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# STAND CONVERSION FOR WILDFIRE RISK MITIGATION

## MANAGEMENT STRATEGIES

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This review explores the benefits, challenges, limitations, logistics, and cost-effectiveness of different management options to convert conifer-dominated stands to aspen-dominated stands. These alternatives can include overstory removal (harvesting, bulldozing, shear blading, prescribed burning) and site preparation (root trenching, drag scarification, broadcast burning) treatments. On sites where parent aspen trees are not present in the original stand, tree planting will be necessary albeit costly in comparison to regeneration by suckering. While extensive literature exists on the regeneration of trembling aspen through suckering, research on artificial establishment with seedlings and its requirements is still in its infancy and rapidly developing.

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# INTRODUCTION

Wildfire management agencies are exploring unconventional vegetation management techniques for reducing the risk of wildfire beyond the wildland-urban interface level. At a stand scale or landscape scale, species conversion to less flammable species has been suggested as a strategy to reduce the wildfire risk of a forest stand and to support species diversity across the landscape. FPInnovations has been approached by Alberta Agriculture and Forestry to explore innovative species conversion principles at a stand scale to reduce the flammability of volatile forest stands.

Stand conversion to less flammable species is one of the three main fuel treatment strategies advocated by FireSmart Canada to mitigate wildfire risk. On a landscape level, wildfire risk mitigation around communities could include conversion of highly flammable coniferous stands (e.g., black spruce) to stands dominated by deciduous species or less flammable conifers. In Alberta, where it is an integral seral or climax component in all forested natural regions (Natural Regions Committee, 2006), trembling aspen has emerged as an ideal candidate for FireSmart stand conversion because of its tolerance to a wide range of site conditions, its unique reproduction strategy through suckering, its rapid growth, and its potential to reduce fire behavior intensity and stand flammability (Shepperd et al., 2006).

This literature review explores the viability of species conversion to trembling aspen and identify key operational strategies to achieve this. The benefits, challenges, limitations, logistics and cost-effectiveness of different options are outlined. Future work in this area may include operational trials of these options to prove their feasibility in the area of interest.

# SITE CONDITIONS: WHERE IS A CONVERSION PROJECT AN OPTION?

Aspen tolerates a wide range of site conditions, from hygric to xeric moisture regimes, but is most productive on nutrient-rich, fresh-to- moist, well-drained sites with sandy loams or clay loams (Steneker, 1976). Aspen is not suited however to lowland sites with wet, clay-textured soils that are not well oxygenated, or sites that have a high-water table and are prone to flooding. Soil moisture is an important factor in the relative growth of aspen however, with lower productivity on dry sites. Seedings, in particular are also highly susceptible to drought.

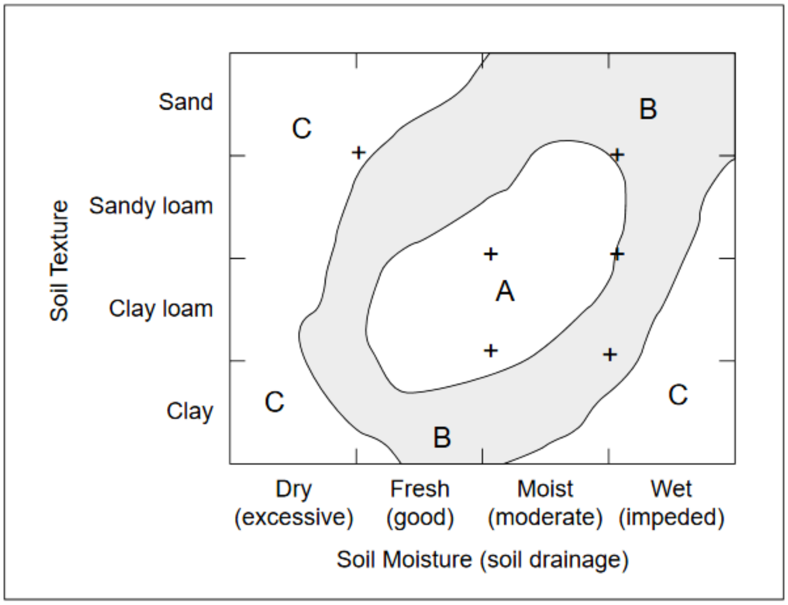


**Figure 1. Matrix of soil texture, moisture, and drainage conditions for good (A), intermediate (B), and poor (C) aspen sites (Steneker, 1976).**

