
Sn	n.a.	n.a.	*(Mod) (25.0 - 26.9)*	**Good* (27.0 - 28.9)**	*(Mod) (25.0 - 26.9)*	*(Poor) (23.0 - 24.9)*	*(V Poor) (< 22.9)*
Sw	n.a.	n.a.	*(Poor) (21.0 - 22.9)*	*(Poor) (21.0 - 22.9)*	*(Mod) (23.0 - 24.9)*	**Mod* (23.0 - 24.9)**	*(V Poor) (< 20.9)*
Aw	n.a.	n.a.	**Poor* (22.0 - 23.9)**	*(Mod) (24.0 - 25.9)*	*(Good) (26.0 - 27.9)*	*(Mod) (24.0 - 25.9)*	**Mod* (24.0 - 25.9)**
Bd	n.a.	n.a.	*(Poor) (21.0 - 22.9)*	*(Poor) (21.0 - 22.9)*	**V Poor* (< 20.9)**	*(V Poor) (< 20.9)*	n.a.
Be	n.a.	n.a.	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*	*(V Poor) (< 18.9)*	n.a.	n.a.
Bu	n.a.	n.a.	*(Poor) (21.0 - 22.9)*	*(Mod) (23.0 - 24.9)*	**V Good* (≥ 27.0)**	**Mod (23.0 - 24.9)**	**V Poor (< 20.9)**
Cb	n.a.	n.a.	**Mod* (23.0 - 24.9)**	*(Poor) (21.0 - 22.9)*	**Poor* (21.0 - 22.9)**	*(V Poor) (< 20.9)*	n.a.
Mh	n.a.	n.a.	**Mod* (22.0 - 23.9)**	**V Good* (≥ 26.0)**	**Good* (24.0 - 25.9)**	**Poor* (20.0 - 21.9)**	n.a.
Mr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ms	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Or	n.a.	n.a.	**Good* (24.0 - 25.9)**	*(Good) (24.0 - 25.9)*	**Poor* (20.0 - 21.9)**	*(V Poor) (< 19.9)*	*(V Poor) (< 19.9)*
Ow	n.a.	n.a.	n.a.	*(V Poor) (< 16.9)*	*(Poor) (17.0 - 18.9)*	**Good (21.0 - 22.9)**	*(V Poor) (< 16.9)*
Wb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Appendix 2

Ontario's Natural Selections

Woody Plant Seed Collection Guidelines for a Changing Climate

Seed collectors have a huge influence on a planting project's capacity to provide social, ecological, and economic benefits for many generations. Follow these guidelines to ensure your seed collections will be genetically diverse and fit, and of high physiological quality and thus better able to withstand climate change, invasive species or other future pressures.

Before you forecast or collect a crop, be sure you can check off these guidelines:

☐ **1. Document and maintain seed lots by collection site location**

- To allow seed to be used in areas it is adapted to.
- To avoid maladapted seed later interbreeding with and contaminating nearby stands. Seed Zone level is the most basic acceptable identity for a collection (see OMNR Tree Seed Zones 1996, page 275). Actual collection area, Township or County level gives the end user more flexibility, particularly in poor seed years, to match the collection source to potential planting sites, possibly in another seed zone. Climate change adaptation strategies such as assisted migration demand better source documentation, to allow strategic movement and assessment of its performance, to either repeat its use, or not.

☐ **2. Collect seed from high quality stands = healthy, vigorous specimens of good form:**

- To avoid poor genetic quality from stands which have been high graded (best trees removed, which often results in a poor quality residual stand).

☐ **3. Collect from areas with a large number of individuals:**

> 100 seed bearing trees for common, abundant species, e.g. pines.
> 5 for naturally rarer or scattered species, e.g. hickory.

- To reduce the risk of collecting inbred seed.
- To increase the amount of collectable seed, per plant and/or per fruit; larger stands of target species reduce the risk of "selfing" and low vigour seedlings.
- To ensure broad genetic diversity within a collection, a buffer against climate change, and other future pressures.

☐ **4. Collect from a variety of individuals distributed throughout the stand (15 to 20 different plants):**

- To avoid collecting seed of only closely related trees.
- To collect a representative sample of the genetic diversity of the stand.
- To ensure broad genetic diversity within a collection, a buffer against climate change, and other future pressures.

☐ **5. Collect seed in a good seed year:**

- To ensure a large number of parents have contributed to the seed crop.
- To obtain more and higher quality seeds (more seed or cones per branch and more seeds per cone).
- To ensure broad genetic diversity within a collection, a buffer against climate change, and other future pressures.

If collecting from plantations:

☐ **6A. Collect from mature plantations of adapted, known seed source, or**

☐ **6B. Collect from mature plantations of proven performance (healthy, not maladapted)**

If collecting from species susceptible to a specific disease or insect:

☐ **7. Collect from healthy individuals or those that have recovered from attack:**

- This will increase probability that some seedlings will be genetically tolerant.

☐ **8. Use handling and storage practices that maximize seed survival:**

- Consult seed manuals and technical field guides.
- To avoid artificial selection pressures which can reduce or skew adapted genetic diversity, i.e. seed that survives high temperatures in an overfilled bag may not survive future pressures.

Ontario's Natural Selections is a seed source certification program administered by the Forest Gene Conservation Association. For more details, see www.fgca.net

FOREST Gene Conservation ASSOCIATION

Appendix 3
Area-Based Assessment Methodology

Based on material provided by Andree Morneault

This appendix describes an area-based assessment methodology. It is best suited to sites where the regeneration is even-aged and more or less even-sized. These types of sites are normally the result of artificial regeneration. It can also be used with natural regeneration following uniform site preparation under a uniformly distributed seed source.

Stratification:

Areas to be assessed should be stratified or grouped into homogeneous units to reduce the number of sample plots required and to increase the precision of the stocking estimate (White et al, 2005). Areas can be stratified if they are expected to lead to a different yield prediction. For example, an area can be stratified if it has a difference in silvicultural system, harvest system, renewal method, number or type of tending treatment, underlying soil, etc. Proper stratification may lead to the greatest gains in survey efficiency.

Number of clusters:

Three clusters per hectare with a minimum of 10 when the project is 3.3 ha or less.

Cluster Locations:

A grid pattern is the preferred method to use when surveying a stand. Establishing clusters along transects with a random start can also be used, but this approach runs the risk of missing significant areas or other variations in a stand/stratum. A uniform grid ensures that every part of the stand/stratum has equal opportunity to be sampled and enables spatial analysis of the data. Cluster locations can be plotted on maps using GIS technology while in the office and UTM coordinates downloaded onto a GPS unit.

Equipment checklist:

- GPS unit (with spare batteries)
- Map
- Compass
- Transit rope (to reduce bias when locating clusters)
- Flagging tape (to mark cluster locations) or pins with flagging tape to mark centres during assessment (to reduce bias when locating clusters)
- Talley board, tally sheets, or electronic data collection device (e.g. Toughbook)
- Assessment stick (marked at 1.13 m for plot layout)

Plot Layout:

A sampling cluster includes 10 circular plots in a row (Figure 1). Each circle covers 4 m² (circles have 1.13 m radius). The surveyor marks the centre of each plot in the cluster.

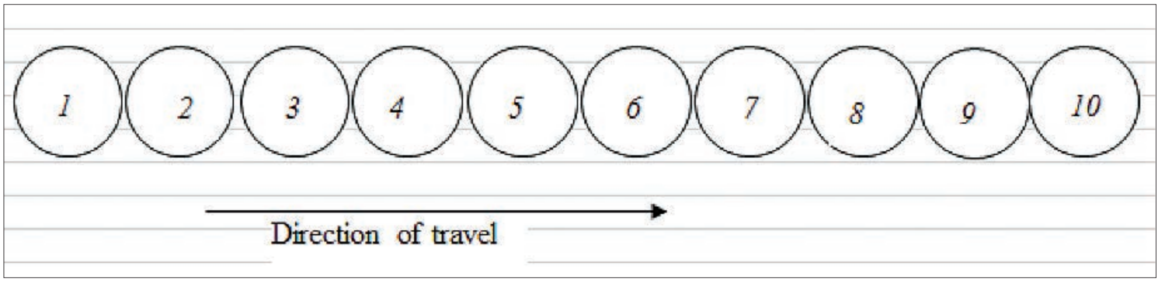


Figure 1: Row method plot layout - a line of circular or square plots per resulting in 10-4 m2 plots per cluster.

Important Principles

1. The first plot should be located at the GPS point or when the surveyor has reached the pre-determined distance.

2. To reduce bias, do not look for a tree or shrub to tie the flagging for plot centre. Use an assessment pin, or place the flagging on the ground if nothing is available to tie it on.

