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Regeneration Techniques for Restoring Forest Cover on Oil and Gas Sites

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Acknowledgements

We want to acknowledge the support from Canada's Oil Sands Innovation Alliance (COSIA), which made this project possible. We also want to acknowledge Matthew Pyper and Sonya Odsen (Fuse Consulting), Michael Cody (Cenovus Energy), Dani Degenhardt (InnoTech Alberta), Janet Mitchell and Virginia Hudson (FPInnovations), Jeannine Goehing and Amanda Schoonmaker (NAIT Boreal Research Institute), and Chris Powter (Enviro Q&A Services) for their contributions to this guidebook.

Cat. No. Fo4-130/2018E-PDF
ISSN 978-0-660-27556-7

PRINTED IN CANADA IMPRIMÉ AU CANADA Recycled paper

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1. Introduction

Silviculture is the practice of controlling the establishment, growth, composition, health and quality of forests at the stand level to meet diverse needs and values. Silvicultural practices can have a strong and beneficial impact on reclaiming areas associated with in situ extraction of oil and gas resources.

Site preparation, forest regeneration and vegetation management are all important aspects of silviculture and reclamation. Multiple techniques and practices can optimize the success of reclamation, which depends on many factors, including the physical, chemical and biological properties of the site.

Some of the great wealth of silviculture knowledge traditionally used by the forest industry will be explained in a series of guidebooks, fact sheets and videos.

This guidebook explains forest regeneration techniques. The Natural Resources Canada Canadian Forest Service (NRCan-CFS) developed this guidebook to help with the successful restoration of disturbed in situ sites.

Reclamation sites may include a wide variety of forest ecosites, soil types and moisture regimes. Different strategies to revegetate the sites are needed, depending on the disturbance type and severity and the length of time since disturbance. Some sites can recover naturally without intervention, while others will need help to regenerate. These factors need to be considered during revegetation planning and implementation.

Several techniques provide the necessary growing conditions and resources on-site while other treatments improve seed and nursery planting stock before planting to help achieve final reclamation outcomes. The choice of revegetation activities and materials used is based on the reclamation objectives and site conditions. Primary revegetation activities include species selection and treatment selection to address abiotic and biotic site limitations and regulatory requirements.

The goal of this guidebook is to provide background knowledge and tools for regeneration techniques that can be used to achieve revegetation objectives based on site conditions, seed or seedling availability and regulatory requirements.

2. Planning

The primary objective of a revegetation plan is to establish functional plant communities that are suitable for the given site conditions and are similar to the undisturbed, native plant communities of the region and target ecosite. The plan must also align with management objectives.

Revegetation of disturbed sites to natural forest ecosystems can be challenging and take a long time (Figure 1). Primary revegetation tasks include selecting revegetation treatments that take into consideration the opportunities and limitations regarding:

- species selection
- abiotic site conditions (e.g. water, nutrients, light availability)
- biotic site conditions (e.g. herbaceous competition)
- potential for natural and/or artificial regeneration
- availability of and timelines for sourcing and deploying plant material
- regulatory requirements (e.g. Alberta Forest Genetic Resource Management and Conservation Standards [FGRMS], Enhanced Approval Process [EAP]).

This chapter outlines opportunities and constraints regarding revegetating disturbed sites to help inform revegetation planning and management.

2.1 Revegetation objectives

This guidebook focuses on forest ecosystems as the targeted end land cover. The target plant community of any reclaimed site should be similar to that found in the undisturbed, native plant community of the region or be aligned with management objectives. The target end land-use for forested land will be either commercial or non-commercial forests. Non-commercial forests include wildlife habitat, recreation and traditional use.

2.2 Species selection

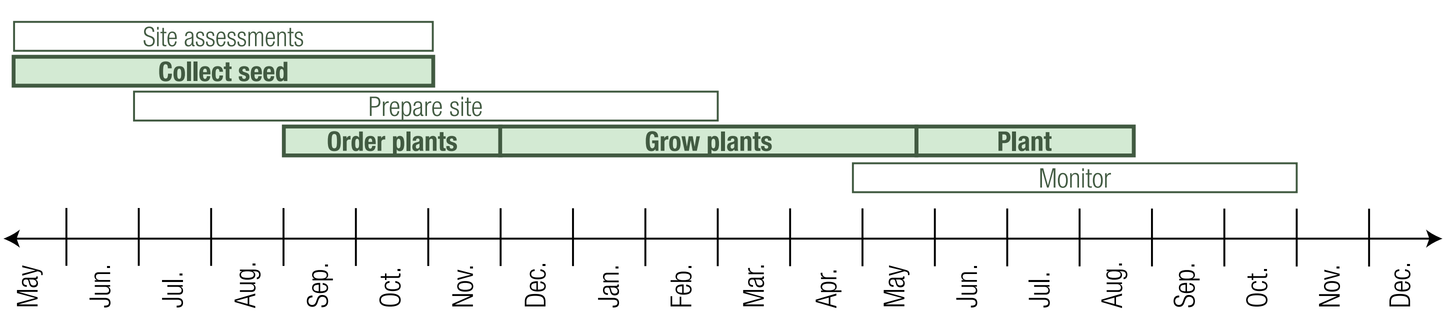
The choice of suitable species for a site depends on several factors, including:

- the off-site undisturbed plant community as the target forest type
- availability of desired species
- timelines for seed collection and nursery production
- regulatory requirements (e.g. FGRMS, Reclamation Criteria).

Desirable species are those that are characteristic of the targeted ecosite and similar to the surrounding off-site vegetation, i.e. the native, undisturbed plant communities. Selecting species based on the undisturbed control will ensure that they are ecologically suitable for the site. It is important to take the successional state of the adjacent stand into consideration as well. Another aspect to consider is climate change in areas where trees might have to be more resilient.

All woody species must be native to the subregion, and, if they are deployed in the Green Area, must comply with the Alberta FGRMS. Sites that require a reclamation certificate need to comply with the reclamation criteria for forested land that require establishing both woody and herbaceous plants characteristic of the early successional forest community for the specified forest type.

Figure 1. Revegetation timelines



2.3 Site resources

Plant establishment (e.g. survival and growth) is dependent on an adequate amount of physical space and biotic and abiotic site factors, including availability of light, soil nutrients, soil microbiology for nutrient cycling, moisture, soil aeration and temperature. The resource needs and quantities will vary by species. Ultimately, the targeted species must match the site conditions. Management efforts (e.g. site preparation) can reduce site constraints and improve growing conditions.

2.4 Vegetation competition

Competition for site resources (i.e. space, water, nutrients and light) between trees and, often, with highly competitive herbaceous understory vegetation can be a significant impediment to the establishment of tree species. Competition for resources will vary depending on the species. For example, shade-intolerant tree species will not survive under significant light competition.

Considerations for revegetation planning include the resource availability of the targeted site type because competition will vary on different sites. Generally, sites that have limited resources will have lower competition than sites that are highly productive. For example, vegetative competition is usually lower on sites that are either extremely wet or dry and have low nutrient levels, compared to sites that demonstrate highly favorable growing conditions including high nutrient levels and moisture availability.

Additionally, sites that are located in close proximity to roads, developments or other human activities are at higher risk of being invaded by weedy or agronomic plant species.