Limiting factors that impede the successful regeneration of aspen at the site level include:

- **Soil compaction:** Soil compaction from associated harvesting activities, especially in wet soils, restricts aspen regeneration (Shepperd, 1993), since most aspen suckers originate from roots 0.8 to 1.8 cm in diameter and within 8 cm of soil surface. Soil compaction can be reduced by using machines with low ground pressure tires or tracks, or by harvesting during winter on frozen soils.
- **Cold soil temperatures (<15°C):** Soil temperatures are a key determinant factor of sucker abundance (Peterson et al., 1989). Deep LFH layers (>15 cm) and/or vegetation cover may delay or prevent soils from warming and inhibit root suckering (Navratil, 1991). Site preparation to expose mineral soil or mix mineral/organic layers may be necessary to sufficiently warm the rooting zone for aspen suckering (Perala, 1991).
- **Dry, sandy soils:** Because of its higher transpiration rate, aspen can be highly susceptible to drought (Davison et al., 1988).
- **Shade**: Aspen is a shade intolerant species requiring full sunlight for survival and growth. A reduction in light availability to 40%–60% full sunlight may reduce sucker density by half, as compared to full sunlight (Groot et al., 1997). A further reduction to 25% of full sunlight will cause a 90% sucker reduction when compared to full sunlight (Groot et al., 1997).
- **High water table:** A water table between 1 and 2.5 m below the surface is preferred (Haeussler et al., 1990).

- **Heavy vegetation competition**: Heavy competition during stand initiation can impede aspen suckering and growth. Calamagrostis grass in particular is a serious competitor in boreal ecosystems and can rapidly dominate a site after harvest negatively impacting aspen and conifer regeneration. The risk is highest on open stands, where Calamagrostis may be well established before harvest (Lieffers et al., 1993). Site preparation by prescribed burning may delay growth of Calamagrostis until aspen suckers fully occupy the site.
- **High slash loading:** Heavy accumulations of slash and debris after harvest will discourage aspen suckering (Peterson & Peterson, 1995) although the effect is generally marginal and will not determine regeneration success (Bella, 1986).

# ESTABLISHMENT ALTERNATIVES

Aspen can be regenerated through a variety of approaches: suckering, natural regeneration from seed, or artificial establishment through planting. The silviculture system chosen will depend in part on existing stand conditions and on the harvesting system used (clearcut, thinning, fuel removal, etc.). Pure aspen stands and mixed species stands are generally suitable for natural regeneration through suckering, whereas stands with smaller aspen components pre-harvest may have to be artificially regenerated.

- **Vegetative reproduction (suckering):** Aspen differs from other deciduous and conifer tree species by its unique ability to regenerate vegetatively through the production of root suckers. Suckering is stimulated when the flow of plant hormone auxin from a parent tree is cut, interrupting apical dominance. When a parent stem is damaged or cut, the reduced flow of auxin into the root systems triggers the production of root suckers (Schier, 1981).
- **Natural regeneration by seed:** Aspen can also be regenerated via seed dispersal, although it is not regarded as a reliable regeneration alternative, because unlike most northern hardwoods, aspen seeds have transient viability. Seeds disperse early to late spring and are viable for only 2–4 weeks even under ideal conditions (McDonough, 1985). Viability declines rapidly under less than optimum conditions, so seeds must come into contact with a suitable mineral or humus seedbed within a few days of dispersal.
- **Artificial establishment**: If a stand conversion site does not have mature aspen components in the stand pre-treatment, artificial establishment will be necessary. This involves clearing the previous stand for full sunlight availability and transplanting nursery-grown aspen stock. This method is more costly and logistically challenging compared to vegetative regeneration by suckering, which can often be accomplished by simply harvesting a site. Compared to suckers, seedlings established by planting or from seed are also slower growing and more prone to drought mortality as they lack the support granted by being part of a larger rootstock.