3. Be consistent in methodology, especially if clusters are to be reassessed or audited

4. Lay the plots out in a straight line

5. The method used to mark the plots and the direction of travel should be well documented on tally sheets to facilitate plot relocation.

6. If the cluster appears to be in an area that is not available for regeneration (no plantable spots because of rock, water, etc.), continue with the assessment, plot by plot, and record the reason for the lack of regeneration on the tally sheet. Sometimes, the first 4 plots of a cluster will be under water, but the remaining 4 will have trees. By recording the data, the area of the stand that is unavailable for regeneration can be calculated.

Data Collection

The following information is collected for each plot using the tally sheet shown in Figure 2.

1. Cluster: cluster number

2. Plot: Plot number

3. Spp: Record the species of each planted/seeded tree and each naturally regenerated tree in the plot.

4. #Stems: Record the total number of all healthy trees for all tree species. In areas of natural regeneration, an upper limit may be set by the project manager (e.g. 30) to maximize efficiency while not compromising the meaningfulness of the data.

5. Comp: record the Competition level: H=High, M=Medium, L=low. Reflects need for tending: H - needs tending now, M - probably needs tending next year, L - no need for tending

6. Reason Unoccpd: Condition preventing tree regeneration. E.g. when roads, slash, water, or bedrock (or very shallow soils over bedrock) cover the majority (>80%) of the plot. Use sub-codes to specify the condition: UR = Road, US= slash, UW= water, UB=bedrock. This area is taken away when calculating net area for stocking and density summaries. Sometimes there are no visible reasons for the lack of trees. Record "B" for Barren. Indicate what is in these plots in the comment column to assist in determining potential treatments (e.g. general category such as brush or grass, or more specifically beaked hazel or bracken fern, etc). This area is included in area available for regeneration.

7. Comments: Add any other useful comments. This column can be used to provide details regarding the condition codes, the presence of insects or disease, etc.

Location:		Area:	
Crew:		Clusters:	
Date:			

			Plant/Seed						Natural				Total		Reason	
	Cluster	Plot	Sp1:	Sp2:	Sp3:	Sp4:	Sp5:	Present	Sp1:	Sp2:	Sp3:	Present	Present	Comp:	Unoccpd	Comments
GPS	1	1						0				0	0			
Northing:		2						0				0	0			
		3						0				0	0			
Easting:		4						0				0	0			
		5						0				0	0			
		6						0				0	0			
Bearing:		7						0				0	0			
		8						0				0	0			
		9						0				0	0			
		10						0				0	0			
Total stems			0	0	0	0	0	0	0	0	0	0	0			
Density: Stems/ha			0	0	0	0	0	0	0	0	0	0	0			
Plots present:			0	0	0	0	0	0	0	0	0	0	0			
Stocking:			0	0	0	0	0	0	0	0	0	0	0			

			Plant/Seed						Natural				Total		Reason	
	Cluster	Plot	Sp1:	Sp2:	Sp3:	Sp4:	Sp5:	Present	Sp1:	Sp2:	Sp3:	Present	Present	Comp:	Unoccpd	Comments
GPS:	2	1						0				0	0			
Northing:		2						0				0	0			
		3						0				0	0			
Easting:		4						0				0	0			
		5						0				0	0			
Bearing:		6						0				0	0			

Figure 2: An example of a tally sheet that can be used during field assessment. An excel version of this tally sheet is available from Forests Ontario

Appendix 4
Clean Equipment Protocol for Industry - Summary

Invasive species are plants, animals and microorganisms that have been accidentally or deliberately introduced into areas beyond their normal range, that out compete native species. Invasive species are a major threat to Ontario's natural areas, and are very costly to deal with once established.

Invasive species can be spread to new areas by contaminated mud, gravel, soil and plant materials on vehicles and machinery.

The best practice is to prevent the spread of invasive species. By inspecting and cleaning equipment and following some simple guidelines, the risk of spreading invasive plants is greatly reduced.

- Identify invasive plants and plan activities accordingly (i.e. schedule work in areas without invasive plants first, leaving infested areas til the end, to reduce the risk of unintentionally moving plants into a new area).
- Record & report sightings of invasive plants (Invading Species hotline at **1-800-563-7711** or online **www.invadingspecies.com/report/** or **www.eddmaps.org/Ontario**)
- Inspect vehicles and machinery before and after entering sites or conducting work along roadways & waterways.

How to Inspect

Before leaving the site, inspect the vehicle thoroughly inside and out for where dirt, plant material and seeds may be lodged or stuck to interior and exterior surfaces. Remove and clean any guards, covers or plates that are easy to remove.

Pay attention to the underside of the vehicle, radiators, spare tires, foot wells and bumper bars. If clods of dirt, seed or other plant material are found, remove immediately and discard where the contamination occurred or in the garbage.

When Cleaning is required

- Safely locate the vehicle and equipment away from any hazards, ensure engine is off and the vehicle or equipment is immobilized.
- Clean the vehicle/equipment in an appropriate area where contamination and seed spread is not possible (or limited).

The site should be:

» Mud free, gravel covered hard surface, or, if this is not available, a well maintained grassy area.

» Gently sloping to assist in draining water and material away from the vehicle or equipment. Care should be taken to ensure that localized erosion will not be created.

» At least 30m away from any watercourse, water body and natural vegetation.

» Large enough to allow for adequate movement of larger vehicles and equipment.

Clean Equipment Protocol for Industry | **Summary** | Ontario Invasive Plant Council

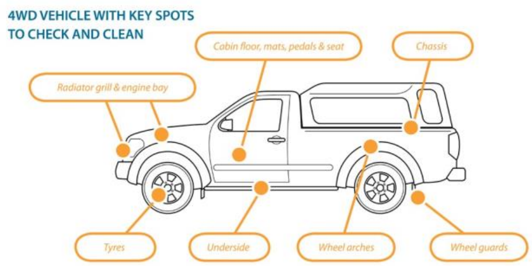
Equipment Required

- [ ] A pump and high pressure hose OR High pressure water unit
- [ ] Air compressor and blower OR Vacuum
- [ ] Shovel
- [ ] Pry bar
- [ ] Stiff brush or broom

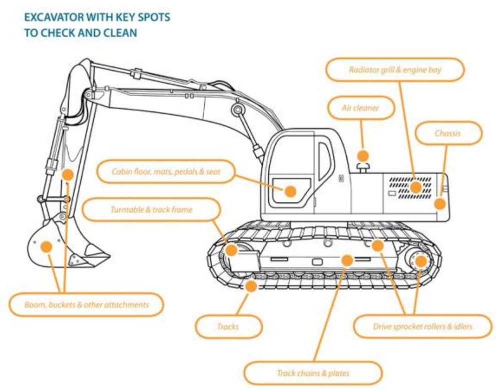
Final Inspection Checklist

- [ ] No clods of dirt should be visible after cleaning.
- [ ] Radiators, grills and the interiors of vehicles should be free of accumulations of seed, soil, mud and plant material parts including seeds, roots, flowers, fruit and or stems.

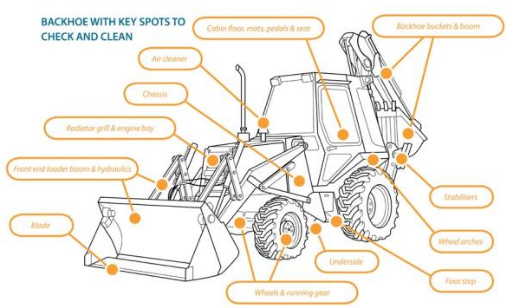
2WD and 4WD Vehicles



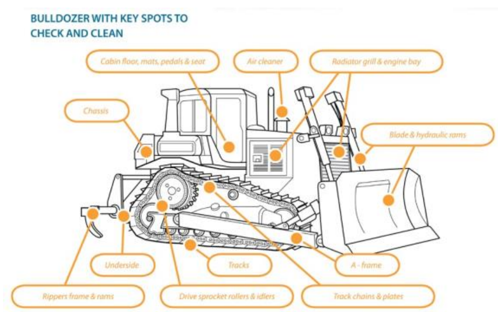
Excavator



Backhoe



Bulldozer



Invasive Species Centre
Catalyst for research and response

Ontario

Peterborough County Stewardship

Ontario Invasive Plant Council

Appendix 5

County of Simcoe
County Forests
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MODIFIED MANAGEMENT RECOMMENDATIONS TO ESTABLISH AND MANAGE RED PINE PLANTATIONS *Based on the presence or future probability of red pine decline*

By Bob Hutchison[1], Graeme Davis[2], John McLaughlin[3]

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ESTABLISHING RED PINE PLANTATIONS

Before planting red pine, check the pH of the A, B, and C soil horizons. For the C horizon, sample at a depth of about 1.5 m.