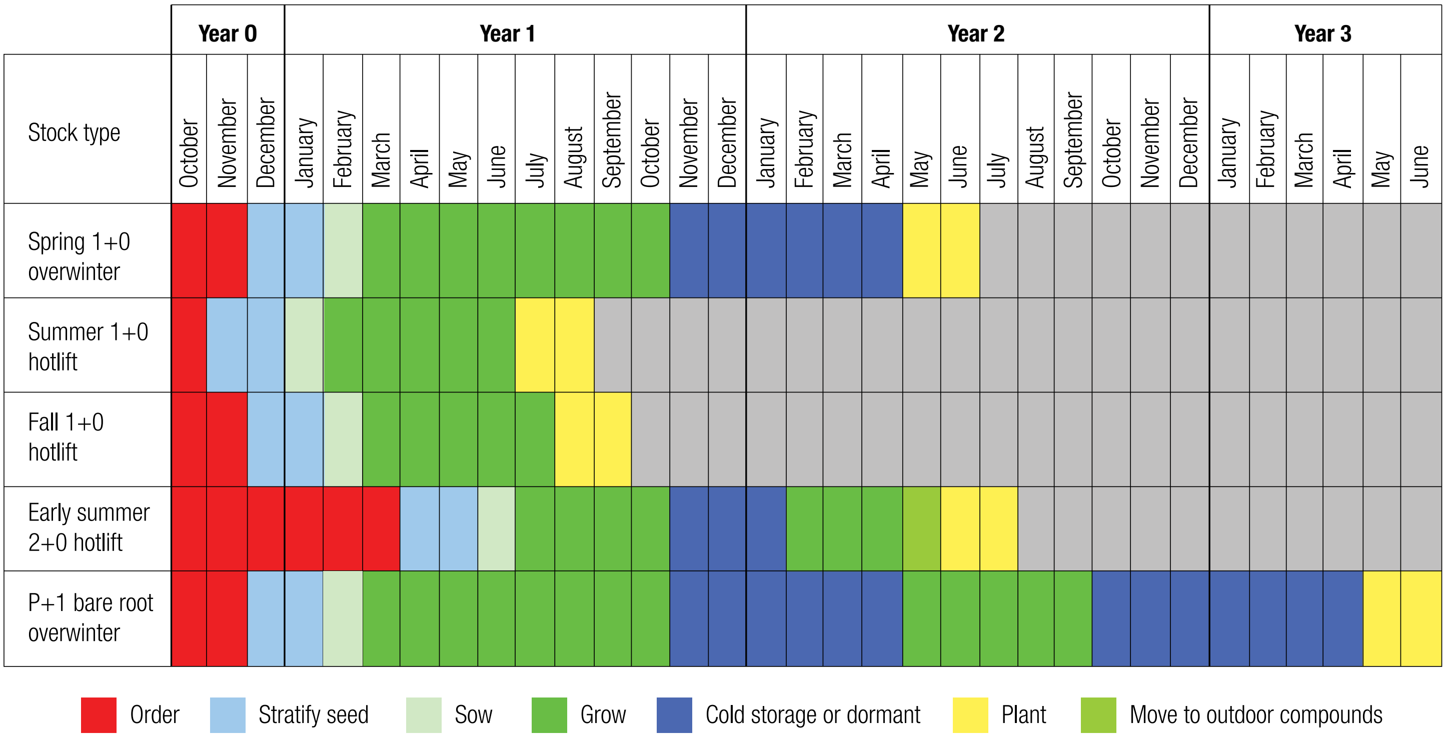
Revegetation plans to establish desirable species must include concurrent management of undesirable species and all weed species that fall under the Alberta *Weed Control Act*. There are a variety of tools to manage undesirable species, including mechanical, chemical and cultural control practices. Pre-disturbance assessments will help identify sites where establishment of undesirable species is a concern and intervention may be required.

2.5 Natural regeneration

To naturally regenerate a disturbed site, sufficient quantities of healthy on-site propagules (i.e. seeds and/or roots) within the topsoil or in close proximity to undisturbed forest areas are required. Success of natural regeneration also depends on adequate preparation of the soil to provide suitable microsites and seedbeds. Natural regeneration may provide inconsistent results, when compared to planting, and does not guarantee definite plant densities or species composition, which needs to be considered during revegetation planning. On sites where natural revegetation is feasible but stocking is not sufficient, seeding or planting woody and/or herbaceous species may be used to supplement natural regeneration.

Given the constraints outlined above, natural regeneration as a method of revegetation is often limited to small disturbance areas with minimal soil disturbance (e.g. minimally disturbed oil sands exploration [OSE] sites) or linear disturbances such as seismic lines and winter roads. If a site is minimally disturbed, exposed soil microsites need to be present to increase natural regeneration success. Natural regeneration is usually not a reliable method on larger and highly disturbed areas, and thus is not currently used for mineable oil sands reclamation. In addition, natural regeneration may suffer from long delays in returning to forest cover.

Figure 2. Tree seedling ordering and planting guideline chart



Credit: Tree Time Services Inc.

2.6 Nursery production and planting nursery stock

Planting trees is the most effective technique to re-vegetate a disturbed site if natural regeneration of trees is not sufficient. Planting tree and shrub seedlings is the most common revegetation method used on large and highly disturbed areas and will typically occur within the first three years after soil placement. One of the biggest challenges on reclamation sites is losing microsites to competing vegetation. Planting within one year of disturbance is key to avoiding this. Planting has the potential to relatively quickly establish targeted plants because the plant material will have significant root and leaf tissue developed before planting on the reclaimed site.

The most important constraint on revegetation planning is the often significant lead time required for nursery production. Most commercial nurseries grow a variety of species, not just commercial trees, and also grow shrubs. However, nurseries often require two to three years to grow species other than commercial trees. This lead time must be considered during planning (Figure 2. Tree seedling ordering and planting guideline chart). This timeline lengthens if seeds have to be collected.

Another consideration is planting density, which can vary from about 500 to 5,000 stems per hectare. For example, if a commercial forest is the primary end land use, medium to dense stocking (>50% cover at maturity) is required. Non-commercial forest land uses (e.g. wildlife or recreation), on the other hand, do not require a minimum stocking density and may be revegetated as open stands, in clumpy stocking, or in density sufficient to increase wildlife habitat and reduce fragmentation.

The logistical constraints of transporting seedlings to the planting site in good condition is another consideration. Transportation is affected by the size of the plant material and limited access to sites.

3. Seed management

Photo: Jean Marie Sobze

3.1 Collection

With 90 seed zones in Alberta, and a great variety of native tree and shrubs species used in reclamation, it is possible that the seed required for a reclamation site might not be readily available for purchase. If the seed is not available – as is the case for many shrub species and trees other than spruces and pines – seeds must be collected in compliance with collection requirements set by the Alberta FGRMS.

Seed collections can be labour-intensive because they often involve hand-picking and populations of many species can be patchy and scattered and are dependent on seed production in any given year. For example, some species such as dogwood have good crop years only every six years.

The Forest Area Office must authorize collection of plant material before the process begins. It is recommended to include a list of all possible species and broaden the collection area to allow for opportunistic collections because some species may not be available in the required amounts while others may be more readily available.

3.1.1 Plant population size

The FGRMS specify geographic and population size requirements for collections, as outlined below, that need to be met for a collection to qualify for unrestricted registration.

Seed collections from non-clonal species (e.g. species other than aspen (Populus tremuloides) and balsam poplar (Populus balsamifera)) must include at least 30 trees from a maximum elevation of 100 metres (m) and a maximum radius of 2 kilometres (km). Collections from clonal species (e.g. aspen and balsam poplar) must include at least 10 well-spaced clones separated by at least 500 m and be within a maximum collection area of 5 km. Collections from shrub species must follow the same standards for clonal and non-clonal species.