## Vegetative regeneration

Vegetative regeneration of aspen is the most common and cost-effective way to establish an aspen stand. The initiation of suckering is controlled by two main factors (Peterson & Peterson, 1995):

- **Apical dominance:** Apical dominance is the repression of suckering by the production of auxin in the parent tree shoots. Disrupting the production of auxin by felling or damaging a parent tree will produce prolific root suckers.
- **Soil temperature:** Soil temperature is the most critical factor in sucker initiation (Peterson et al., 1989). Increases in soil temperature from increased solar radiation after harvest may even stimulate sucker production in undamaged parent aspen trees. Sucker production is maximized at temperatures of 20$^{o}$C (Steneker, 1976), while temperatures lower than 15$^{o}$C inhibit it (Maini, 1967).

If there is an adequate aspen component in the stand pre-harvest and site conditions are favourable, suckering may reach as many as 250 000 stems/ha after a stand replacing disturbance (clearcutting or fire). Most suckering occurs in the first growing season after cutting: studies have found that more than 98% of the recorded aspen stems were established in the first growing season (Krasny and Johnson, 1992). By the second year, mortality due to intra-specific competition begins. Aspen, unlike most conifers, can self-thin and will not suffer from stagnation or require spacing interventions. Stand densities at age six tend to be in the range of 20 000–25 000 stems/ha, regardless of whether the initial suckering density was as low as 44 000 stems/ha or as high as 225 000 stems/ha (Peterson & Peterson, 1992). Adequate stocking of aspen in order to produce an aspen stand is considered to be at last 10 000 at year two (Perala, 1977).

## Required pre-harvest stand conditions

In order to establish a pure aspen or aspen-leading stand from suckering, there must be a sufficient number of well-distributed mature aspen stems on site prior to harvest. Davidson et al. (1988) recommended aspen stand components of 100–120 aspen stems/ha or >20% aspen basal area/ha. Research has found adequate aspen stocking post-harvest (10 000 stems/ha) with as few as 25–50 well-distributed aspen stems/ha (Navratil & Bella, 1988). Doucet (1989) reports that full stocking can be achieved with a basal area of 5 $m^2$/ha pre-harvest if the stems are spaced <8–10 m apart. Aspen stems must be relatively evenly distributed across the site, as most aspen suckers are generally found within 5 m of the nearest parent tree, with dispersion declining rather abruptly within another 10 m. (Greene et al., 1999).

Parent aspen age seems to have no impact on suckering densities. Trees aged 20 to 150 years have yielded similar amounts of suckers (Maini, 1968), and stands as young as two years old have produced as many as 75 000 suckers/ha after harvest (Perala, 1972). The vigour of the parent trees however does influence suckering ability. Stands that are dominated by old and diseased trees may not be able to produce sufficient amounts of viable suckers, as less photosynthate is channeled to the roots in deteriorating stands (Schier & Campbell, 1980).

## Overstory removal

### *Harvesting*

Even-aged silviculture systems that remove all stems and maximize sunlight are the preferred choice for aspen regeneration, whether natural or artificial. The highest levels of aspen sucker regeneration and early growth will be achieved when a vigorous aspen or mixedwood stand is clearcut, interrupting apical dominance by mature aspen trees and increasing soil temperatures. Full-tree or tree-length harvesting operations that do not produce high amounts of slash and do not compact the soil are best for maximizing sucker production.

Dispersed aspen basal area retention exceeding approximately 4 $m^2$/ha will inhibit aspen suckering and reduce growth (Perala, 1977). If the goal is to maximize suckering, mature aspen retention should be minimal, and ideally not exceeding 35–50 stems/ha. (McCulloch & Kabzems, 2009).

Some aspen suckering may be achieved under uneven-aged systems (i.e., resulting from thinning or fuel removal treatments) if canopy gaps are large enough. Openings of approximately 0.4 ha (63 x 63 m) provide adequate conditions for regenerating aspen in gaps (Perala and Russell, 1983). However, some aspen suckering has been observed in gaps as small as 20 to 25 m in diameter (0.04–0.06 ha) (Paré & Bergeron, 1995; Carlson & Groot, 1997; Kneeshaw & Bergeron, 1998; Cumming et al., 2000).