1. If A and/or B horizons are alkaline (pH > 7):
   - Do not plant red pine

   Crop is likely to fail by 30 to 40 years of age due to nutrient deficiency.

2. If A and B horizons are acidic but the C horizon is alkaline:
   - Reasonable growth and longer rotations are possible but the stand will be predisposed to root disease, especially if the combined depth of the A and B horizons is <1 metre

   Armillaria root disease will reduce stand health but without post-thinning stump treatment Annosus root rot will also increase.

Sites with compacted soil (bulk density >1.4) will be more susceptible to root rot because red pine does not root well in dense soil – especially if it is alkaline.

Richer soils may result in more root disease and as such are not necessarily better red pine sites.

MANAGING YOUNG (<50 YEARS) RED PINE PLANTATIONS

Check the pH of the C horizon to determine if future decline is probable. (If the plantation is in reasonable health at this stage it is unlikely that the A or B horizons are alkaline.)

If the C horizon is alkaline:

- If not already present in the understory, consider options to establish desirable species as soon as possible
- Ensure that an aggressive thinning regimen is in place (i.e., consider light selection thinning in addition to row removal at first thinning)

RECOMMENDATIONS BASED ON LEVEL OF PLANTATION DECLINE

The recommendations provided below are applicable where a typical prescription for a healthy stand in the 50 to 70+ year age class would include a 25 to 35% reduction in suppressed or poorly formed stems and improved spacing (typical residual target basal area of 28-30 m ha^{-2}).

Management objectives include maximizing timber values and moving towards stand conversion.

1. Stand is relatively healthy but has occasional decline pockets and/or scattered individual mortality:
   - Mark as for regular selection cutting but with more emphasis on trees of smaller diameter class and poorer quality or declining health and that affect final stand spacing
   - Mark two live trees surrounding decline pockets or unhealthy stems
   - PLUS, when approaching decline pockets switch to marking from above and remove larger diameter trees (maintaining prescribed % reduction) within 50 to 75 m around the declining stems.

2. Stand has scattered decline pockets and/or scattered individual mortality throughout:
   - Mark entire stand from above for selection cutting but emphasize the removal of larger diameter classes and unhealthy trees with declining crowns regardless of diameter

   OR if marking from above seems unnecessary:
   - Mark all trees with thinning or declining crowns (some openings will be created and basal area may be substantially reduced)
   - Where basal area remains above the target, reduce it to 26 to 28 m^2ha^{-1} using spacing as the main criteria.

3. Stand exhibits severe decline throughout:
   - Remove overstory leaving only white pine (if present)
   - Consider retaining areas with little commercial value to minimize damage to regeneration and to provide wildlife habitat

For all scenarios, monitor stands biannually to check for continued spread of decline. If so further measures (marking and removal) may be necessary.

Complete overstory removal is a feasible option where adequate advanced regeneration is present. Where this is not the case, consider other approaches to ensure adequate regeneration following harvest.

In younger (30-50 years) stands, sampling soil may help to determine the likelihood of future decline problems. Where the C horizon is alkaline, decline is more likely and it is prudent to assume a younger rotation age and consider options to ensure adequate advanced regeneration.

For more information about management recommendations for red pine plantations, contact Graeme Davis, R.P.F., County of Simcoe [Graeme.Davis@Simcoe.ca; (705) 726-9300 ext.1177]

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Cette publication hautement spécialisée *Mortality in Southern Ontario Red Pine Plantations: Causes, Consequences, and Management Options* n'est disponible qu'en anglais en vertu du Règlement 411/97, qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère de Richesses naturelles au information.ofri@ontario.ca.

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Appendix 6 - History of Afforestation Programs in Ontario

The history of reforestation and afforestation in southern Ontario has been well documented (Lambert and Pross 1967, Borczon 1982, Armson 2001, Bacher 2011). Early farmers recognized the need for trees and forests and the benefits they provided in Ontario's landscape. The government promoted tree planting as one way of preventing further degradation of agricultural lands and watersheds.

The provincial government's first formal response to the challenge of missing forests came in 1871, when they passed *An Act to Encourage the Planting of Trees Upon the Highways in the Province*, which gave local municipalities the authority to pass by-laws regarding roadside trees. This Act was eventually replaced by the 1883 *Ontario Tree Planting Act*, which paid landowners a small incentive fee to plant trees. Although this approach was largely unsuccessful in achieving large-scale replanting, some spectacular examples of these plantings can still be seen in southern Ontario (Fig. 1.2). These acts also helped to establish a necessary relationship between the government and landowners as partners in planting programs. This would become the foundation of more successful programs in the following centuries (Armson et al. 2001).

Figure 1.2: 120-year-old sugar maples lining a rural concession road near Orangeville, Ontario. [Photo source: Eric Boysen, NewLeaf Forest Services]

For the purposes of this guide, we will use the following definitions:

- "Afforestation" is the direct human-induced conversion of land that has not been forested for a period of at least 50 years into forested land through planting, seeding, promotion of natural regeneration, or a combination of these approaches.
- "Reforestation" is the direct human-induced conversion of non-forested land that was once forested (but is no longer forested) into forested land through planting, seeding, promotion of natural regeneration, or a combination of these approaches.
- "Deforestation" is the direct human-induced conversion of forested land into non-forested land.

1.1.2 The Agreement Forest (Community Forest) program

The most significant impetus for reforestation was a report by Professor Edmund J. Zavitz to the Ontario Legislature in 1908. Between 1905 and 1908, Zavitz toured "old Ontario" to document the challenge of soil erosion. He also visited the first government nursery, established in 1904 at the Ontario Agricultural College. His 1908 *Report on the Reforestation of Waste Lands in Southern Ontario* became the foundation for large-scale planting efforts. He estimated that there were almost 150 000 ha of land in Simcoe, Norfolk, Lambton, Northumberland, and Durham counties that were described as "waste lands" and that needed attention (Zavitz 1909). Initially, this came in the form of distribution of free seedlings from provincial tree nurseries to landowners. Between 1905 and 1919, some 3.4 million trees were distributed. The 1911 *Counties Reforestation Act* gave county governments the right to pass bylaws to acquire land for reforestation purposes. However, little progress was made, so in 1921, the *Reforestation Act* was passed, enabling the province to enter into agreements for reforesting, developing, and managing lands held by the counties (the Agreement Forest Program). Simcoe County joined the program in 1922, and the area now known as the Hendrie Tract was planted (Borczon 1982). The Agreement Forest Program was active between 1921 and 1998, when the government returned management and control of these forested areas to their owners. By 1998, 56 agreements had been signed for 128 853 ha of plantations and natural woodland (Table 1.1, Fig. 1.3, 1.4, 1.5). Today, these forests are known collectively as Community Forests, and serve as a testament to Zavitz's vision of the future in his 1908 report:

> "The policy of putting these lands under forest management has many arguments in its favour. It will pay as a financial investment; assist in insuring a wood supply; protect the headwaters of streams, providing breeding grounds for wild game; provide object lessons in forestry and prevent citizens from developing under conditions which can only end in failure."

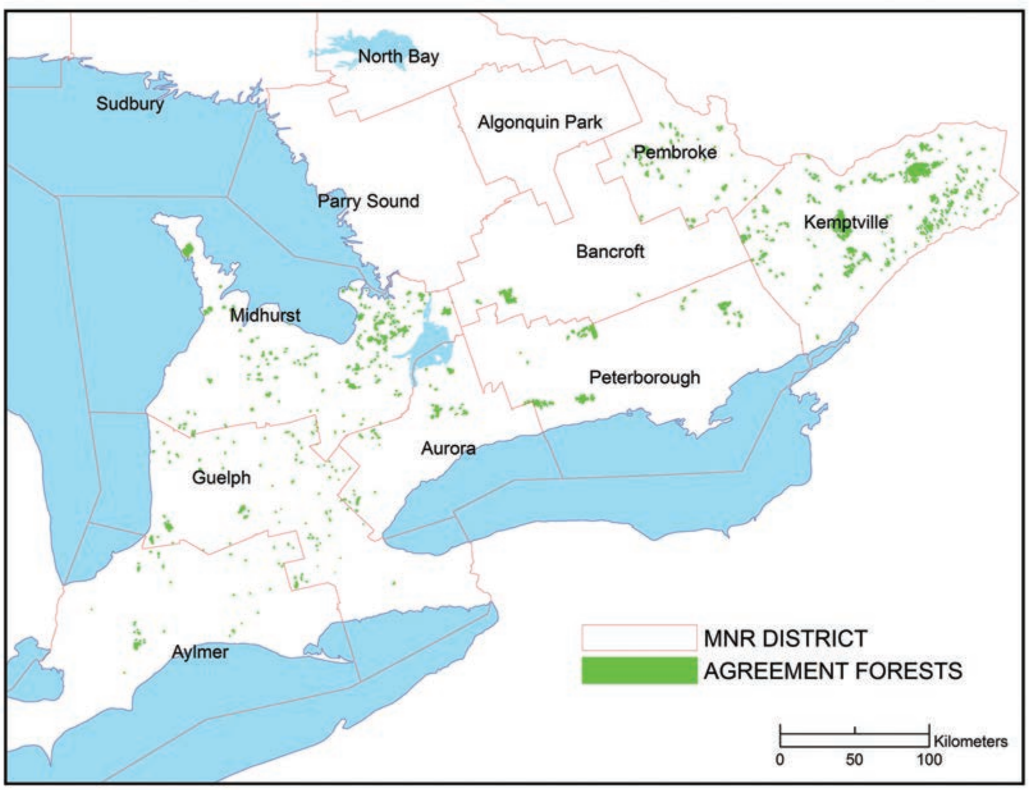

Figure 1.3: Distribution of Agreement (Community) Forests in southern Ontario, March 2000.

