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Vegetation Management for Restoring Forest Cover on Oil and Gas Sites

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Preface

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 vegetation management tools and techniques. Natural Resources Canada Canadian Forest Service (NRCan-CFS) developed this guidebook to help with the successful restoration of disturbed in situ sites. Although the tools and techniques discussed in this guide can be applied to disturbed sites throughout the boreal forest in Canada, the focus of this guidebook is Alberta.

Disclaimer: This guidebook provides only advice on best practices. We urge the reader to confirm regulatory compliance and authority before choosing the best technique or tool.

Multiple techniques and practices can optimize the success of reclamation . . .

1. Introduction, definitions and planning

Vegetation development following disturbance

The presence of weedy and undesirable species on sites targeted for reclamation causes several concerns, including high costs associated with controlling weed species both on- and off-site.

One aspect of vegetation management is meeting the legal responsibility to control weeds (outlined in the Regulations and guidelines section). Vegetation management is also needed to establish desirable, target plant species and reach reclamation targets.

Following industrial disturbance, vegetation will develop according to the given site conditions (e.g. climate, soil nutrients, soil moisture) and external factors, including disturbance type (e.g. well pad, seismic line, pipeline), disturbance nature (severity and contamination), and management activities. All these factors will influence the ability of a site to regenerate to forest vegetation and to rapidly achieve reclamation objectives.

The two key **reclamation objectives** for industrially disturbed sites are:

- re-establishing native, functional forest plant communities that are compatible with the intended land use and characteristic of an early successional forest community of the targeted ecosite
- complying with the *Environmental Protection and Enhancement Act*'s approval conditions and/or reclamation criteria to obtain a reclamation certificate if industrial developments take place on specified land[1]

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

These challenges are particularly relevant to mining and in situ oil sands areas. Forested areas disturbed by oil sands development can be rapidly colonized and dominated by non-native species that are often fast growing and highly competitive. The greater the disturbance and traffic on industrial production facilities and roads and the longer the site remains active, the higher the likelihood that weed species spread and become established. Developing an effective vegetation management plan and promoting the establishment of rapid forest cover are therefore key objectives of most operators.

What are desirable plant species?
Desirable species for forested lands are species that are characteristic of the targeted ecosite and similar to the native, undisturbed plant communities of the surrounding off-site vegetation. The desired plant community will contain both native herbaceous and woody species characteristic of the early successional community of the targeted ecosite. Ecosite guides provide species lists that are typical of different ecosites across Alberta.

Generally, listed weed species are fast-growing, often highly competitive species that can spread rapidly.

What are undesirable species and weeds?
Generally speaking, undesirable species are those that fit in one of the following categories:

- slow or hinder the establishment of the target vegetation through competition
- spread rapidly, causing productivity declines on adjacent land
- are listed as a weed under Alberta legislation

Weeds are commonly defined as plant species that are unwanted or undesirable. In Alberta, weeds are defined as plant species that are listed in the *Weed Control Regulation of the Weed Control Act*. The regulation lists 75 weed species of which 29 are designated as noxious weeds and 46 as **prohibited noxious weeds.**[2]

[1] If the developments are not on specified land, the Alberta Public Lands Dispositions office sets criteria to achieve a Letter of Clearance.
[2] Note that municipalities are able to designate weed species within their particular jurisdiction (Weed Control Regulation, s. 9). It is therefore important to determine weed status in each jurisdiction an operator is working in.

Generally, listed weed species are fast-growing, often highly competitive species that can spread rapidly. Plants designated as noxious weeds are widely distributed and considered not eradicable. Management of noxious weeds thus targets strategies for containment, including methods that impede or destroy growth. Plants designated as prohibited noxious weeds, on the other hand, are either not currently found in Alberta or are in only few locations, which makes eradication possible. Early detection and prompt destruction of prohibited noxious weeds is obligatory under the regulation.

Early detection and prompt destruction of prohibited noxious weeds is obligatory under the regulation.