3.1.2 Collection size

The required amount of material collected will depend on a variety of factors, including:

- eventual deployment requirements
- storage longevity of the seeds (e.g. >20 years for conifers and 3 to 8 years for aspen/poplar)
- seed crop periodicity
- seed yield per unit of volume or weight of the fruit
- number of seeds required per plantable seedling

In addition, a portion of each seed collection is required:

- for seed testing
- to account for losses during seed extraction and cleaning
- for potential retention by the government

For Stream 1 material (wild trees and shrubs collected from public lands), up to 30,000 viable seeds or 5% of the total seedlot (whichever is less) can be retained for conservation purposes by the government. For an example of how to determine collection size, see Table 1.

It is recommended to record the amount of raw material collected to determine how full the seed heads/fruits are and to calculate the number of seeds per unit volume or unit weight of the fruit.

Table 1. Example for determining the collection size using trembling aspen (Populus tremuloides)

Seed requirement and characteristics	
Seedlings annual requirement	20,000
Storage longevity or seed crop periodicity	4 years
Seeds required per plantable seedling	7
Total of seeds required	560,000
Seeds (seeds or kilograms)	9,000,000
Kilograms of seed or litres of catkins	40
Volume of aspen catkins to collect (litres)	16

Credit: Dan McCurdy, Boreal Horticultural Services Ltd.

3.1.3 Collection timing

It is important to consider the timing of collection when planning reclamation because it often requires at least a year to source suitable seed from the correct seed zone and a second year to grow the trees or shrubs for planting.

Collection times vary considerably among species and can vary within species in different years, depending on weather. For example, the seed collection period for aspen is very narrow (3 to 5 days), whereas for other species such as green alder, the collection period is 4 to 12 weeks. It is necessary to survey collection sites when plants are flowering to determine suitable harvest dates. The only exceptions are some conifer species (e.g. jack pine) that carry serotinous cones year-round. Collection timelines for a variety of species are shown in Table 2.

Dry fruits (e.g. cones and dry capsules) should be harvested as seeds ripen but before they open. Similarly, fleshy fruits should be harvested when the fruit is ripe but before dispersal. Vegetative material such as softwood cuttings are taken during the growing season whereas hardwood cuttings are harvested during the dormant period (late winter or early spring) and stored (frozen at -4˚C or cool at 4˚C, depending on the time of collection) until deployed.

3.1.4 Harvest guidelines

Ideally, plant material should be harvested from areas that are intended for future disturbance such as harvest blocks or from already disturbed habitats such as roadsides, to minimize impacts on existing vegetation. However, for some species, this practice may not always be feasible.

Harvest methods will vary depending on the type and size of the targeted plant (e.g. tree or shrub). It is recommended to use non-destructive harvest methods when possible.

For example, seed and fruit may be collected from clear-cut trees or from upright plants where access to material is possible. Where pruning is required, it is recommended to remove only a minor portion of the crown. As a general rule, it is recommended to collect similar amounts of material from each parent plant sampled in the collection. It is also important to leave an adequate amount of material at the collection location for wildlife and regeneration.

To allow for diverse genetic material, collections should sample individuals spaced throughout the collection population and sample several populations within the same seed zone. These collections can differ in geographic location and in time to account for genetic diversity.

Table 2. Collection timelines, including flowering and seed dispersal periods, for a selection of tree and shrub species

Species	Apr. 13–19	Apr. 20–26	Apr. 27–May 3	May 4–10	May 11–17	May 18–24	May 25–31	Jun. 1–7	Jun. 8–14	Jun. 15–21	Jun. 22–28	Jun. 29–Jul 7	Jul. 6–12	Jul. 13–19	Jul. 20–26	Jul. 27–Aug. 2	Aug. 3–9	Aug. 10–16	Aug. 17–23	Aug. 24–30	Aug. 31–Sep. 6	Sep. 7–13	Sep. 14–20	Sep. 21–27	Sep. 28–Oct. 4	Oct. 5–11	Oct. 12–18	Oct. 19–25	Oct. 16–Nov. 1	Target volume
Fall 2015																														
Larix laricina – tamarack				F	F	F													S	S	S									60 L cones
Betula papyrifera – white birch	F	F	F	F	F	F	F	F											S	S	S	S	S	S	S	S	S	S	S	15 L catkins
Alnus viridis – green alder			F	F	F	F	F	F	F	F										S	S	S	S	S	S	S	S	S	S	25 L fruit
Rhododendron groenlandicum – Labrador tea						F	F	F	F													S	S	S	S	S	S	S		5 L fruit
Viburnum edule – low-bush cranberry											F	F	F	F			S	S	S	S	S									60 L clean fruit
Vaccinium myrtilloides – blueberry						F	F	F	F	F	F						S	S	S	S	S									20 L clean fruit
Vaccinium vitis – idaea											F	F	F	F						S	S	S	S	S	S					25 L clean fruit
Arctostaphylos uva-ursi – bearberry			F	F	F	F	F	F												S	S	S	S	S	S	S	S	S	S	40 L clean fruit
Rosa acicularis – prickly rose								F	F	F	F						S	S	S	S	S	S	S	S	S	S				80 L clean fruit
Spring 2015																														
Populus balsamifera – balsam poplar			F	F				S	S																					40 L catkins
Populus tremuloides – trembling aspen		F	F				S	S																						20 L catkins
Salix bebbiana – Bebb's willow (research)			F	F					S	S																				10 L catkins

F = Flowering; S = Seed dispersal

Credit: Dan McCurdy, Boreal Horticultural Services Ltd.

To minimize the required effort, collections should consist of multiple species at the same location that have similar phenology. Also, it is recommended to prioritize collection efforts in good seed years to improve overall yield.

Collected fruits need to be kept cool because exposure to high temperature in the field may reduce germination rates and even shorten the length of time fruits can be stored.

All plant material collected from public lands or intended for deployment on public lands in Alberta must be registered with ATISC and must be received for registration within 6 months of collection date.

3.2 Seed processing

Seed planted on public land must be processed and tested by facilities registered by the Alberta Tree Improvement and Seed Centre (ATISC). For a list of approved facilities, see *Approved Commercial Seed Processing and Testing Facilities*. The moisture content of each seedlot must be tested for registration and storage. The testing facility must indicate the moisture content and the geographic location of the collection in the Registration Request Form, which needs to accompany all shipments from the processing facility to the storage facility. Other testing such as germination percentage, purity, and 1,000 seed weight are not required.

3.3 Seed storage

All registered seed and vegetative material must be stored in an approved seed storage facility. Currently, the only approved storage facility is the ATISC located in Smoky Lake, Alberta. All processed material intended for storage must be labelled with the temporary or registered lot number as specified on the Registration Request Form.

Cleaned seeds either will be utilized immediately for plant propagation or field deployment or will be dried and stored until required for deployment at a later date. Seed will be stored under controlled conditions, i.e. frozen at -18°C and at moisture content of 4 to 8%.

Registered vegetative material can be retained in stooling beds at approved locations until deployment on the planting site. These beds must be available for inspection if requested by the ATISC.

3.4 Registration

All plant material collected from public lands or intended for deployment on public lands in Alberta must be registered with ATISC and must be received for registration within 6 months of collection date. The only exceptions are collections from wild transplants and vegetative material that are sourced within 5 km and 100 m elevation of the planting site; this plant material does not require registration for deployment (for further details see 3.5 Deployment).