Studies on the effects of season of harvest on sucker production are generally inconclusive (Navratil, 1991). Harvesting during the winter has resulted in prolific suckering and best growth in some studies, as suckers become established earlier and capitalize on a longer first growing season. However, studies have found that stem density after a few growing seasons is the same on summer and winter harvest sites (Bella & DeFranceschi, 1972; Perala, 1981; Bates et al., 1993; Bella, 1986). Benefits of summer logging include the increased disturbance to organic layers and ground vegetation. In a Manitoba-Saskatchewan study, summer harvesting that destroyed shade-producing shrub competition resulted in better aspen sucker production (Steneker, 1976). A disadvantage of summer logging is the risk of soil compaction during harvesting activities, especially in wet and fine-textured soils.

### *Bulldozing*

If the stand is non-commercial, overstory removal by bulldozing or shearblading may be a viable option. Bulldozing, or pushing whole trees over, is more cost-effective than felling and has been reported to produce more suckering when carefully done. In a push-felling study, keeping the blade off the ground and pushing trees over severed large roots to a distance of 1–1.5 m from the parent stem without disturbing or compacting the lateral root system, resulting in densities of 10 000–38 000 stems/ha five years after treatment (Shepperd, 1996).

*Shearblading*

Shearblading refers to using a sharp straight blade on a crawler tractor to cut trees, brush and thick duff layers. A standard dozer blade is not recommended for this purpose as it can cause excessive topsoil disturbance and damage shallow aspen roots. The stems are sheared off at ground level, and some mineral soil disturbance may be achieved. While shearing on frozen ground is preferable, it is not necessary if care is taken to avoid excessive soil disturbance (Perala, 1983). Both shearblading and bulldozing can produce high amounts of slash, windrowing and piling may be necessary maintain low fuel loading on site and encourage soil warming for sucker regeneration.

Perala (1983) reported suckering densities of 14 000–50 000 stems/ha after shearblading and windrowing a 50-year-old sparse aspen stand of 4–7 $m^2$/ha in Wisconsin. In Alaska, shearblading and windrowing in decadent aspen stands of (11 $m^2$/ha, 750 trees/ha and 75 years of age) resulted in 74 000–209 000 stems/ha (Paragi & Haggstrom, 2007).

Compared to bulldozing, shearblading has the added advantage of removing thick organic layers and providing some soil disturbance. Shear blading is done best during the dormant season on frozen soils. It may not be recommended in stands with a basal area of over 18 $m^2$/ha or for trees larger than 20 cm in diameter. Paragi and Haggstrom (2007) report shearblading without windrowing costs of $185/ha and, and $310/ha total treatment cost for shearblading with windrowing. Shearblading was the lowest cost overstory removal alternative when compared to chainsaw felling ($570/ha) and prescribed burning ($790/ha).

*Prescribed burning*

Prescribed burning may be used after harvesting or overstory removal as a site preparation treatment to reduce slash loading and thick duff layers, or it may be used as an overstory removal treatment in a mixedwood to eliminate more flammable conifers and stimulate deciduous growth. Prescribed fire is particularly appropriate in areas where machine access is not possible and where mechanical treatments are not an option.

Suckering response is often vigorous after a fire, as post-fire conditions (interrupted apical dominance, increased soil temperatures, removal of duff layer and slash, removal of competing vegetation) are ideal for stimulating sprouting. In some cases, suckering response may be even more vigorous than after clearcut harvesting (Fraser et al., 2003). As with harvesting, aspen must exist in the overstory and be uniformly distributed across the site in order to achieve full site coverage post-fire.

The fire prescription and method of ignition will vary depending on site objectives and existing stand conditions. Both hand-held (driptorch) and aerial (helitorch) ignition methods can be used successfully in regeneration of aspen. In pure aspen stands, a light to moderate intensity surface fire that consumes surface litter is often enough to top-kill aspen due to their thin bark. A light intensity surface fire will top-kill small diameter aspen, while a moderate surface fire top-kills most aspen, with few surviving large diameter trees.