Why are undesirable species a problem?
Undesirable species growing on reclaimed lands presents several challenges. These species:

- interfere with desirable plant species establishing themselves by competing for site resources
- delay or impede natural succession toward the desired forest plant community
- displace native vegetation
- spread rapidly to adjacent lands, potentially causing a decline in forest productivity
- require expensive weed control programs to control and/or destroy weeds on- and off-site
- are regulated by the *Weed Control Act*
- are regulated through the *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands*.

Ecosystems in the northern boreal region are known to have a higher degree of resistance to weed invasion than those under cultivated agricultural systems in warmer climatic zones. The environmental variables such as temperature, light levels, nutrient availability, soil acidity and plant communities, especially the presence of bryophytes, play an important roles in weed resistance. A few agronomic weed species have expanded into the boreal zone and colonized these ecosystems. However, their decline in abundance after the initial few years suggests biotic resilience.

Regulations and guidelines
Under the *Weed Control Act*, the land owners or land occupants are legally obligated to control noxious weeds and to destroy prohibited noxious weeds.

"Control" includes management methods that inhibit the growth and spread or destroy the growth of the plant, including the plant's seed.

"Destroy" includes methods that kill all growing parts of the plant or render reproductive mechanisms non-viable.

The *Weed Control Act* further prohibits the movement of equipment and vehicles that would spread noxious and prohibited noxious weeds.

The *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands* require that noxious weeds are controlled, prohibited noxious weeds are eliminated, and that the density and distribution of weeds on-site are comparable to off-site controls.

Role of vegetation management
Vegetation management refers to the methods and tools used to selectively remove and/or add plant species (e.g. trees, shrubs, herbaceous and graminoid species) within a site or area.

The objectives of vegetation management for reclamation include:

- ensuring that target vegetation has the best possible growing conditions

- preventing and minimizing the establishment of undesirable species
- controlling noxious weeds
- destroying prohibited noxious weeds

Historically, vegetation management on reclaimed forest lands targeted rapid re-vegetation of sites using agronomic species including grasses and forages. Reclamation objectives for forested lands have changed and now target the development of functional forest plant communities including a diversity of native woody and herbaceous species. Vegetation management is critical to establishing desirable plant communities and to achieving reclamation objectives.

Vegetation management on reclaimed forested land targets the temporary suppression of undesirable species. Once the target forest community has been established, the impact of competition lessens, and vegetation management becomes less relevant. Therefore, a key goal of vegetation management is to do one of the following:

- protect investments made during planting
- increase the success of natural regeneration by reducing competition during the establishment period when these trees and understory species are most susceptible to competition

Vegetation management methods

Various tools can help manage undesirable species while simultaneously supporting desirable species. Common methods are discussed in detail in these chapters:

- "Mechanical controls"
- "Chemical and biological controls"
- "Cultural controls"

Vegetation management methods must be selected based on the desired plant community, existing weed populations on- and off-site, site conditions and regulatory requirements.

Integrating multiple controls can increase the overall effectiveness of the vegetation management program and help reach reclamation objectives. Integrated vegetation management (IVM) will be discussed in the "Integrated Vegetation Management" chapter.

> **Vegetation management on reclaimed forested land targets the temporary suppression of undesirable species.**

Steps to effective vegetation management

There are four core steps in developing and delivering a vegetation management plan:

1. Developing a vegetation management plan
2. Preventing weeds and preparing a site to promote desirable species
3. Choosing the appropriate methods for vegetation control
4. Monitoring and evaluation

Developing a weed management plan is a core step in effective vegetation management, but one that is often overlooked. A weed management plan will include management goals, an inventory of existing weed populations (most effective when the majority of plants are in bloom from June to September), prevention measures and control methods.

Pre-disturbance and pre-reclamation assessments will help identify sites where establishing undesirable species is a concern, identify species and their distribution, and guide management actions.

Monitoring will help identify whether applied treatments reached goals and assess whether follow-up treatments are necessary.