The FGRMS set out two types of registrations, **Stream 1** and **Stream 2 Registration**. Stream 1 Registration applies to material from wild trees and shrubs collected from public lands. Stream 2 Registration applies to material from Controlled Parentage Programs (CPP) and does not include shrubs. Further discussion will include Stream 1 material only. For detailed information on both Stream 1 and 2 Registrations, see the *Alberta Forest Genetic Resource Management and Conservation Standards*.

Registration of Stream 1 material will be either unrestricted or restricted. **Unrestricted Registration** applies to collections that fully comply with the geographic and number requirements described in Appendix 4 of the FGRMS. Unrestricted material can be deployed on public land within the seed zone of origin and following deployment standards as described in 3.5 Deployment in this document. There are two types of unrestricted collections: Point Collections and Seed Zone Collections.

- **Point Collections** are collections from a single seed zone that meet all FGRMS requirements regarding number of parent plants, harvest area size and elevation. For example, a pine collection from a minimum of 30 parent plants, an area smaller than 2 km, and within 100 m elevation change is considered a Point Collection.
- **Seed Zone Collections** are collections from within a single seed zone that meet the minimum number requirements for parent plants but do not meet the area and elevation requirements for point collections. For example, a pine collection from at least 30 parent trees that are harvested from an area greater than 2 km within a single seed zone is deemed a Seed Zone Collection.
- **Restricted Registration** applies to collections that do not meet the requirements for Point or Seed Zone Collections. These collections may be subject to deployment restrictions beyond those applied to unrestricted collections.

To complete registration, all plant material must be sent to ATISC and must include the Registration Request Form, which needs to accompany all shipments from the processing facility to the storage facility. Registration will be complete when material is assigned a registered lot number.

3.5 Deployment

As a general rule, only registered material – unrestricted or restricted – can be deployed on public land and must be deployed within the seed zone of origin (i.e. seed zone from which the material was collected). Exempt from the above rule are collections from wild transplants and vegetative material that are sourced within 5 km and 100 m elevation of the planting site; these may be deployed without registration. A maximum of 5,000 individual propagules of a single clone can be deployed in this manner. This material must not be multiplied or serially propagated.

As well, material from **Point Collections** can be deployed up to 1 km outside the seed zone of origin provided that the elevation change does not exceed 100 m. Point Collections may also be eligible for wider movement (i.e. beyond 1 km) outside the seed zone of origin if a variance request is applied for and granted.

Material from **Seed Zone Collections** can be deployed within the seed zone of origin only, and a variance request for movement outside of the seed zone of origin will not be considered. Deployment of this material is further limited to 5 million seedlings/propagules per collection.

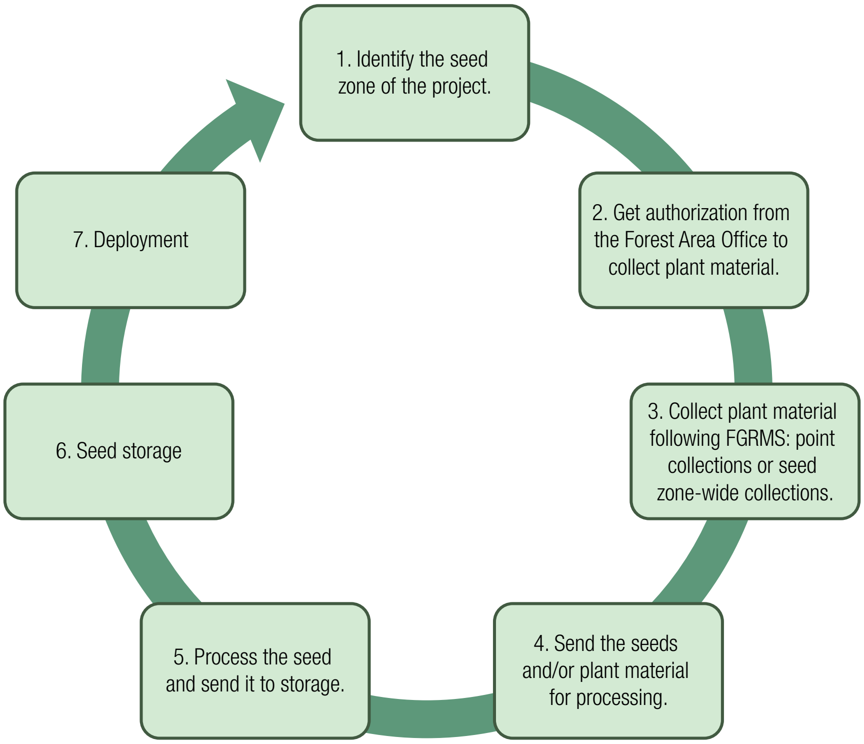
To withdraw registered materials for deployment on public land, the Reforestation Seed and Vegetative Materials Withdrawal and Transportation Form (FGRMS) must be submitted to ATISC.

3.5.1 Variance

A variance request is required to deploy plant material outside its seed zone of origin beyond the principles described above. Approval is granted through the ATISC based on climatic and ecological similarities between the collection site and deployment site.

As a general rule, only registered material – unrestricted or restricted – can be deployed on public land and must be deployed within the seed zone of origin (i.e. seed zone from which the material was collected).

Figure 3. Alberta Forest Genetic Resource Management and Conservation Standards – Stream 1 standards



3.6 Using FGRMS in reclamation: Step-by-step

Figure 3 provides an overview of the steps involved in Stream 1 standards from collection, handling, registration, and storage to deployment of material from wild plant populations in the Green Area, as governed by the FGRMS. For detailed information and application forms, see the Alberta Forest Genetic Resource Management and Conservation Standards.

4. Seed zones

4.1 What are seed zones?

To plant stock to establish on a reclamation site, the stock must have acceptable conditions for survival, growth and regeneration. This can only be assured if plants are genetically adapted to the conditions of the planting site. Seed zones are a critical tool for ensuring that planting stock is well adapted to planting site conditions, and for conserving genetic diversity within species.

Seed zones are geographic subdivisions of the 6 natural regions and 21 natural subregions of Alberta, based on climatic, ecological and genetic criteria.

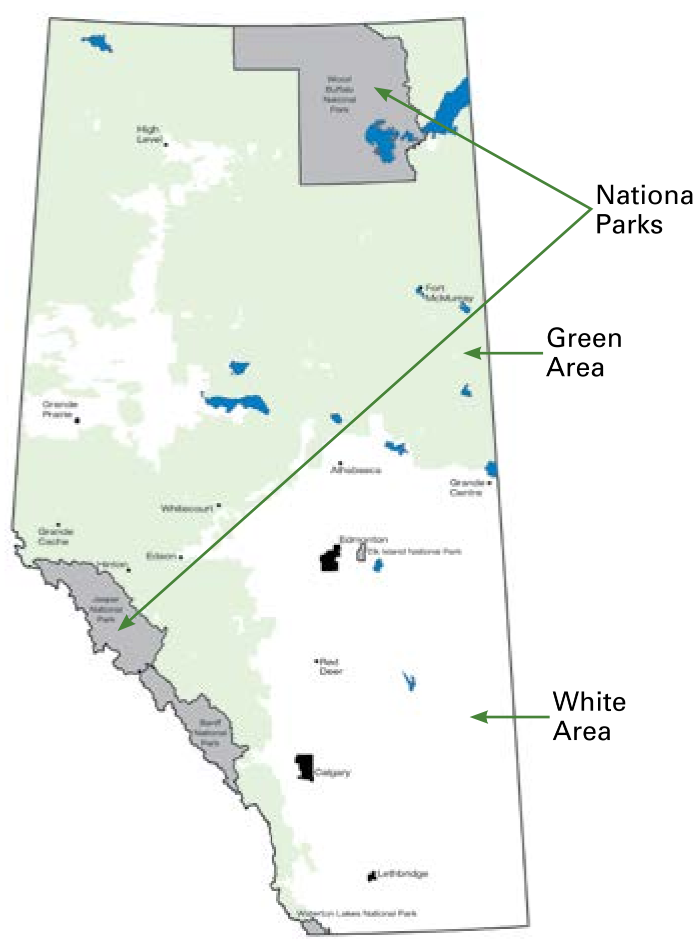
Seed zones are geographic subdivisions of the 6 natural regions and 21 natural subregions of Alberta, based on climatic, ecological and genetic criteria. The province of Alberta is divided into 90 seed zones (Figure 4), of which 74 are applicable to the Green Area (Figure 5). The seed zonation system includes all native, woody forest plant species (i.e. trees and shrubs) and covers the entire province of Alberta.