Table 1.1: Agreement forest area in 1998, by ownership group.

Ownership group	Number of agreements	Total agreement area (ha)
Counties	16	59 606
Regional municipalities	6	19 036
Townships	6	1131
Conservation authorities	26	44 487
Federal government	1	2752
Industry or corporation	1	1841
Total	56	128 853

Figure 1.4: Early farmers faced many obstacles, including the need to clear trees and stumps. However, many of these lands were eventually shown to be unsuitable for agriculture. [Photo source: OMNRF archives]

Figure 1.5: Sand drifts covering fenceline. [Photo source: OMNRF archives]

1.1.3 The 1966 *Woodlands Improvement Act*

The Agreement Forest program focused on larger tracts of land owned by municipal governments, but government foresters in southern Ontario increasingly recognized that there were vast areas of mostly marginal privately owned agricultural land that could also benefit from reforestation. This land had been abandoned due to poor soils, poor economics, small field size, or a combination of these factors that rendered agriculture unworkable and unprofitable. The 1966 *Woodlands Improvement Act* allowed the government to enter into agreements with individual landowners to provide assistance for reforestation and stand improvement in existing woodlands. The landowner committed a minimum of 5 acres of land to forestry for 15 years, agreed to provide necessary protection for the trees, and purchased planting stock at a subsidized rate. In turn, the government prepared the site, planted the trees, and monitored their development during the 15-year period. After expiry of the initial agreement, forest management advisory and assistance services were made available. The program proved to be very popular, and by the time the last trees specified by an agreement had been planted (in 1993), more than 137 000 ha were under management and more than 213 million seedlings had been planted (Puttock 2001).

Many lessons have been learned over the last century about how to establish and manage plantations of Ontario's tree species and about the roles of governments (provincial and local), private landowners, industry, and concerned citizens in ensuring a healthy working landscape that preserves all the values provided by the land (Fig 1.6). Southern Ontario's forest landscape has been restored in many areas, bringing a healthier balance among trees, agriculture, and urban areas. These man-made forests have helped to increase forest cover, and now provide habitat for many species, purification of air and water, forest products and forestry jobs, and carbon sequestration to combat global warming. One of the most important lessons was the need to recognize the limitation imposed by soil and site conditions; before we can restore the forest to a more natural state after large-scale disturbances such as agriculture, we must first restore the site. Today's forest managers need to understand these lessons and Ontario's history as we embark on future afforestation efforts.

Figure 1.6: These familiar gate post signs marked properties participating in the Woodlands Improvement Act agreement program. The sign on the left was used from 1966 until 1988, and was replaced by the more modern sign (right). [Photo source: Eric Boysen, Newleaf Forest Services]

The 50 Million Tree Program, 2007

The 50 Million Tree Program was announced in August 2007, and committed the Ontario Ministry of Natural Resources (now, the Ontario Ministry of Natural Resources and Forestry) to plant 50 million trees on 25 000 ha of private and public land. The 50 Million Tree Program saw an evolution of the delivery mechanism with the provincial government engaging Forests Ontario, a not-for-profit organization, to administer the program following Ontario Ministry of Natural Resources and Forestry (OMNRF) guidelines. Many aspects of the program were similar to the *Woodlands Improvement Act* agreements with the landowners committing to plant at least a minimum area (in this case 1 ha) and to provide necessary protection for a 15-year period.

Forests Ontario managed the seed forecasting and collection program to ensure the availability of high-quality seed from known sources, developed agreements with tree nurseries to produce nursery stock that meets the program's requirements, filled a knowledge-transfer role to teach interested people what they need to know to succeed, and raised overall afforestation capacity. Work was carried out through delivery agents including Conservation Authorities, forestry consultants, indigenous communities, municipalities, and local stewardship councils. The delivery agents engaged landowners, developed agreements, carried out the afforestation work, and reported their accomplishments.

References

References

AAFC. 2015. Pruning Trees and Shrubs. Agriculture and Agri-Food Canada, Ottawa, ON. Agroforestry Fact Sheet.

Anderson, H. 2012a. Invasive Dog-strangling Vine (*Vincetoxicum rossicum*): Best Management Practices in Ontario. Ontario Invasive Plant Council, Peterborough, ON.

Anderson, H. 2012b. Invasive Garlic Mustard (*Alliaria petiolata*): Best Management Practices in Ontario. Ontario Invasive Plant Council, Peterborough ON.

Anderson, H. 2012c. Invasive Common (European) Buckthorn (*Rhamnus cathartica*): Best Management Practices in Ontario. Ontario Invasive Plant Council, Peterborough ON.

Anderson, T.W. 1989. Vegetation changes over 12,000 years. GEOS 18(3), 39–47.

Archibald, D.J. & Bowling, C. 1995. Jack Pine Density Management Diagram for Boreal Ontario. Ontario Ministry of Natural Resources, Northeast Science and Technology, Timmins, ON and Northwest Science and Technology, Thunder Bay, ON. Technical Note TN-005.

Armson, K.A. 2001. Ontario's Forests: a Historical Perspective. Ontario Forestry Association and Fitzhenry and Whiteside, Toronto, ON.

Armson, K.A., Grinnell, W.R. & Robinson, F.C. 2001. Chapter 1. History of reforestation in Ontario. In Wagner, R.G. & Colombo, S.J. (eds.), Regenerating the Canadian Forest: Principles and Practice for Ontario. Ontario Ministry of Natural Resources. Fitzhenry and Whiteside, Toronto, ON. pp. 3-22

Bacher, J.C. 2011. Two Billion Trees and Counting—the Legacy of Edmund Zavitz. Dundurn, Toronto, ON.

Beckwith, A.F. & Roebbelen, P. 1983. Red pine plantation growth and yield tables. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, ON. Forest Research Report No. 108.

Bidwell, P.K., Turner, B., Archibald, D.J. & Maurer, N. 1996. An Approach to Pre-harvest Silviculture Prescriptions in Boreal Ontario. Ontario Ministry of Natural Resources, Northeast Science and Technology, Timmins, ON, and Northwest Science and Technology, Thunder Bay, ON. NEST Technical Note TN-014 and NWST Technical Note TN-034.

Borczon, E.L. 1982. Evergreen Challenge—the Agreement Forest Story. Ontario Ministry of Natural Resources, Toronto, ON.

Bottero, A., D'Amato, A.W., Palik, B.J. et al. 2017. Density-dependent vulnerability of forest ecosystems to drought. Journal of Applied Ecology 54, 1605–1614.

Burgess, D., MacAfee, K., Wetzel, S. & Wang, B.S.P. 2011. Annotated Bibliography of Eastern White Pine and Red Pine: 1960–2007. Natural Resources Canada, Canadian Forest Service, Canadian Wood Fibre Centre, Ottawa ON.

Chapman, L.J. & Putnam, D.F. 1984. The Physiography of Southern Ontario. Ontario Geological Survey, Toronto, ON. Special Volume 2.

Colombo, S. J. 2008. Ontario's forests and forestry in a changing climate. Climate change research report CCRR-12. Ontario Forest Research Institute, Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario, Canada. 22p. ISBN 978-1-4249-7495-5 (PDF).

Coulombe, C., Bélanger, G., Lavallée, R., Laflamme, G., & Daoust, G. 2004. A Simple Effective Tool for Controlling White Pine Weevil and Blister Rust on Norway Spruce and Eastern White Pine. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Quebec, QC.

Davis, C. & Meyer, T. 2004. Field Guide to Tree Diseases of Ontario. Revised edition. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. NODA/ NFP Technical Report TR-46.