It is critical to know the species found on each site as well as to understand the resources available to determine suitable treatment methods and timing. Questions that need to be addressed include:

- life cycle of the weed (e.g. annual versus biannual or perennial)
- reproductive mechanism of the weed
- distribution of the weed (local and regional, widespread versus outlier populations)
- resistance of weeds to certain methods (e.g. herbicide resistance)
- potential damage to natural resources, especially forestry or agricultural resources
- resources available

The second step is preventing weeds from becoming established on reclaimed sites, and it is the most cost-effective method. Operators must ensure on-site staff and contractors are aware of, and adhere to, preventative measures, including:

- avoiding moving equipment through infested areas
- washing equipment to remove soils and weeds before moving to a new site
- using only certified seed that is free of weeds
- reducing soil disturbance and bare soil by using temporary and interim reclamation with desirable species (see the "Cultural controls" chapter)

Controlling established weed populations is the third step, and it can require significant investments. Prompt weed control is thus strongly recommended because it can limit the spread, reduce costs and ultimately provide better growing conditions for desirable vegetation to establish.

The final step is monitoring – it plays a crucial part of any vegetation management program and should be carried out frequently. Monitoring will help identify whether applied treatments reached goals and assess whether follow-up treatments are necessary. Timely monitoring will help detect weed spread early and thus allow for prompt and proactive treatment interventions.

2. Mechanical controls

The control of weeds involves reducing or eradicating existing plants, propagules and seeds of undesirable species so that they no longer interfere and compete with desirable vegetative growth. The over-arching objective is to meet end use goals and achieve reclamation certification, where required.

This chapter provides an overview of controlling and eradicating weeds through mechanical means. The associated advantages and limitations of implementation, as well as application frequencies and timing, are discussed in detail to help managers. consultants and operators identify the most applicable methods to implement as part of their integrated vegetation management plan.

2.1 Cultivation

Cultivation is one of the oldest techniques used to control undesirable species and aims to physically damage plants. It is accomplished by using mechanical cultivation equipment (i.e. ploughs, disks, and cultivators) or by using hand tools (i.e. hoes, spades and hand-cultivators) (Figure 1). Though largely non-selective, cultivation is an important component of an integrated weed management program, especially for rhizomatous weeds.

Mode of action

Cultivation is conducted using mechanical equipment or by hand to disturb the root of target plants, either severing the top of the plants from the roots and/or breaking the connection between the roots and soil.

Advantages

- The results are immediate.
- This method is effective on annual and winter biennial weeds.
- Mechanical cultivation is relatively inexpensive but costs can add up if multiple treatments are required within a growing season.
- Cultivation is most useful as part of an integrated vegetation management for species that reproduce from roots. It is used to break up roots to stimulate emergence, which is followed by treatment with foliar herbicide.

Limitations

- Mechanical cultivation is non-selective and can range from light treatments (using agricultural equipment i.e. disks and cultivator) to heavier treatments (using forestry equipment i.e. rip ploughs). The heavier treatments may cause substantial disturbance to the soil (potentially admixing of soil layers) and to desirable plants.
- Mechanical cultivation also requires significant energy and generates greenhouse gas (GHG) emissions.
- Hand-cultivation using hoes and rakes can be highly selective but expensive and impractical for large areas.
- Cultivation can decrease soil stability and increase the potential of soil erosion.
- Repetitive treatments are almost always necessary because effects on weeds are very short-lived.

Figure 1. Mechanical equipment and tools used in cultivation

(a) (b) (c)

Note: (a) straight shank ripper for tilling soil 0–30 cm, (b) RipPlow for tilling soil >30 cm, (c) hand tools (rake, spades and hoe) for soil with <15 cm of surface frost.

- Cultivation, if used in isolation, can lead to increased spread of rhizomatous species.

- Damage to trees is a risk with the use of equipment (when used post-planting).

Frequency and timing

- For long-term eradication, cultivation treatments may have to be executed for several years if seeds remain in the soil and continue to germinate.

- Cultivation should be done before plants set seed, typically two to three times over the course of the growing season.