The seed zonation system deems individual plant species within each seed zone similar enough to be exchangeable between different areas of the same seed zone. This means that collection and deployment of seeds and propagules for revegetation and reclamation activities must take place within the same seed zone. Exceptions to the above collection and deployment rule are outlined in chapter 3 “Seed management.”

Prior to the seed zonation system, Alberta restricted seed movement through a seed transfer guideline (i.e. maximum radius of 80 km and 150 m elevation movement from collection site).

Figure 4. Seed zones of Alberta

Figure 5. Green Area of Alberta



4.2 Seed zones in policy

The seed zonation system is regulated through the FGRMS. The standards, first introduced in 2003 and revised in 2005, 2009 and 2015/16, regulate the management and movement of wild seed and propagule collection, handling, registration, storage and deployment. Although the standards originated from work done with commercial tree species, they apply to all woody material, including trees and shrubs, used for reforestation and reclamation on public land, and must be followed in the Green Area.

The purpose of the standards is to ensure the long-term success of reforestation and reclamation activities by:

- Planting material that is adapted to the local site conditions (genetic adaptation), and

- Preserving the genetic composition and resilience of wild plant populations through genetic diversity.

Restricting movement of seed and vegetative material within areas delineated as seed zones minimizes the loss of productivity and decline of forest health.

The FGRMS are identified in the reclamation policy in the *Enhanced Approval Process (EAP) Integrated Standards and Guidelines* (200.2.9): *"Revegetation with trees or shrubs within the Green Area shall be consistent with the Alberta Forest Genetic Resource Management and Conservation Standards"* (Alberta Energy Regulator, 2013).

4.3 Implications for reclamation

Restricting movement of seed and vegetative material within areas delineated as seed zones minimizes the loss of productivity and decline of forest health because of poor or unsuitable genetic adaptation. Ultimately, this enables long-term survival and success of planting stock used for reforestation and reclamation.

5. Seedling stock quality and seedling production

5.1 Stock quality

Management objectives will dictate the appropriate species for the site, but regardless, planted seedlings must be healthy and of good form. Good quality conifer seedlings should have large buds, a single stem, and abundant roots. The seedlings should be the appropriate size for the targeted species and the height and root collar diameter should match the nursery specifications for the stock type. Seedlings that are too succulent, have already flushed, have a forked stem, or show signs of mold or drought stress should be avoided.

5.2 Seedling and nursery production

5.2.1 How to order high quality seedlings (i.e. what specs to use)

When purchasing seedlings for planting, plan ahead. Generally, 1 to 3 years lead time is required with specific timing depending on the seedling that you require. The process starts with submission of a sowing request to the nursery. The sowing request will specify plant species, seed zone, seedlot, seedling specifications (height, diameter), and delivery date. Optimal seedling quality is not yet known for shrubs and other understory species used in land reclamation, further research is required.

Management objectives will dictate the appropriate species for the site, but regardless, planted seedlings must be healthy and of good form.

The nursery will purchase seed for the organization requesting seed if it is available. If not, seed will need to be collected, and this can add considerable time (see Chapter 3). The nursery will determine the germination rate and vigour of the seed, and based on the delivery date, will determine the sowing date.

The planting stock needs to be grown from seed best suited to the site. The source of the seed, or provenance, should match the planting site for climate, elevation and geographical locations. Once the seed zone is identified (see Chapter 4), suitable species can be selected.

Hardwood cuttings can also be used on reclamation sites, including dogwood (*Cornus sericea*), willow (*Salix spp.*), and balsam poplar (*Populus balsamifera*). Some nurseries have the facilities to install stooling beds to reproduce multiple harvests (cuts) from the same plants. Stooling is a type of layering that involves planting a rootstock, letting it grow, cutting it close to the ground, and then mounding it with dirt around the shoots to create new rootstocks that can be cut later.

5.2.2 Type and size of stock

The ideal seedling is one that provides good performance at the planting site for the least cost. Suitable stock, i.e. type and size, will depend on the overall management goals for the site, the presence of an existing seed source, the site capability and characteristics, economics, and time period available to establish a new stand (or multi layered plant community). The stock type best suited for a site will depend on the expected amount of competition from grass, shrubs and other trees, on soil characteristics, and on the potential for browsing from domestic livestock or wildlife. When site conditions are severe or competition is high, larger stock is preferred.

Planting stock is most commonly grown in containers or as bare root stock but can also be grown as a transplant. Container stock or plugs are grown in containers (for example, Styroblocks®), removed from the container and planted. The seedling's root system is typically surrounded by a growing medium such as peat and then injected with fertilizers, soil amendments and other water soluble products through an irrigation system to allow for ongoing nutrition.

They are less susceptible to damage and stress of handling and are easy to grow, transport, handle, store and plant. They are designated as 1+0, 2+0, etc.; the first number indicates the years grown in the container. The second number indicates the number of years a seedling was in a transplant bed.

Bare root stock is grown in a seedbed outdoors, lifted and then planted. Bare root seedlings do not have soil around their roots at the time of planting and are more susceptible to drying out. Transplants start as a plug, are removed from the container and then are moved to the field for an additional 1 to 2 years. This produces large seedlings that can compete on sites with competitive vegetation. Transplants are designated as 1+1, 1+2, etc.; the second number indicates the years grown in the outdoor beds at the nursery. Large container stock seedlings are also available but tend to be more expensive.

The size of seedlings is determined by the container size and time grown at the nursery. The cavity in the plug styrofoam block (PSB) is measured by diameter and depth. For example, a seedling designated as a "415" is grown in a cavity that is 4 cm in diameter and 15 cm deep. Container stock generally range in height from 12 to 30 cm with a root collar diameter (RCD) of 2.4 to 5.0 mm. Bare root seedlings, on the other hand, have an average height of 50 cm and a RCD of 6 mm.

5.2.3 Nursery practices – timing

The growing cycle at the nursery depends on the delivery date, species and the seedling being produced. The initial sowing date is determined by the final delivery date of the stock type and size of the seedlings required. Generally the cycle requires 18 months, but could take as long as 3 years for 2+0 spring stock or as little as 4 to 6 months for 1+0 stock for a summer plant.