Dey, D.C. & Buchanan, M. 1995. Red Oak Acorn Collection, Nursery Culture and Direct Seeding: a Literature Review. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, ON. Forest Research Information Paper No. 122.

Dixon, A. 2003. A Photographic Treatise on How Best to Grow Veneer Quality Lumber. Northumberland Stewardship Council, Peterborough, ON.

Drew, T.J. & Flewelling, J.W., 1977. Some recent Japanese theories of yield density relationships and their application to Monterey pine plantations. Forest Science 23, 517–534.

Drew, T.J. & Flewelling, J.W., 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. Forest Science 25, 518–532.

DuPlissis, J. 1998a. NF98–362 Chemical Weed Control in Tree Planting Projects: Part I–Pre-emergence Herbicides. University of Nebraska, Lincoln, NE. Extension Paper 581.

DuPlissis, J. 1998b. NF98–363 Chemical Weed Control in Tree Planting Projects: Part II–Post-emergence Herbicides. University of Nebraska, Lincoln, NE. Extension Paper 580.

Dyke, A.S. 2004. An Outline of North American Deglaciation with Emphasis on Central and Northern Canada. Geological Survey of Canada, Ottawa, ON.

Edge, G. 2004. Direct Seeding of Hardwoods in Wisconsin. Wisconsin Department of Natural Resources, Division of Forestry, Madison, WI.

Edwards, J.E., Pearce, C., Ogden, A.E. & Williamson, T.B. 2015. Climate Change and Sustainable Management in Canada: A Guidebook for Assessing Vulnerability and Mainstreaming Adaptation into Decision-making. Climate Change Task Force, Canadian Council of Forest Ministers, Ottawa, ON.

Environment Canada. 2000. Planting the Seed: a Guide to Establishing Prairie and Meadow Communities in Southern Ontario. Environment Canada, Environmental Conservation Branch, Downsview, ON.

Farnden, C. 1999. Guidelines for Developing Stand Density Management Regimes. British Columbia Ministry of Forestry, Forest Practices Branch, Victoria, BC.

FGCA. 2017. Adapting to a Changing Climate: a Report for Southern Region Sustainable Forest License Holders. Forest Gene Conservation Association, Kemptville, ON.

Gilmore, D.W. & Palik, B.J., 2006. A Revised Handbook for Red Pine in the North Central Region. USDA Forest Service, North Central Research Station, St. Paul, MN. General Technical Report NC-264.

Gleeson, J., Gray, P., Douglas, A., Lemieux, C.J. & Nielsen, G. 2011. A Practitioner's Guide to Climate Adaptations in Ontario's Ecosystems. Ontario Centre for Climate Impacts and Adaptation Resources, Sudbury, ON.

Gross, H.L. 1985. White Pine Blister Rust: a Discussion of the Disease and Hazard Zones for Ontario. In: Sullivan, C.R., Plexman, C.A., Whitney, R.D. et al. (eds.), White Pine Symposium (supplement), Petawawa National Forestry Institute, Chalk River, ON. Proceedings of the Entomological Society of Ontario. 116:73-79.

Hodge, J.C., Juzwik, J., Gross, H.L. & Retnakaran, A. 1990. White Pine Blister Rust and White Pine Weevil Management. Guidelines for White Pine in Ontario. Ontario Ministry of Natural Resources, Pest Management Section, Toronto, ON. Report PM-36.

Horton, K.W. & Bedell, G.H.D. 1960. White and Red Pine—Ecology, Silviculture and Management. Canada Department of Northern Affairs and National Resources, Forestry Branch, Ottawa ON. Bulletin 124.

IJC. 2012. International Upper Great Lakes Study: Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels. International Joint Commission, Ottawa, ON. Final Report, March 2012.

IPCC. 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

Jalava, J.V., Sorrill, P.J., Henson, J. & Brodribb, K. 2002. The Big Picture Project: developing a natural heritage vision for Canada's southern-most ecological region. In Bondrup-Neilson, S., Munro, N.W.P., Nelson, G., et al. (eds.), Managing Protected Areas in a Changing World. Proceedings of the Fourth International Conference on Science and Management of Protected Areas. University of Waterloo, Waterloo, ON. pp. 639–649.

Johnson, F., Paterson, J., Leeder, G., Mansfield, C., Pinto, F., & Watson, S. 1996. Artificial Regeneration of Ontario's Forests: Species and Stock Selection Manual. Ontario Ministry of Natural Resources. Ontario Forest Research Institute, Sault Ste. Marie, ON. Forest Research Information Paper No. 131.

Johnson, G.R. & Sucoff, E. 1999. Minimizing De-icing Salt Injury to Trees. University of Minnesota Extension, Minneapolis–St. Paul, MN. *299*

Johnston, M.H.; Campagna, M.; Gray, P.A.; Kope, H.H.; Loo, J.A.; Ogden, A.E.; O'Neill, G.A.; Price, D.T.; Williamson, T.B. 2009. Vulnerability of Canada's tree species to climate change and management options for adaptation: an overview for policy makers and practitioners. Canadian Council of Forest Ministers, Ottawa, Ontario. 44 p.

Keddy, P. 1999. Earth, Wind and Fire. An Ecological Profile of Lanark County. First Edition—Natural History of Lanark County. Mississippi Valley Field Naturalists, Almonte, ON.

Kelty, M.J., 1992. Comparative productivity of monocultures and mixed-species stands. In Kelty, M.J., Larson, B.C. & Oliver, C.D. (eds.), The Ecology and Silviculture of Mixed-Species Forests. Kluwer Academic Publishers, Boston, MA. pp. 125–141.

Kelty, M.J., 2006. The role of species mixtures in plantation forestry. Forest Ecology and Management 233, 195–204.

Kristensen, D., 1996. An Assessment of the Songbird Habitat Quality Provided by Red Pine Plantations in Eastern Ontario. Eastern Ontario Model Forest, Kemptville ON. Information Report No. 25.

Lambert, R. & Pross, P. 1967. Renewing Nature's Wealth. Ontario Department of Lands and Forests, Toronto, ON.

Love, D.V. & Williams, J.R.M. 1968. The Economics of Plantation Forestry in Southern Ontario. Department of Regional Economic Expansion, Ottawa, ON. Canada Land Inventory Report no. 5.

MacCracken, M. 2001. Prediction versus Projection – Forecast versus Possibility. WeatherZine. Edition 26. https://sciencepolicy.colorado.edu/zine/archives/1-29/26/guest.html [accessed June 2019]

Manion, P.D. 1991. Tree Disease Concepts. Prentice Hall, Upper Saddle River, NJ.

McKenney, D.W., Allen, D.J., Fraleigh, S., Pedlar, J.H. & Campbell, K.L. 2008. Growth of Southern Ontario Hardwood Research Plantations. Natural Resources Canada, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report GLC-X-9E.

McKenney, D.W., Mackey, B.G. & Joyce, D. 1999. Seedwhere: a computer tool to support tree transfer and ecological restoration decisions. Environmental Modelling and Software 14, 589–595.

McLaughlan, M.S., Myketa, D. & Bell, F.W. 1996. Managing vegetation with herbicides: a review of glyphosate, 2,4–D, hexazinone, triclopyr and simazine. In Bell, F.W., McLaughlan, M. & Kerley, J. (comp.) Vegetation Management Alternatives—A Guide to Opportunities. Ontario Ministry of Natural Resources, Northwest Science & Technology, Thunder Bay, ON. Technical note TN-37.

McPherson, T.S. & Timmer, V.R. 2002. Amelioration of degraded soils under red pine plantations on the Oak Ridges Moraine, Ontario. Canadian Journal of Soil Science 82, 375–388.

Miller, G.W., Stringer, J.W., & Mercker, D.C. 2007. Technical Guide to Crop Tree Release in Hardwood Forests. University of Tennessee Extension, Knoxville, TN. Publication PB1774.

Morganstern, E.K., & Copis, P. 1999. Best White Spruce Provenances in Ontario. Natural Resources Canada, Petawawa Research Forest, Petawawa, ON. Information Report ST-X-16.

Morrison, D.J. & Mallett, K.L.1996. Silvicultural Management of Armillaria Root Disease in Western Canadian Forests. Cdn. Journal of Plant Pathology 18, 194-199.

Naylor, B. 1998. Habitat management guidelines. In A Silvicultural Guide for the Tolerant Hardwood Forest in Ontario. Ontario Ministry of Natural Resources, Toronto, ON. pp. 10:1-31. *300*

Newton, P.F. 2009. Development of an integrated decision-support model for density management with jack pine stand-types. Ecology and Modelling 220(23), 3301–3324.

Nienstaedt, H., & Teich, A.H. 1972. Genetics of White Spruce. USDA Forest Service, Washington, DC.