The highest suckering density and growth rates however are linked to high severity fires in various studies, even those that consumed the entire duff layer and some of the superficial root system (Brown & DeByle, 1989; Krasnow & Stephens, 2015; Fraser et al., 2004; Fraser et al., 2003). Pre-fire live conifer and dead aspen basal area in a stand were identified as stand characteristics that reduce post-fire suckering density (Krasnow & Stephens, 2015).

In mixedwoods or where conifers exist in the understory, high intensity fires will be necessary in order to kill the conifers. However, this brings risks associated with heavy fuel loading and ladder fuels and may limit the pool of candidate sites (Shepperd, 2000). These risks could be mitigated by using prescribed burns as a site preparation treatment after harvesting or overstory removal treatments.

Prescribed burning should take place in the spring or fall, as soon as fuel and weather conditions are right, and preferably before leaf flush or after leaf fall, when root carbohydrate reserves are not yet depleted by respiration (Weber, 1990; DeByle & Winokur, 1985), although dense suckering has also been observed after leaf flush (Fraser et al., 2004). Suckering response after a spring burn has been found to be the most vigorous in various studies (DeByle & Winokur, 1985; Fraser et al., 2004; Guedo & Lamb, 2013). Stands burned in spring will sucker that growing season, while those burned in late summer or fall will sucker during the next growing season.

## Site preparation

### *Drag scarification*

Overstory removal/harvesting activities may provide enough mineral soil disturbance to improve soil warming and reduce competing vegetation. If this is not the case, light scarification may be an option. With drag scarification, large chains and barrels are pulled behind a wheeled or tracked prime mover, with the intention of exposing mineral soil and warming the rooting area to promote suckering. In a scarification study, drag scarification with chains with no or one attached sharkfin barrel resulted in gains of 60%–78% density over non-scarified controls after the first growing season (Weingartner, 1980). Operations must take place shortly after harvesting and before suckering has occurred, in order to avoid damaging regeneration. Drag scarification may not be suitable for all sites however, particularly those with rocky or steep (>25%) ground.

### *Root trenching*

In situations where the management objective is to retain a sparse aspen overstory (such as in an open aspen stand or a clearcut with aspen retention), root trenching can be used as an alternative to stimulate suckering without removing existing aspen trees. It involves digging trenches around standing aspen trees in order to sever the main lateral roots, stimulating suckering by cutting roots off from the apical dominance exerted by the parent trees. It can be done using a ripper tooth mounted on a dozer where high maneuverability is not required, or with an excavator equipped with a cutting blade or tooth attached to the bottom of the bucket for smaller areas. The ripper works around parent trees, creating trenches a distance of approximately 5 m away from the base of the parent tree or patch of trees, and reaching approximately 50 cm into the soil.

Because of the range in available machinery, root trenching works in a variety of sites and is not heavily constrained by topography or site conditions, however light and soil temperature conditions must still be met to ensure adequate suckering and growth. In a study near Cranbrook, B.C., root trenching with an excavator resulted in sucker densities of 5 000–22 000 stems/ha (Gray, 2013). In another study, a small aspen patch that was edge-ripped with a single pass of a ripper tooth mounted on a bulldozer resulted in densities of 26 000 stems/ha up to 20 m away from the edge of the patch and into the adjoining meadow (Shepperd, 2000). The benefits of root trenching combined with other treatments such as prescribed burning or harvesting have not been tested (Shepperd, 2000).

### *Disk trenching*

Mechanical site preparation by disc trenching, or disking, is not generally recommended to regenerate an aspen stand from suckering. While it may promote initial aspen suckering by severing roots, the initial gains in sucker density are generally short-lived (Fraser et al., 2006). The mechanical disturbance resulting from disking is too excessive and can be detrimental to sucker survival and growth (Basham, 1988; Perala, 1977).

### *Broadcast burning*

Broadcast burning may be an option in conjunction with harvesting or overstory removal if the resulting post-harvest site conditions are not conducive to aspen suckering. Broadcast burning improves suckering potential by warming the soil, reducing slash accumulations, removing thick duff layers, and reducing competing vegetation. As opposed to mechanical site preparation alternatives, it does not compact the soil and it can be used on steep terrain. However, it can be costly, risky, and highly restricted by weather.