2.2 Manual removal

Manual removal of plants is one of the oldest techniques used to control weeds. However, because of the cost and marginal effectiveness, manual removal should be used only on small infestations of noxious weeds in areas where other treatments cannot be deployed.

Mode of action

The hand-pulling method removes plants from the soil or breaks the tops off woody plants.

Advantages

- effective for small infestations and annual or biennial weeds with small rhizomes

- very selective and has low environmental impact

- minimal disturbance suitable for environmentally sensitive areas where equipment cannot be used (aquatic or riparian areas)

Limitations

- time- and labour-intensive (higher cost) with marginal and short-term success

- not efficient for large open areas

- The seeds may still be viable if pulled weeds have set seed and are not removed from the field.

- This method is not as effective for rhizomatous weeds because the root crowns and their adventitious roots must be removed or plants will re-sprout. This is often difficult unless the soil is quite moist

Frequency and timing

- Annual hand-pulling done at least two or three times per year will increase long-term eradication.

- If any dormant seeds remain in the soil, this treatment may have to be repeated over several years to completely eliminate weeds.

2.3 Mechanical cutting and mowing

Cutting or mowing plants directly removes the above-ground biomass of the plant, depleting its energy reserves in the roots and thereby limiting future growth.

Mode of action

Using motor-manual (brush saw or chainsaw) or motorized equipment (grass mower or brush cutter) to reduce the above-ground biomass of woody and/or herbaceous species.

Advantages

- rapid management of small areas for reducing above-ground biomass (particularly of woody and herbaceous species)

- can be used in combination with or as a pre-treatment for other control methods (i.e. apply herbicide to surfaces exposed on woody vegetation after cutting)

- The litter produced by mowing will act as a mulch, increasing moisture availability and biological activity (via decomposition). After the litter is decomposed, it will add nutrients to the soil.

Limitations

- Mowing can fragment roots and increase the number of propagules in the soil.

- non-selective

- not an option for rough or rocky terrain

- not an option for low-growing plants (less than the mowing height)

- marginally effective in controlling species that spread by rhizomes

- Repetitive treatments may be needed to achieve longer-lasting reduction of above-ground growth.

Frequency and timing

- Mowing or cutting should be done before plants set seed, preferably at the flower stage for forbs or the boot stage for grasses (when the developing seed head begins to push through the uppermost leaf sheath).

- For long-term eradication, treatment may have to be repeated for several years if seeds remain in the soil and continue to germinate.

- This method is typically done two or three times over the growing season.

2.4 Mulch

Applying mulch is one of the more traditional methods for managing undesirable species. Material used for mulch can be organic and inorganic (natural and synthetic) (see Table 1). Mulch can be created by chipping downed wood or detritus or from locally sourced hay or straw.

Organic sources have the added benefits of

- improving soil moisture content (by reducing moisture evaporation and increasing water infiltration)

- improving soil structure

- positively affecting fungal and insect pests

- moderating the soil temperature

- increasing soil biological activity

The effectiveness of organic mulch depends on

- the type of material used

- how densely the mulch material is packed

- the movement of mulch materials (via wind, flooding, animals, etc.), which may leave the soil surface exposed for invasive plants to grow in

Therefore, organic mulches could be used in combination with landscape fabrics or plastic sheets for a more effective, long-term control of undesirable species. Several novel spray-on organic mulch products exist. They use recycled newsprint waste and chopped cereal straw, which reduce mulch movement over time.

Mode of action

Applying mulch is adding any material on top of the soil to modify the energy (i.e. light) and the water flux required for seed germination and plant growth.

Advantages

- Mulch material can be inorganic (natural and synthetic) or organic (i.e. wood chips). Often organic materials can also improve soil moisture retention, gas exchange, soil nutrients, soil structure and biological activity.