NRC. 2017. Trees, Insects and Diseases of Canada's Forests. Natural Resources Canada, Ottawa, ON. (http://tidcf.nrcan.gc.ca/)

Oliver, C. & Larson, B. 1996. Forest Stand Dynamics: Update Edition. John Wiley & Sons, Inc., New York, NY.

OBC. 2011. Ontario's Biodiversity Strategy, 2011: Renewing Our Commitment to Protecting What Sustains Us. Ontario Biodiversity Council, Peterborough, ON.

OCSRE. 1993. Field Manual for Describing Soils in Ontario. 4th ed. Ontario Centre for Soil Resource Evaluation, Guelph, ON. Publication No. 93–1.

OMAF & AC. 1992. Best Management Practices: Farm, Forestry and Habitat Management. Ontario Ministry of Agriculture and Food, Toronto, ON, and Agriculture Canada, Ottawa, ON.

OMAFRA. 2015. Guide to Weed Control 2016–2017. Ontario Ministry of Agriculture, Food & Rural Affairs, Toronto, ON. Publication 75.

OMNR. 1973. Forest Tree Planting. Ontario Ministry of Natural Resources, Forest Management Branch, Toronto, ON.

OMNR. 1986. Managing Red Pine Plantations. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 1989. Common Pests of Trees in Ontario. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 1992. Stock Handling Guidelines for Southern Region. Ontario Ministry of Natural Resources, Southern Region Science and Technology Transfer Unit, Brockville, ON.

OMNR. 1994. Cover Crops Help Tree Seedlings Beat Weed Competition. Ontario Ministry of Natural Resources, Landowner Resource Centre, Manotick, ON. Extension Note.

OMNR. 1995a. Planning for Tree Planting. Ontario Ministry of Natural Resources, Landowner Resource Centre, Manotick, ON. Extension Note.

OMNR. 1995b. Room to Grow: Controlling the Competition. Ontario Ministry of Natural Resources, Landowner Resource Centre, Manotick, ON. Extension Note.

OMNR. 1995c. Clearing the Way: Preparing the Site for Tree Planting. Ontario Ministry of Natural Resources, Landowner Resource Centre, Manotick, ON. Extension Note.

OMNR. 1999. Protecting Trees from Vole Damage. Ontario Ministry of Natural Resources, Landowner Resource Centre, Manotick, ON. Extension Note. *301*

OMNR. 2000. A Silvicultural Guide to Managing Southern Ontario Forests, Version 1.1. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 2004. Ontario Tree Marking Guide, Version 1.1. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 2010a. Natural Heritage Reference Manual for Natural Heritage Policies Under the Provincial Policy Statement, 2005. 2nd ed. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 2010b. Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 2010c. Forest Management Guide for Great Lakes-St. Lawrence Landscapes. Ontario Ministry of Natural Resources, Toronto, ON.

OMNR. 2010d. Seed Zones of Ontario. Ontario Ministry of Natural Resources, Toronto, ON. Forest Management Directives and Procedure FOR 06 02 01 (internal document).

OMNR. 2011. A Land Manager's Guide to Conserving Habitat for Forest Birds in Southern Ontario. Ontario Ministry of Natural Resources, Toronto, ON.

OMNRF. 2015. Forest Management Guide to Silviculture in the Great Lakes–St. Lawrence and Boreal Forests of Ontario. Ontario Ministry of Natural Resources and Forestry, Toronto, ON.

OTSP. 2014. Seeds of Ontario Trees and Shrubs: Field Manual for Crop Forecasting and Collecting. Ontario Tree Seed Plant, Angus, ON, and Forest Gene Conservation Association, Kemptville, ON.

OWA. 2003a. Woodland Notes. The Art of Timber Cruising: Part 1 Point Sampling. Ontario Woodlot Association, Kemptville, ON.

OWA. 2003b. Woodland Notes. The Art of Timber Cruising: Part 2 Fixed Area Plots. Ontario Woodlot Association, Kemptville, ON.

OWA. 2009. A Landowner's Guide to Careful Logging. Ontario Woodlot Association, Kemptville, ON.

Panill, P. 2005. Pruning Young Hardwood Trees. Maryland Chapter of the Walnut Council, West Lafayette, MD, and Maryland Forest Service, Frederick, MD.

Paterson, J.M. & Fayle, D.C.F. 1984. Early prediction of plantation performance for red pine. Forestry Chronicle 60, 340–344.

Pedlar, J.H., McKenney, D.W., & Fraleigh, S. 2006. Planting black walnut in southern Ontario: midrotation assessment of growth, yield and silvicultural treatments. Canadian Journal of Forest Research 36, 495–504. *302*

Pedlar, J.H., Fraleigh, S., & McKenney, D.W. 2007. Revisiting the work of Fred von Althen—an update on the growth and yield of a mixed hardwood plantation in southern Ontario. Forestry Chronicle 83(2), 175–179.

Penner, M. 2001. A Density Management Diagram for White Spruce Plantations in Ontario. Ontario Ministry of Natural Resources, Toronto, ON. Unpublished report.

Pielke, R. A. and Wilby, R. L., (2012), Regional climate downscaling: What's the point?, Eos Trans. AGU, 93(5), 52.

Puttock, D. 2001. Critical Review of Historical and Current Tree Planting Programs on Private Lands in Ontario. Ontario Ministry of Natural Resources, Toronto, ON. Ontario Government Climate Change Initiative, Project CC-109.

Rauscher, H. M. 1984. Growth and Yield of White Spruce Plantations in the Lake States (a Literature Review). USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. Research Paper NC-253.

Riley, J.L. & Mohr, P. 1994. The Natural Heritage of Southern Ontario’s Settled Landscapes. A Review of Conservation and Restoration Ecology for Land-use and Landscape Planning. Ontario Ministry of Natural Resources, Southern Region Science and Technology Transfer Unit, Aurora, ON. Technical Report TR-001.

Saunders, M.R. & Puettmann, K.J. 2000. A Preliminary White Spruce Density Management Diagram for the Lake States. University of Minnesota, Department of Forest Resources, St. Paul, MN. Staff Paper Series No. 145.

Smith, D.J., & Woods, M.E. 1997. Red Pine and White Pine Density Management Diagrams for Ontario. Ontario Ministry of Natural Resources, North Bay ON. SCSS Technical Report 48.

Stiell, W.M. 1980. Response of white spruce plantation to three levels of thinning from below (1958–1978). Forestry Chronicle 56(1): 21–27.

Stringer, J.W., Clatterbuck, W. & Seifert, J. 2009. Site Preparation and Competition Control Guidelines for Hardwood Tree Plantings. University of Kentucky, Cooperative Extension, Lexington, KY. Cooperative Extension Service Publication Series, Publication FOR-107.

Swanston, Christopher W.; Janowiak, Maria K.; Brandt, Leslie A.; Butler, Patricia R.; Handler, Stephen D.; Shannon, P. Danielle; Derby Lewis, Abigail; Hall, Kimberly; Fahey, Robert T.; Scott, Lydia; Kerber, Angela; Miesbauer, Jason W.; Darling, Lindsay; Parker, Linda; St. Pierre, Matt. 2016. Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd ed. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. http://dx.doi.org/10.2737/NRS-GTR-87-2

Szuba, K. & Naylor, B. 1998. Forest Raptors and Their Nests in Central Ontario. A Guide to Stick Nests and Their Users. Ontario Ministry of Natural Resources, South Central Sciences Section, North Bay, ON. Field Guide FG-03.

Taylor, E.P. & Jones, R.K. 1986a. Soil Interpretation and Training for Forestry 1981–1985 in Central and Southwestern Regions, Site Region 6e & 7e. Ontario Institute of Pedology, Guelph, ON.

Taylor, E.P. & Jones, R.K. 1986b. Guide to Tree Species Suitability for Site Regions 6e and 7e: Using Field Recognizable Soil Properties: Central and Southwestern Regions, Addendum 1 to: Field manual for Describing Soils. University of Guelph, Ontario Institute of Pedology, Guelph, ON. Publication No. 85–3. *303*

Teich, A.H., Skeates, D.A. & Morganstern, E.K. 1975. Performance of White Spruce Provenances in Ontario. Environment Canada, Petawawa Forest Experimental Station, Chalk River, ON, and Ontario Ministry of Natural Resources, Forest Research Branch, Maple, ON. Special Joint Report.