After the seedling order is received, the seed owner authorizes seed withdrawal from the ATISC. Conifer seed needs to be stratified before use, that is, it is subjected to periods of soaking followed by exposure to cool temperatures. This period can take up to 4 weeks for conifers and up to 12 weeks for some shrub species. This will result in faster, more consistent, improved germination. The seed is soaked in distilled water for 24 hours, drained, placed in mesh bags, and then loosely tied plastic bags. The bags are placed on a shelf in a walk-in cooler at 5°C. The stratification process will be done by the ATISC or the nursery. Stratified seed is sowed in styrofoam containers (Styroblocks®) prefilled with a growth substrate (often peat) at the nursery and then grown in greenhouses with control over watering and fertilizing.

Stock for spring planting is lifted in the fall after seedlings are fully hardened, placed into small bundles (5 to 25 trees/bundle depending on stock size) and packed into boxes with liners. Seedlings overwinter in a freezer/cold-storage unit and are kept at a constant -2°C. Freezing reduces respiration, maintains dormancy and inhibits the formation of molds and fungus.

In the spring, seedlings are retrieved from cold storage and shipped to the planting site on a schedule that will allow the trees to slowly thaw in time for planting. Stock shipped frozen needs to be thawed slowly because tissue can be damaged if thawed too quickly. Seedlings can also be thawed at the nursery before being shipped. After seedlings are thawed, they lose dormancy rapidly, therefore stock must be kept at 1 to 2°C to maintain vigour.

Stock for summer planting operations is lifted from June to August and packaged and shipped to the planting site immediately (within 2 to 3 days). This type of stock is often referred to as "hot lift." These seedlings are still physiologically active and are very susceptible to damage during handling.

5.2.4 Handling of seedlings (transport to site and on-site storage)

Make sure that all planting stock is handled carefully to avoid damage, from shipping and transporting to the site until the time the seedlings are planted. During shipping and transporting to the site, seedling boxes need to be handled with care. Boxes should be packed firmly in trucks or trailers. Do not allow them to be crushed during transport. Do not allow crew to drop or throw boxes when loading or unloading trucks.

Make sure to avoid exposing the seedlings to excessive temperatures or dryness. Bare root stock is especially vulnerable to drying out. After seedlings are thawed, the temperature should be maintained at 1 to 2°C for spring planting and 5 to 6°C for summer planting. The temperature in the boxes should be checked frequently.

In the spring, seedlings are retrieved from cold storage and shipped to the planting site on a schedule that will allow the trees to slowly thaw in time for planting.

Seedling cost will depend on seedling type (size and type of stock), quantity of seedlings ordered, delivery date (storage costs), sowing date (increased heating costs), and any special handling required.

Climate-controlled vehicles such as refrigerated trucks are ideal for transporting seedlings long distances. It is important to keep the boxes ventilated and to ensure that there is air flow around the boxes, but to not expose them to wind during transport. Avoid travelling at mid-day or parking in the sun.

Once the seedlings arrive at the planting site, plant them as soon as possible. If this is not possible, store them in the shade. Use heat reflecting tarps (e.g. SilvaCool® tarps) or shade tents suspended above the seedling cache, if necessary. Reduce heat stress and maintain moisture by opening the boxes and the liners, standing up the bundles of seedlings and adding water to keep the roots moist. Check the temperature on a regular basis.

5.2.5 Nursery cost overview

Seedling cost will depend on seedling type (size and type of stock), quantity of seedlings ordered, delivery date (storage costs), sowing date (increased heating costs), and any special handling required. Stock type and size will affect overall cost because more smaller seedlings can be grown in a Styroblock® than larger ones (e.g. PSB211 are grown in Styroblocks® with 240 cavities, while the PSB 412 only have 77 cavities per block).

6. Artificial regeneration

6.1 Artificial regeneration

The regeneration process includes species selection, seedling production, site preparation, planting or seeding and management of competing vegetation. Artificial regeneration (i.e. planting) provides more control over the species, spacing and timing of the regeneration than natural regeneration (plants originating from propagules, roots and seeds, present on or close to the site). Preferred species can be selected, and planting allows density to be controlled. It can provide a head start over natural regeneration, depending on site conditions and disturbance. To ensure the planting quality is high and target densities are met, supervision of on-site planting activities is required.

6.2 Planting

6.2.1 Timing of planting

There are two optimum planting periods, spring and summer, in which seedlings grown for those periods will perform well. The optimum planting period varies for coniferous and deciduous species.

Currently, deciduous species are best planted in the spring while coniferous species can be planted in spring or summer. Trees can be planted in the fall, but they will be more susceptible to frost damage, to frost heaving because of their lack of root development, and to other agents (rodents or wildlife). It is therefore not recommended.

Sometimes winter planting of black spruce takes place in mostly remote areas, where one entry (site preparation and planting) is most cost-effective. However, the survival rates of winter planting can be very low.

Spring planting utilizes seedlings that were grown in the nursery the previous fall until dormant and cold-tolerant. Ideally, soil temperatures should be above 5°C. Spring planting should not extend past the middle of June because the seedlings will not be biologically synchronized with their environment and will not perform as well or may not harden off.

Summer planting usually begins in mid to late June and should be completed by late July to allow time for sufficient root development. Seeds are sown in mid to late winter. Conifer seedlings are grown such that they have set a terminal bud before planting time, and the needle cuticle development is sufficient to help with drought tolerance. Deciduous seedlings are planted with active leaves, directly from the nursery. These leaves can desiccate under low soil moisture conditions, which affects seedling development and survival. It is not ideal, but also not unusual for the seedlings to lose their leaves after planting.

6.2.2 Quality of planting

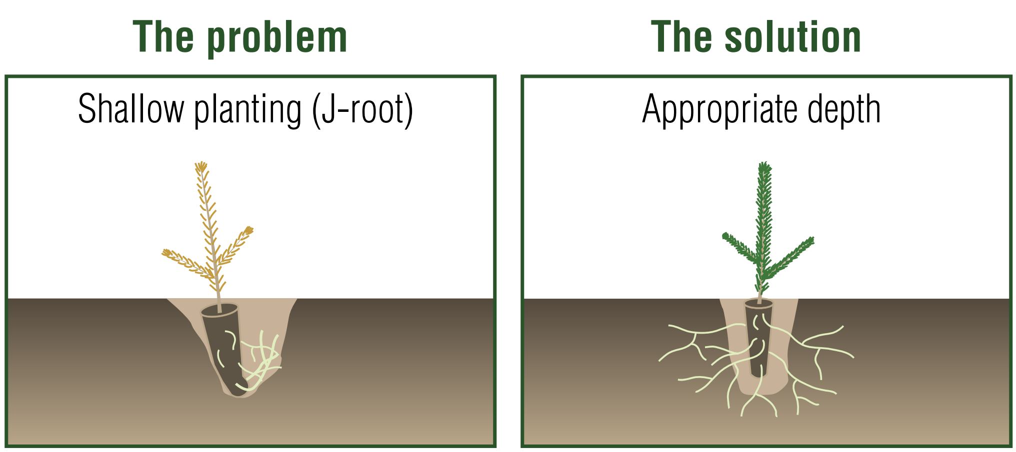
Most planting is done manually by crews with specialized planting shovels. Tree planters carry seedlings in bags mounted by harnesses. The condition of the seedlings, stocking handling during transportation and field storage, and planting quality will affect survival and early growth.

As mentioned before, the seedlings need to be kept cool and moist with enough air circulation. The trees are actively growing and will generate sufficient heat to damage the trees or stimulate fungal growth.