Table 1. Mulches available for weed control

Organic	Inorganic and natural	Inorganic and synthetic*
Wood chips Sawdust Hardwood bark chips Softwood bark chips Spruce and pine needles Hay and straw Spray-on mulch**	Sand Gravel Pebbles and cobble	Geotextiles Landscape fabrics Polyethylene, burlap, natural fibres Plastic sheets Polypropylene

*spunbond fabric (high tensile strength), non-woven, woven (needle-punched fabric or natural burlap); installed using U-shaped nails, landscape fabric stables, sandbags or stones

**slurry of recycled newsprint waste and cereal straw (<5 cm deep)

- Mulch can also reduce evaporation and erosion and can increase soil biological activities through an increase in soil temperature and moisture over time.
- Some organic materials may be available on-site, thereby reducing transport costs.
- Mulch is effective on most plants and rhizomes.

Limitations

- may alter the soil microbial population (density and community) because of the change in soil conditions
- may alter the soil fertility and carbon-nitrogen ratio (side effect of photolysis)
- non-selective
- not as effective on perennial weeds, bulbous weeds or weed seeds with hard seed coats
- Heavy applications reduce the potential for natural recolonization. Plastic sheets may hinder growth of desirable species because of decreased soil water infiltration and excessive soil heating. Application of mulch may be expensive and labour-intensive and using plastic sheets may not be feasible for large areas, especially if the material needs to be removed after a few years.

Frequency and timing

- The effectiveness of mulch as a weed suppressant depends on the material used (thickness and longevity); the packing and installation of the mulch; and the movement of mulch material.;
- Synthetic inorganic mulch material (i.e. polypropylene fabric) can degrade in UV light over time, so should not be used alone as a long-term weed management strategy. Instead, it should be placed under organic and/or natural inorganic material to suppress weeds.

2.5 Solarization (plastic mulching)

Solarization (known as plastic mulching) is a non-selective, pre-emergent vegetation control treatment similar to mulching. However, solarization uses heat generated under the material to eliminate undesirable vegetation rather than modifying the amount of light and water to deter seed germination and plant growth.

Mode of action

Cover the area with thin plastic sheets (see Figure 2) to capture radiant energy from the sun to dry and eliminate vegetation through heat generated under the sheets. The plastic sheets can be transparent or black and a variety of widths and thickness.

Figure 2. Plastic sheets used for vegetation control – solarization

(a)

(b)

Note: (a) clear polyethylene plastic sheets, (b) black polyethylene plastic sheets

Black plastic absorbs most solar radiation and transmits only a limited amount but clear plastic transmits 85 to 95 % of solar radiation and absorbs very little. This means clear plastic may be more effective at increasing soil temperature than black plastic and at eliminating plants. Double-layer solarization should be considered in wetter climates for a more effective insulation.

Solarization uses heat generated under the material to eliminate undesirable vegetation rather than modifying the amount of light and water to deter seed germination and plant growth.

Advantages

- effective at killing the dormant part of weeds (i.e. root crowns) and reducing the seed bank of undesired species
- It is an effective control for pathogenic fungi, bacteria and nematodes in addition to controlling weeds.
- also regulates soil moisture and reduces nutrient loss through leaching

Limitations

- non-selective
- This treatment should be used before planting seedlings, which may limit the window of application.
- requires close contact between the plastic sheets to the soil surface, therefore, mowing or mechanical cutting needs to be completed first
- may not be efficient for large areas because of material costs
- may alter soil biota (impact density and community of fungi and bacteria)
- may alter soil chemistry (a side effect of photolysis)
- may be less effective if rain accumulates on top of the sheets, thus reducing soil temperature
- The effective depth is about the top 10 cm.
- not as effective on perennial weeds, bulbous weeds or weed seeds with hard seed coats
- effectiveness depends of light intensity and the amount of daylight during the treatment period
- may enhance germination and growth if the soil temperature does not reach sub-lethal levels
- Rips and tears can form in the plastic sheets, which will reduce the effectiveness of solarization.
- may yield a large amount of plastic waste. Biodegradable plastic sheets are available but may not last with repeated use.
- not effective on north-facing slopes or areas where there is inadequate light exposure

Frequency and timing

- Typical treatment times range from 4 to 14 weeks depending on the direction of the sheets. The difference is because the north-south sheets will heat up significantly more than those placed in the east-west direction because of the angle of solar radiation during sunrise and sunset.
- Repeated solarization of a site can supress native and overall biodiversity, therefore, frequency should be monitored.