Thompson, I., Mackey, B., McNulty, S., Mosseler, A. (2009). Forest Resilience, Biodiversity, and Climate Change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 43, 67 pages

UNITAR 2015. Resource Guide for Advanced Learning on: Predicting and Projecting Climate Change. United Nations Institute for Training and Research. https://www.uncclearn.org/sites/default/files/guide_predicting_and_projecting.pdf [accessed June 10th, 2019]

von Althen, F.W. 1988. Effects of spatial arrangement in mixed species hardwood plantations. Northern Journal of Applied Forestry 5, 203–207.

von Althen, F.W. 1990. Hardwood Planting on Abandoned Farmlands in Southern Ontario: Revised Guide. Forestry Canada, Ontario Region, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

Wagner, R.G. & Colombo, S.J. 2001. Regenerating the Canadian Forest—Principles and Practices for Ontario. Fitzhenry and Whiteside Ltd., Markham, ON.

Wallace, J. & Scott, J. 1995. Under Cover: a Guide To Using Cover Crops In the Maritimes. Nova Scotia Organic Growers Association, Sackville, NB, and Atlantic Canadian Organic Regional Network, Sackville, NB.

White, T.J.R., Dominy, S.W.J. & Allen, D.J. 2005. Review of Best Practices for Tree Planting on Marginal Agricultural Lands in Ontario. Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie, ON.

Whitney, R.D. 1994. Minimizing Losses to Tomentosus Root Rot in Ontario. Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie ON. Technical Note 82.

Whitney, R.D. & Dumas, M.T. 1994. Minimizing losses to Armillaria root rot in Ontario spruce. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Frontline Technical Note 84.

Wilby, R. L., and S. Dessai (2010), Robust adaptation to climate change, Weather, 65(7), 180–185

Woods, M.E. & Penner, M. 2000. Growth and Yield Response of Red Pine Plantations to Thinning. Ontario Ministry of Natural Resources, South Central Sciences Section, North Bay, ON. SCSS Technical Note 06.

Zavitz, E.J. 1909. Report on the Reforestation of Waste Lands in Southern Ontario. Ontario Department of Agriculture, Toronto, ON.

Zeleznik, J. & Zollinger, R. 2004. Weed Control in Tree Plantings. North Dakota State University, Extension Service, Fargo, ND. 304

English and Latin species names

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Acadian flycatcher: *Empidonax virescens*

American
- beech: *Fagus grandifolia*
- chestnut: *Castanea dentata*
- elm: *Ulmus americana*
- hazel: *Corylus americana*

Annual ryegrass: *Lolium multiflorum*

Armillaria root rot: *Armillaria* species (*A. mellea, A. ostoyae, A. obscura*)

Arrow-leaved aster: *Symphotricum urophyllum*

Ash: *Fraxinus* species

Asian long-horned beetle: *Anoplophora glabripennis*

Austrian pine: *Pinus nigra*

Bacterial leaf scorch: *Xylella fastidiosa*

Barley: *Hordeum vulgare*

Basswood: *Tilia americana*

Bedstraw: *Galium* species

Beech: *Fagus grandifolia*

Big shellbark hickory: *Carya laciniosa*

Birches: *Betula* species

Bitternut hickory: *Carya cordiformis*

Black
- ash: *Fraxinus nigra*
- cherry: *Prunus serotina*
- gum: *Nyssa sylvatica*
- locust: *Robinia pseudoacacia*
- oak: *Quercus velutina*
- spruce: *Picea mariana*
- walnut: *Juglans nigra*

Blue jay: *Cyanocitta cristata*

Blue vervain: *Verbena hastata*

Broad-winged hawk: *Buteo platypterus*

Brown-eyed Susan: *Rudbeckia triloba*

Buckthorn: *Rhamnus cathartica*

Bur oak: *Quercus macrocarpa*

Butternut: *Juglans cinerea*

Butternut canker: *Sirococcus clavigignenti-juglandacearum*

Canada
- plum: *Prunus nigra*
- wild rye: *Elymus canadensis*
- yew: *Taxus canadensis*

Cedars: *Thuja* species

Cedar leafminer: *Argyresthia canadensis*

Cherry birch: *Betula lenta*

Chinquapin oak: *Quercus muehlenbergii*

Common milkweed: *Asclepias syriaca*

Cooper’s hawk: *Accipiter cooperii*

Corn: *Zea mays*

Creeping red fescue: *Festuca rubra*

Crossbills: *Loxia* species

Crows: *Corvus* species

Cytospora canker: *Cytospora* species

Diplodia tip blight: *Sphaeropsis sapinea*

Dog-strangling vine: *Vincetoxicum (Cynanchum) rossicum*

Dogwood: *Cornus* species

Douglas-fir: *Pseudotsuga menziesii*

Dutch elm disease: *Ophiostoma ulmii*

Eastern
- cottonwood: *Populus deltoides*
- gall rust: *Cronartium* species
- white cedar: *Thuja occidentalis*

Elms: *Ulmus* species

Emerald ash borer: *Agrilus planipennis*

European
- larch: *Larix decidua*
- pine sawfly: *Neodiprion sertifer*
- pine shoot moth: *Rhyacionia buoliana*
- spruce sawfly: *Gilpinia hercyniae*

Eutypella canker: *Eutypella parasitica*

Evening primrose: *Oenothera* species

Forest tent caterpillar: *Malacosoma disstria*

Foxglove beardtongue: *Penstemon digitalis*

Garlic mustard: *Alliaria petiolata*

Green ash: *Fraxinus pennsylvanica*

Grey goldenrod: *Solidago nemoralis*

Gypsy moth: *Lymantria dispar*

Hackberry: *Celtis occidentalis*

Hawthorn: *Crataegus* species

Hemlock: *Tsuga canadensis*

Hemlock looper: *Lambdina fiscellaria*

Hemlock woolly adelgid: *Adelges tsugae*

Heterobasidion root rot: *Heterobasidion annosus*, *Heterobasidion irregulare*

Hickories: *Carya* species

Hickory bark beetle: *Scolytus quadrispinosus*

Hickory decline: cause unknown

Hybrid poplar: *Populus* species

Hypoxylon canker: *Hypoxylon* species

Ironwood: *Ostrya virginiana*

Jack pine: *Pinus banksiana*

Japanese larch: *Larix kempferi*

Kentucky coffee-tree: *Gymnocladus dioicus*

Kirtland's warbler: *Setophaga kirtlandii*

Larch (tamarack): *Larix laricina*

Larch casebearer: *Coleophora laricella*

Largetooth aspen: *Populus grandidentata*

Leaf anthracnose: several fungal species

Little bluestem: *Schizachyrium scoparium*

Loggerhead shrike: *Lanius ludovicianus*

Maples: *Acer* species

Milkweed: *Asclepias syriaca*

Nectria canker: *Nectria* species

Needle blight: *Rhizosphaera* species

Needle cast: *Lophodermium seditiosum*

Northern goshawk: *Accipiter gentilis*

Norway spruce: *Picea abies*

Nuthatches: *Sitta* species

Oaks: *Quercus* species

Oak wilt: *Ceratocystis fagacearum*

Oats: *Aveno* species

Pignut hickory: *Carya glabra*

Pines: *Pinus* species

Pine

- engraver: *Ips pini*
- needle rust: *Coleosporium asterum*
- shoot beetle: *Tomicus piniperda*

Pin oak: *Quercus palustris*

Perennial ryegrass: *Lolium perenne*

Poplars: *Populus* species

Pythium wilt: *Pythium* species

Raspberry: *Rubus* species

Ravens: *Corvus* species

Red

- alder: *Alnus rubra*
- maple: *Acer rubrum*
- millet: *Eleusine coracana*
- oak: *Quercus rubra* (*borealis*)
- pine: *Pinus resinosa*
- ring rot: *Phellinus pini*
- spruce: *Picea rubens*
- squirrel: *Tamiasciurus hudsonicus*

Red-headed pine sawfly: *Neodiprion lecontei*

Red-tailed hawk: *Buteo jamaicensis*

Reed canary grass: *Phalaris arundinacea*

Ryegrass: *Lolium* species

Sapwood streak: *Ceratocystis* species

Sassafras: *Sassafras albidum*

Scleroderris canker: *Gremmeniella abietina*

Scots pine: *Pinus sylvestris*

Septoria canker: *Septoria musiva*

Shagbark hickory: *Carya ovata*

Sharp-shinned hawk: *Accipiter striatus*

Showy tick-trefoil: *Desmodium canadense*

Shumard oak: *Quercus shumardii*

Silver maple: *Acer saccharinum*

Sirococcus shoot blight: *Sirococcus* species

Slender wheatgrass: *Elymus trachycaulis*

Sooty mold: *Catenuloxyphium semiovatum*

Soybean: *Glycine max*

Spruces: *Picea* species

Spruce needle rust: *Chrysomyxa* species

Sudden oak death: *Phytophthora ramorum*

Sugar maple: *Acer saccharum*

Sugar maple borer: *Glycobius speciosus*

Swamp white oak: *Quercus bicolor*

Sycamore: *Platanus occidentalis*

Tamarack: *Larix laricina*

Tar spot: *Rhytisma acerinum*

Thousand canker disease: *Geosmithia morbida*

Tomentosus root rot: *Inonotus tomentosus*

Two-lined chestnut borer: *Agrilus bilineatus*

Tulip tree: *Liriodendron tulipifera*

Velvet-top fungus: *Phaeolus schweinitzii*

Verticillium wilt: *Verticillium* species

Virginia mountain mint: *Pycnanthemum virginianum*

Wheat: *Triticum* species

White
- ash: *Fraxinus americana*
- birch: *Betula papyrifera*
- clover: *Trifolium repens*
- millet: *Panicum miliaceum*
- oak: *Quercus alba*
- pine: *Pinus strobus*
- pine blister rust: *Cronartium ribicola*
- pine weevil: *Pissodes strobi*
- spruce: *Picea glauca*