Nonetheless, broadcast burning can be a very effective site preparation treatment after overstory removal. In an Arizona study, a site that was harvested then burned resulted in much more suckering than a site with conifer overstory removal alone (Shepperd, 2000). Light severity burns may not remove enough slash, ground vegetation, and organic matter to promote adequate aspen suckering (Horton & Hopkins, 1963), instead, medium severity prescribed fires are preferred, particularly when carried out immediately following harvest and before suckering has started (Peterson & Peterson, 1995).

## Artificial establishment

While regeneration through suckering is the most cost-effective and readily available alternative for establishing aspen, artificial establishment will be necessary if an identified conversion site does not have existing mature aspen components in the stand. This involves clearing the previous stand for full sunlight availability and suitable microsites, and either transplanting nursery-grown aspen stock or seeding.

While seeding of aspen is less costly than planting, it has a high risk of failure. Due to the low survival rate of the seed and the high volume of seed required, seeding is considered impractical (Landhäusser et al., 2019).

Planting aspen nursery stock is the most costly treatment, with a higher required planting density and a higher seedling cost[1] compared to conifer planting. However, it reduces the risk associated with germination and early establishment challenges and reduces the time it takes for a site to be fully stocked.

Aspen nursery stock can be produced from root cuttings or it can be seed-grown in containers. Vegetative propagation can be successful but has fallen out of favour due to the lack of genetic diversity of the stock and challenges in producing sufficient planting material (Jacobs et al., 2015, Macdonald et al., 2015; Landhäusser et al., 2019). Currently, the majority of aspen reclamation programs in the boreal forest use nursery stock (Landhäusser et al., 2012) produced almost exclusively from seed.

## Seed collection and handling

Given the biology of aspen reproduction, the logistics associated with aspen seed collection are more complicated than those associated with conifer seed. The primary challenge in aspen seed collection is the extremely short seed-harvesting window. The collection window generally ranges from three to five days in the early spring. During the seed ripening period, female trees must be monitored daily because seeds collected prematurely will not germinate well, if at all, and aspen seeds disperse quickly after ripening (Landhäusser et al., 2019).

Another seed collection-related challenge is the rapid loss of viability of aspen seed. Aspen seed remains viable at long-term storage temperatures of -18°C to -20°C for up to five to eight years (Pinno et al., 2012). Most temperate conifer seed stock, on the other hand, can be viable under similar storage conditions for 20 to 40 years depending on the species (Simpson et al., 2004). However, tests carried out from 2014 to 2017 show that industry-owned seed lots processed by private facilities are viable for shorter periods, with an average lifespan of three to four years and with some seed lots losing viability after less than two years (Robb, 2017). Aspen seed is only viable for a few weeks at room temperature, so cleaning and storing in a timely manner is critical to maintaining seed quality (Landhäusser et al., 2019). A complete account of aspen seed collection and handling guidelines is described by Robb (2019), Smreciu et al. (2013), and Landhäusser et al. (2019).

## Nursery stock production and logistics

Practices at the nursery after sowing influence the physiological and morphological features of the seedlings and thus determine their resistance to stress and their ability to establish. Planted seedlings often display transplant shock or reduced growth after outplanting and have historically performed poorly compared to suckers (Shepperd, 2000; Steneker, 1976). This shortcoming is partly due to the lack of development of quality nursery stock (Landhäusser et al., 2019). Historically, aspen stock type and seedling quality was assessed similarly to conifer stock and was based on height, root collar diameter, and terminal bud size (Chavasse, 1980; Thompson, 1985;

[1] 615A 1+0 spring aspen nursery stock currently ranges from $1.30-$1.60 per seedling, although the price can vary significantly with seed availability (cost), plug size, etc.

Navarro et al., 2006). More recent work has shown that these measures of seedling quality do not apply to aspen, and that outplanting performance of aspen is primarily related to root-to-shoot ratios and root carbohydrate reserves (Landhäusser et al., 2012). In a 2012 study, height growth was better in aspen stock types with high root-to-shoot ratios and root carbohydrate reserves and performance of these types was notably better in more stressful environmental site conditions, such as low moisture and low soil nutrients. (Landhäusser et al., 2012). Other studies similarly found that the optimal balance between cost and seedling quality was found in short to medium-sized seedlings with higher root-to-shoot ratios (Kulbaba, 2014; Le et al., 2020). Root-to-shoot ratios and root carbohydrate reserves can be increased by manipulating bud set timing at the nursery through a variety of methods, thus directing resources towards storage in the roots rather than shoot growth (Landhäusser et al., 2019).