2.6 Prescribed burns

Fire is a natural component of the boreal forest and much of the vegetation in this ecosystem has adapted to fire disturbances. Properly managed fires (prescribed burning) have been used for vegetation management, either as a site preparation treatment before planting or for the management of non-native invasive species covering large areas of land. This short-term vegetation management technique can also promote the natural regeneration of native species, improve the growth and yield of forests, manage pests (including insects, fungi and weeds), control disease, increase flowering (of some plants), and improve seedling establishment.

Mode of action

Managed fires can be used to control pests (including weeds, insects and pathogens) over large areas while promoting the natural regeneration of native species.

Advantages

- an effective pre-treatment for herbicide application
- Fire may promote the growth of some native grasses and forbs as well as some tree and shrub species (where present) with deep root systems.
- enhances the establishment of fire-adapted species such as jack pine and lodgepole pine, if cones are present on site
- Burning can release nutrients from old plant growth.
- removes and/or reduces the forest floor organic layers necessary for seedbeds to create microsites
- accelerates mineralization rates in soils and increases the concentration of cations and anions (or nutrients) available for plant uptake

Limitations

- Effectiveness depends on the intensity and duration of the fire.
- may not be effective on some undesirable grasses (i.e. reed canary grass and smooth brome)
- may even stimulate additional stem production and lead to grass dominance, unless the fire burns through the entire sod layer
- higher costs for fuel and equipment than what is required for herbicide application
- releases GHG emissions
- Higher liability costs are due to accidental fire damage and require qualified fire managers and containment strategies, especially in drier climates.
- seasonal limitations (i.e. fire bans)

Fire may promote the growth of some native grasses and forbs as well as some tree and shrub species (where present) with deep root systems.

Frequency and timing

- The effectiveness of this technique depends on several variables that control the intensity and duration of the fire, as well as on the timing of the application.
- Important variables to consider prior to application include relative humidity, air temperature and wind speed. Burning should not occur if the conditions may lead to fire spreading outside of the controlled area (i.e. relative humidity is less than 20%, air temperature is greater than 27°C, and/or wind speeds exceed 30 km/hr).
- one-time application (may not be used on an annual basis because of the lack of fuel for burning)

3. Chemical and biological controls

There are several chemical and biological means to control and eliminate undesirable vegetation. This chapter provides an overview of these controls, along with the associated advantages, limitations, application frequencies and timing for each control method.

It is important to note that the most effective vegetation management plan is to avoid the presence of undesirable vegetation by establishing desirable vegetation. To determine if vegetation management is required, conduct a vegetation assessment and then apply an integrated control strategy (chemical, biological and mechanical) to meet the overarching objectives of achieving the end-use goal and attaining reclamation certification where required.

All chemical and biological control products should be used only in accordance with product label instruction to ensure efficacy and regulatory compliance.

3.1 Herbicides

Herbicide is a highly effective and efficient chemical control used to manage undesirable vegetation. Herbicide application must be completed by personnel with a pesticide applicator certificate. Herbicides are typically applied under two strategies: either prior to planting (chemical site preparation) or after tree seedlings are planted (tending or release).

Timing is a critical aspect of herbicide use. The best time to control weeds depends on several variables including weed emergence timing, weed densities, the competitive ability of weeds compared to seedlings, and environmental factors.

Herbicides also vary widely in their impact on plant species. A select number of active ingredients in herbicides are registered for use in reclamation for a forested ecosystem (Table 2). Thus, it is imperative to understand and select the herbicides that are most suited to control the undesirable plant species among desirable plants. Herbicides with glyphosate are non-selective and are typically used before planting. However, depending on differences in the onset of seasonal dormancy between coniferous and deciduous trees and native herbaceous species, other herbicides can be used to control undesirable grass and broadleaf species.