Tree planters need appropriate tools and to know how to plant a tree. Buckets or planting bags to keep the roots of trees moist are critical to avoid drying out of the seedlings during planting. Tree planting shovels are designed specifically for tree planting and make it more efficient to plant a tree at the right depth.

The planting hole needs to be deep enough to accommodate the full length of the roots. If the roots are bent or "J-rooted," the tree will grow for several years and eventually fall over because of the instability of the supporting root structure. The seedling should be planted

Figure 6: Planting depth



to the root collar (top of plug should be just below the soil surface). The seedling should be planted firmly and tightly without air pockets, but not too tight to crush the roots.

The management objectives will determine the target density (trees/ha) of the planting. Seedlings need enough room to grow, and stocking will determine inter-plant distance. Stocking levels should be based on the densities recommended in the reclamation criteria. Planting higher densities of a combination of native species (trees and shrubs) will often be desirable on industrial reclamation sites.

Planting higher densities of a combination of native species (trees and shrubs) will often be desirable on industrial reclamation sites.

6.2.3 Microsite selection and creation

It cannot be stressed enough that to provide the seedling with the best growing conditions, the planter needs to choose the best microsite. Ideal microsites can be created through site preparation.

A separate guide book provides more information on site preparation, but generally, sites are prepared to overcome site limiting factors and create microsites for reforestation. This is accomplished by physically altering slash (e.g. tree tops and branches left after harvesting), duff (i.e. top, litter layer of forest floor), and soil layers by a variety of methods, including scalping, trenching, plowing, mixing and mounding. Through site preparation, factors that are limiting for seedling survival and growth may be overcome. These factors are related to soil temperature, soil moisture, soil compaction, available nutrients and competing vegetation. Over a small geographic area (even within one disturbed site) conditions may vary. To obtain the best result, the site preparation method must be matched to these conditions.

The ideal microsite for planting a seedling has adequate soil moisture but with sufficient drainage, enough soil aeration to provide oxygen to the roots and physical space to grow, organic matter to provide nutrients, and a low level of vegetative competition. If seedlings are planted on unsuitable sites, they will suffer high mortality, grow poorly and be more susceptible to insect and disease problems. Different species will have different requirements.

Tree planters need training to be able to identify the best microsite available for the particular species. As part of this series, several videos are available that clearly explain how to choose and recognize the optimum planting site. In addition, a short training period by a local silviculture forester might also be beneficial.

6.2.4 Fertilization

Additional nutrients can be added to the site in a broadcast application or at the time of planting with "tea bags" containing fertilizer. The tea bag is placed in a separate hole adjacent to the planted tree to provide a local source of nutrients for the tree. The company that provides the fertilizer can adjust the blend to suit the conditions on the site and tailor the recipe to maximize benefits. Broadcast fertilizer applications should be applied only on sites where competing vegetation is less of an issue because the fertilizer application may enhance growth rates of competing species as well.

6.2.5 Cost of planting

Reforestation costs will vary with target density (trees/ha), the size of the area to be treated, site preparation treatments, and the size and type of planting stock. The site conditions (access to the site, slope, and ground roughness) will affect the planters' productivity and the overall cost to plant.

Although initial treatments can be expensive, if done properly they will result in a vigorous, healthy plant community that will require minimal treatments in the future. Predictability of the future site is also much greater with planting, and will significantly reduce future planning and treatment costs.

If treatments are done poorly, future and more costly interventions may be needed because many industrial reclamation sites are small and widely dispersed, incurring high travel time and productivity costs. At the time of writing, the cost of seedlings (1-0 and 2-0) ranged from 24 to 50¢/tree).

6.3 Direct seeding

Although planting is the most common method of artificial regeneration, seeding for some species can also be used under the right conditions. Seed can be dispersed by aerial or ground equipment. Aerial seeding can be used for large areas, but success can be variable because there is little control on where the seed lands, and it requires a large quantity of seed.

Seed needs to land on suitable microsites to germinate and grow. Direct seeding using ground-based equipment provides more control over seed dispersal and can be done in conjunction with site preparation.

Direct seeding using ground-based equipment provides more control over seed dispersal and can be done in conjunction with site preparation.

Direct seeding is a cost-effective treatment that can cover large areas quickly for less than the cost of tree planting. With seeding, the cost of growing seedlings at the nursery and planting them on site is unnecessary. Higher densities can be achieved with little added cost, and the season for seeding is longer than for tree planting.

Direct seeding does have disadvantages. It requires more seed and takes longer to establish seedlings than tree planting, which is a strong disadvantage on sites with heavy vegetative competition.

Germination success is dependent on uncontrolled external factors such as weather and seed predator populations. Variations in microsites can result in clumpy or irregular stocking, requiring re-seeding, in-fill planting or spacing. Dormant seeds should be stratified before seeding or seeding must be done in the fall or winter to allow for natural stratification in the spring.

6.4 Maintenance and monitoring

After the plants have established either through natural or artificial regeneration methods, follow-up and monitoring are necessary. This typically consists of monitoring the survival and growth of the seedlings and assessing the level of vegetative competition.

One to two years after planting, an initial survival and competition assessment should be done, with additional in-fill planting, as required, and any vegetation management requirements.

It is important to do an additional assessment about five years after establishment to monitor for competing species and plan for vegetation management, if required.

6.4.1 Browse protection

Browse by domestic animals or wildlife can severely impact the survival of planted seedlings. Strategies to manage browsing can include planting species not favoured by the browsing animals, planting higher densities (sacrifice some of the plants), using companion plants (planting other species to deflect the damage away from the crop trees), and installing physical barriers (guards on the trees or roughing up the site during site preparation to reduce site access by the animals). The appropriate strategy will be determined by the browsing animal, the severity of the browsing pressure and the resources available.

6.4.2 Vegetation competition

Control of competing vegetation is critical in the early stages of a newly planted reclamation site and often means the difference between success and failure. Grass and other non-desirable plant species can compete with the newly planted seedlings for light, moisture and nutrients. The amount and type of competition will determine the preferred species and size of stock for the site.

Generally larger stock will perform better than small stock in a competitive environment unless there are other limiting factors such as low snow levels, high winds or warm winters resulting in a high probability of winter desiccation.

Grass can be severely damaging during winter when it is flattened by snow and flattens the planted stock at the same time.

Vegetation control can range from physical barriers and mechanical cutting to chemicals to reduce or eliminate the unwanted species. Herbicide use will depend on the tree species characteristics and the type of unwanted vegetation.

The best defence against competing vegetation is to planting or seeding a site immediately after reclamation has been completed (or as soon as possible).

Delaying planting for 2 to 3 years after a site has been reclaimed will enable competing vegetation to occupy available microsites, greatly increasing competition on a site. While this approach requires additional up-front planning, it is one of the easiest and best ways to ensure successful regeneration on a site.

Vegetation control can range from physical barriers and mechanical cutting to chemicals to reduce or eliminate the unwanted species.

7. Natural regeneration

7.1 Introduction

Although natural regeneration is not as predictable as artificial regeneration, under ideal conditions it may be a suitable alternative for regenerating reclaimed sites.

The initial cost of relying on natural regeneration is lower than planting, which makes it an attractive option, but three basic conditions need to be met to guarantee success:

- seed supply
- suitable seedbed
- favourable environmental conditions

Natural regeneration is unlikely to succeed if any of these conditions do not exist and cannot be created or provided through intervention (i.e. site preparation).