New research on aspen nursery stock production has also found that drought conditioning seedlings in the nursery is possible by manipulating irrigation levels (Sloan et al., 2020). Those seedlings with lower irrigation level regimes were found to perform better (greater height, photosynthetic rates, faster xylem flow velocities) than those with higher irrigation level regimes.

## Nursery logistics and timing of lifting

In the boreal forest, nursery aspen stock is generally sown in early May. The stock is lifted in late summer or fall and planted, or it may be lifted in early winter then packed and stored frozen at -3°C for up to seven months before planting in the spring (Landhäusser et al., 2012). These storage procedures are based on requirements for conifer stock production and not tailored for aspen due to lack of aspen-specific research and nursery production guidelines (Landhäusser et al., 2019). The timing of lift depends on the desired timing of planting, and it may carry consequences on the morphological characteristics and associated field performance of the seedlings. Landhäusser et al. (2012) showed that summer-planted seedlings (lifted in late summer) had lower root volume, root dry mass, root-to-shoot ratio, and root carbohydrate reserves compared to fall-planted (lifted late September) or spring-planted (lifted in November and stored frozen until spring) seedlings after the first growing season.

## Planting

Seedling performance in the field varies depending on planting timing. Spring- and fall-planted aspen seedlings were shown to have 44% greater height growth than summer-planted seedlings in a 2012 planting timing trial (Landhäusser et al., 2012). The use of dormant seedlings in both these cases increased the resistance of the seedlings to damage from handling and environmental stresses during the planting operations. Summer planting results have been shown to be poorer compared to spring and fall plantings, likely due to the lower root volume and root carbohydrate reserves from lifting the stock earlier in the season before seedling dormancy (Landhäusser et al., 2012).

Planted aspen seedlings are highly susceptible to mortality from intra- and inter-specific vegetation competition. Below-ground competition from grasses is a known problem for aspen seedlings (Bockstette et al., 2018). Vegetation management or prescribed fire may be required to ensure quick establishment of aspen on high-risk sites.

Cluster planting, a practice where aspen is planted in small high-density patches of 10 to 20 trees spaced 25 cm apart, has also proved effective in reducing vegetation competition and helping the aspen component achieve crown closure faster, reducing the need for costly high-density planting and the risk of plantation failure due to mortality from competition (Pinno et al., 2017).

Apart from the recent studies highlighted here, there is little to no information available on how the many other factors related to outplanting (site conditions, planting procedures, site preparation, microsite selection, etc.) affect the establishment performance of seedlings in the field (Landhäusser et al., 2012). Most current guidelines for reforestation in temperate forests are primarily based on conifer species, which may have different requirements than deciduous species like aspen. These guidelines are the result of decades of research, so the development guidelines specific to aspen reforestation via seedlings should be considered in its infancy (Landhäusser et al., 2019). This is the primary challenge to overcome in reforestation with aspen seedlings. More research is still needed on stock production, seedling handling, planting procedures, timing of planting, site conditions, site preparation, and planting spot selection to ensure successful establishment of aspen by tree planting (Landhäusser et al., 2019).

# CONCLUSION

This report explores the benefits, challenges, limitations, logistics, and cost-effectiveness of different management options to convert conifer-dominated mixedwood stands to aspen-dominated stands through several overstory removal (harvesting, bulldozing, shearblading, prescribed burning) and site preparation (root trenching, drag scarification, broadcast burning) alternatives. These alternatives offer a wide range of options depending on site conditions, site objectives, and cost limitations. There is extensive literature on the regeneration of aspen through suckering and, if several site and stand conditions are met, it remains the preferred method for establishing aspen due to its cost-effectiveness. On sites where parent aspen trees are not present, tree planting will be necessary albeit costly in comparison to regeneration by suckering. While extensive literature exists on the regeneration of aspen through suckering, research on artificial establishment with seedlings and its requirements is still in its infancy and rapidly developing.

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