Wild bergamot: *Monarda fistulosa*

Wild lupine: *Lupinus perennis*

Willows: *Salix* species

Yellow birch: *Betula alleghaniensis*

Yellow-headed spruce sawfly: *Pikonema alaskensis*

Glossary and list of abbreviations

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Adaptive management: an iterative process of learning by doing that follows a general progression of setting goals, evaluating evidence, making and implementing decisions, monitoring and evaluating outcomes, and revisiting decisions as new information is derived directly from practice.
Afforestation: the direct human-induced conversion of land that has not been forested for an extended period of time (e.g. 50 years) into forested land through planting, seeding, promotion of natural seed sources, or a combination of these approaches.
Agroforestry: combining afforestation with agriculture.
Allelopathy: the release of toxic chemicals by one organism that interferes with the reproduction, growth, or survival of a competing species.
Aspect: see "slope aspect".
BA: basal area is the cross-sectional area of a tree at breast height. Can be aggregated as the Basal Area per hectare to describe the stocking of a stand.
BAF: basal area factor of a wedge prism – typically a 2 m^2/ha BAF is used in Ontario.
Band spraying: applying a herbicide in narrow bands leaving unsprayed bands between.
Breast height: 1.3 meters, the standardized height above ground for measuring tree diameters
Bud capping: covering the buds with unpalatable caps that prevent browsing.
Bud check: when the terminal bud of conifers does not expand properly or at all.
Bulk density: the weight of a soil per unit of volume.
Commercial thinning: a thinning in which the harvested trees are removed from the site and used for commercial purposes.
Companion planting: planting of a non-crop species between trees of the crop species to increase the spacing between these trees, thereby improving the quality of their stems.
Crop plan: a detailed list of your objectives, explanations of how you plan to achieve them, and a budget for the labour, time, and money required to achieve your objectives.
Cross-row thinning: cutting access rows roughly perpendicular to the rows of trees at a predetermined spacing to improve machine access.
Crown land: land owned by the government of Ontario and managed on behalf of the public.
DBH: diameter at breast height (1.3 m above the ground).
DBH_q: see "quadratic mean diameter at breast height".
Deforestation: the direct human-induced conversion of forested land into non-forested land.
Degree-days: the sum of the number of days above a certain minimum temperature (typically 5°C) multiplied by the temperatures on those days.
Directional felling: controlling how trees fall during harvesting so that they don't strike and damage residual trees.
DMD: density management diagram.
Drumlin: elongated, domed hill created by movement of a glacier.
Esker: winding ridge of gravel and other sediments formed by rivers flowing under a glacier.
Fixed-area sampling: sampling method that uses plots of a defined size and shape.
Free-to-grow: the stage of forest development where pre-determined regeneration standards have been met (species mix, stocking, density, height, etc.) and the crop trees are essentially free of competing vegetation.
Frost-heaving: when expansion of the soil during freezing ejects recently planted seedlings.
Frost pocket: a low-lying area where frost develops.

Girdling: damage, including intentionally mechanical damage, that affects the full circumference of a stem, thereby preventing or greatly impeding movement of nutrients between the roots and leaves, often leading to death of the tree.
Glacio-fluvial deposits: relatively flat deposits of sand and other materials created by outflows of water from glaciers.
Gleying: blue–grey streaks in a soil that indicate a lack of oxygen due to a lack of drainage.
Graminicide: a herbicide that targets grasses.
Group selection: a modification of the selection silviculture system where small groups of trees are removed in an are normally less than 2 tree heights in diameter.
Ha (hectare): an area of 10 000 m_2 (about 2.5 acres).
Herbaceous species: non-woody plant species.
IPM: integrated pest management using a range of mechanical, biological, physical, cultural, behavioral, and chemical control techniques to suppress pests and invasive species at every stage of their life cycle.
Leader: the shoot at the top of a tree that will form its main stem.
Lifting: removal of seedlings from the soil for storage.
Long-butting: sawing off short unmerchantable portions from the butt end of a log due to decay or defect
MAI: mean annual increment.
Microclimate: the climate immediately around a seedling or tree.
Moraine: eroded materials deposited at the receding front edge of or underneath a melting glacier.
Mulch: a layer of material that is spread around the base of individual trees to control competition.
Nitrogen fixation: transfer of nitrogen from the atmosphere into plant-available forms in the soil.
Old field: an abandoned crop field or pasture that is no longer being managed for agriculture.
Phenology: the timing of physiological events during a plant's annual growth cycle, such as bud break or flowering.
Point sampling: a method of sampling trees within a given area. Once a sampling point has been established, a wedge prism of a known BAF is used to sample trees.
Pre-commercial thinning: a thinning that does not yield trees of commercial value, often designed to improve spacing of crop trees.
Pre-emergence herbicide: a herbicide that is applied before weed seeds have a chance to germinate.
profile: see "soil profile"
Propagule: any part of a plant that can generate a new individual.
Pruning: removal of branches (e.g., to improve a tree's resistance to the wind, to divert more resources to producing a larger stem or a stem with fewer large knots).
Quadratic mean diameter at breast height (DBH_q): the square root of the mean of the squared DBHs.
Refill planting: filling gaps where planted seedlings or older trees died.
Reforestation: the direct human-induced conversion of non-forested land that was recently forested (but is no longer forested) into forested land through planting, seeding, promotion of natural seed sources, or a combination of these approaches.
Riparian: adjacent to a stream or body of water.
Scalping: removal of the sod layer at the soil surface.
Scarification: disturbance of the soil surface (e.g., by scalping) to expose the underlying mineral soil and create a suitable seedbed.
SDI: stand density index, which represents the ratio of the actual density to the maximum density.
Seed bank: the collection and preservation of ungerminated seeds of known origin, used to produce seedlings for afforestation.

Seed zones: administrative boundaries designed to guide the movement of seed and plant propagules to ensure genetic suitability to local climatic conditions
Self-pruning: natural loss of lower branches.
Self-thinning: when the stand density becomes so high that the available resources are no longer sufficient to sustain the life of all of the trees, the smallest and most supressed trees begin to die.
Shade-intolerant species: species that require large amounts of light, and that grow best in the open or below larger gaps in a forest canopy.
Shade-tolerant species: species that are capable of growing in the shade beneath a canopy of mature trees, and may even prefer those conditions.
Site-index curve: a graph of the expected height of dominant trees as a function of their age at breast height.
Silvopastoralism: combining forestry with animal husbandry.
Single-cohort plantations: plantations in which all trees were established at the same time.
Site preparation: preparing the site for planting or artificial seeding, typically by harrowing or other measures to create suitable planting spots or seedbeds and to control competing plants.
Slope aspect: the direction in which a slope faces (e.g., south).
Soil horizons: distinct horizontal layers with different characteristics that develop in soils.
Soil profile: a side-view that shows the vertical layering of the soil horizons.
Stick nests: platforms that large birds create from sticks and twigs and that they use for nesting, often for many years.
Stocking level: the number of trees per unit area, expressed as a % of "fully stocked".
Stock type: the type of seedling selected for planting (e.g., bareroot, container).
Stub: a live tree that has been cut well above the normal stump height.
Stratification – spatial: dividing a plantation into groups of sub-sites with similar characteristics.
Stratfication – seed: the process whereby seed dormancy is broken, by adjusting temperature and moisture conditions for a set period of time, to encourage germination
Succession: the gradual replacement of one plant community with a different community.
Super-canopy trees: trees that extend above the canopy.
Taproot: a single dominant root.
Tending: management to protect the health and vigor of a forest.
Thinning: removal of some trees to give the remaining trees more room to grow.
Thinning from below: removal of suppressed or low-quality understory trees.
Thinning shock: thinning-induced stress that causes reduced growth for one or more years.
Variable-retention harvesting (variable-density thinning): harvesting or thinning in which both dispersed and aggregated patches of trees are retained on the same site, creating a range of gap conditions and lighting levels.

Ontario