Other factors to take into consideration are that stands established through natural regeneration are likely to take longer than planted stands to reach a stage free of competition, and the species choice will be restricted to what is available on site or in the neighbouring undisturbed areas. Therefore, if management objectives require predictability, a very specific species mix, stand density and short time frame, natural regeneration may not be the right treatment to achieve those objectives.

7.2 Seed supply

Successful natural regeneration relies on having an appropriate seed source on site or near enough for seed dispersal to reach the site.

During soil stripping and levelling, the surface soil can be stripped and stored for later use in stockpiles. During reclamation, the site is regraded, and the top soil is returned to provide a suitable growing medium. This soil can act as a seedbank containing seeds and viable plant propagules from the original stand or plant community, if managed properly. Along with desired species, stockpiled soil can potentially contain undesirable weed species.

Seed propagule viability and soil quality in a stockpile are dependent on the age and height of the pile. Generally, it is not recommended to stockpile soil in large piles (>6 m high) for longer than 8 months because plant seed vigour and root viability significantly decline over time, diminishing the potential success of natural regeneration.

Most seeds are found and germinate within the top 5 cm of the soil; therefore, if soil is stockpiled to great depths, seeds may be buried, which lowers their potential emergence when used for future reclamation purposes.

Successful natural regeneration relies on having an appropriate seed source on site or near enough for seed dispersal to reach the site.

Large stockpiles stored for long periods may create anaerobic conditions under the surface, which can cause seed mortality. Seeds in small stockpiles may experience premature germination or seed rot from aerobic conditions if stored for too long.

Stockpiling increases soil bulk density and reduces aggregate stability, degrading overall soil structure, and reduces mycorrhizae and microbial populations, which can negatively impact plant growth.

On pine tree sites where soils are not stripped, such as winter builds, there may be sufficient seed for good natural regeneration.

Seed can also come from nearby donor plants such as shrubs or trees in the adjacent undisturbed forest. The donor plants need to be of the desired species and close enough to disperse seed into the disturbed area and across the entire opening, so this may be a suitable method for small or narrow openings with adequate climatic and soil conditions, but not large openings.

Seed amounts are dependent on the characteristics of the specific trees. Some trees produce consistent amounts of seeds regularly and others have mast years where seed production is abundant. This will vary by species so ensuring that the desired seed supply is available when required is unpredictable, and where the seed lands when it is dispersed is uncontrollable.

7.3 Suitable seed bed

The second condition for successful natural regeneration is a suitable and receptive seedbed.

Some species, such as pine and spruce, require exposed mineral soil to germinate; others prefer well decomposed organic material or a mix of the two.

Top soil re-distributed on the site is likely to be an ideal seedbed provided it is not too loose and dry or compacted. If the seedbed is not ideal, site preparation treatments may be applied to overcome limiting factors. These factors are related to soil temperature, soil moisture, soil compaction and available nutrients.

Site preparation can also be used to spread coarse woody debris and top soil, to distribute cones if they are on site, and to reduce or remove competing vegetation.

For tree planting, the ideal microsite for natural seedlings has adequate soil moisture but with sufficient drainage, enough soil aeration to provide oxygen to the roots and physical space to grow, organic matter to provide nutrients, adequate light levels and a low level of vegetative competition.

If seeds land on an unsuitable microsite, they may still germinate, but will grow poorly and will not persist.

If the seedbed is not ideal, site preparation treatments may be applied to overcome limiting factors.

7.4 Growing conditions

The final condition to meet after a suitable seed source and seedbed is that the site environment is suitable for the desired crop species.

Seeds require moisture, warmth and light. If the microsite is shaded, overhead vegetation could be removed through a site preparation treatment that can reduce competitive vegetation or by applying chemicals (for conifer regeneration) after the stand is established. If the opening is small or a linear disturbance and the shade is coming from adjacent stands, natural regeneration will be constrained, and shade-tolerant species should be chosen for artificial regeneration.

If the site is open and the microsites are exposed to extreme temperatures (either too hot or prone to frost pockets), vegetation can be left to protect the germinants and seedlings but be cognisant that too much vegetation can hinder growth or cause mechanical damage.

If all the conditions can be met, natural regeneration may be a viable option. In addition to the lower cost for establishment, natural regeneration has the advantage that the seeds are genetically adapted for local conditions. They have the ability to develop a natural root system on location contributing to a more resilient future forest.

8. Competing vegetation

The key objective for revegetating industrially disturbed forested sites is re-establishing functional and resilient forest plant communities with native species that are characteristic of the region and ecosite.

Desirable plants include both woody and herbaceous species that are characteristic of an early successional forest community. This chapter provides an overview for factors influencing vegetation management plans and treatments. An in-depth discussion of vegetation management treatments can be found in the separate guidebook, part of this series.

8.1 Principles of plant community development

Following site disturbance and reclamation, forest plant communities will typically recover following patterns of secondary succession characteristic of the forest type. Each successional stage, i.e. early-, mid-, and late-succession, is characterized by distinctive plant species that have unique growth strategies and resource requirements.

For example, early successional stages are characterized by so-called “pioneer” species that are fast-growing and often very shade-intolerant. These pioneer species will alter the abiotic environment in favour of later-successional species that will progressively replace the early successional species.

Establishing diverse forest communities with woody and herbaceous species that have a variety of growth strategies and resource needs poses challenges. One of the major challenges is the competition for site resources between trees and neighboring vegetation.

Disturbed sites can be rapidly colonized and dominated by herbaceous broadleaf and grass species, woody shrubs, competing tree species, and non-native species. Establishing trees through natural or artificial regeneration can be impeded by competition between young trees and fast-growing, often more competitive herbaceous understory plant species.

Another challenge is that some of the herbaceous species that are competitors with trees for site resources are also desirable and, in fact, target species for establishing diverse forest plant communities on disturbed sites.

Not all herbaceous plant species are undesirable. This poses a challenge if vegetation management is being considered for a site.

Competition most often occurs as a combination of both above ground competition for light and below ground competition for water and nutrients. Growth of trees on sites dominated by more aggressive herbaceous species can be limited by the lack of suitable microsites and associated resources including nutrients, water and light.

For example, shade-intolerant species, such as poplars, have higher light requirements and often do not tolerate significant light competition by neighbouring plants.

Competition for aforementioned resources varies temporally and is often most intense during the early establishment phase and decreases over time as trees are able to reach canopy closure and consequently out-compete herbaceous understory species.

Growth of trees on sites dominated by more aggressive herbaceous species can be limited by the lack of suitable microsites and associated resources including nutrients, water and light.

8.2 Competition risk factors

Competition will vary depending on resource availability. Generally, sites that have fewer resources will compete less than productive sites.

For example, competition is usually less on sites that are either extremely wet or dry or have few nutrients compared to sites that have highly favourable growing conditions including higher amounts of nutrients and moisture.

These highly productive sites favour vigorous establishment of fast-growing, often herbaceous, species at the expense of slower growing or less competitive woody species.

Another factor that affects the extent of tree-herb competition is the proximity of the site to roads and areas of human activity. Sites located near roads or frequented by equipment or subject to human impacts are at higher risk of invasion by undesirable species, in turn, making active weed management necessary.

8.3 Vegetation management

Revegetation plans to establish desirable species must include concurrent management of undesirable species and all noxious weed species that fall under Alberta's *Weed Control Act*. Tools to manage undesirable species include mechanical, chemical and cultural control practices. Pre-disturbance and pre-reclamation assessments will help identify sites where undesirable species are a concern and where management will be required.

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Notes