To reduce the risk to environmental and human health, several parameters and operational practices should be considered when applying herbicide. First, the half-life or persistence of herbicides is critical because herbicide carryover in soil can have a negative impact on desirable plants. The width of buffer zones to sensitive areas (i.e. surface water bodies) is also critical to protect environmental health. Other common strategies to employ include

- signage
- carefully managing herbicide concentrations to ensure efficacy but limit excessive losses
- spraying with appropriate application practices (i.e. nozzles, spray pressure, height of application)
- optimal weather conditions (no wind, cool temperature) to optimize targeting and reduce the potential drift of herbicides to adjacent areas

. . . it is imperative to understand and select the herbicides that are most suited to control the undesirable plant species among desirable plants.

Mode of action
Herbicides are chemicals used to eliminate undesirable plants, retard their growth and selectively alter plant cover without injuring desirable plants. Table 2 summarizes common active ingredients used in reclamation along with their mode of action, selectivity, controls and application options.

Table 2. Common active ingredients used in reclamation

Herbicide group	Mode of action	Active ingredient	Selective to[1]	Effectively controls[2]	Application options
2	ALS/AHAS inhibitors*. These chemicals block the normal function of ALS/AHS, which is essential in protein synthesis.	Imazapyr	Non-selective	Broadleaf weeds, shrubs, grasses and trees	Foliar (not aerial)
		Metsulfuron	Grasses	Broadleaf weeds, trees	Foliar (not aerial)
4	Synthetic auxins. These chemicals disrupt plant cell growth in the newly forming stems and leaves. They affect protein synthesis and normal cell division, causing stem distortion, leaf cupping and eventually death.	2, 4-D	Grasses	Broadleaf weeds, brush, trees	Foliar (including aerial)
		Aminocyclopyrachlor	Grasses	Broadleaf weeds, brush	Foliar (including aerial)
		Aminopyralid	Grasses	Broadleaf weeds, brush	Foliar (including aerial)
		Clopyralid	Grasses	Broadleaf weeds, brush	Foliar (including aerial)
		Dicamba	Grasses	Broadleaf weeds, shrubs	Foliar (including aerial)
		MCPA	Grasses	Broadleaf weeds	Foliar (including aerial)
		Picloram	Grasses	Broadleaf weeds, shrubs	Foliar (including aerial)
		Triclopyr	Grasses	Broadleaf weeds, brush and deciduous trees	Foliar (including aerial)
5	A systemic herbicide readily absorbed through the roots and foliage and translocated upward. Inhibits photosynthesis at photosystem II.	Hexazinone	Non-selective	Broadleaf weeds, grasses	Foliar (not aerial)
		Simazine	Non-selective	Broadleaf weeds, grasses	Foliar (including aerial)
7	Inhibition of photosynthesis at photosystem II.	Linuron	Deciduous trees, some grasses	Broadleaf weeds	Foliar, soil
9	Inhibitors of EPSP* synthase. These chemicals inhibit the protein synthesis.	Glyphosate	Non-selective	Broadleaf weeds, grasses, brush	Foliar (including aerial)
29	Inhibits cellulose biosynthesis.	Indaziflam	Grasses, trees	Broadleaf weeds and grasses	Foliar (not aerial)

Note: Herbicides are classified into groups based on their chemical family, active ingredients and modes of action.

*ALS = acetolactate synthase, AHAS = acetohydroxyacid synthase, EPSP = 5-enolpyruvylshikimate-3-phosphate synthase

[1] Selective to means the herbicide will not damage or injure the noted species.

[2] Effective control means the herbicide will give a minimum of two growing seasons of top growth control to the noted species.

Foliar application techniques relate to applying herbicides to the leaves of the plants. Delivery approaches range from aerial spraying to localized spot spraying. To minimize the effect on the surrounding vegetation, one of the goals of herbicide treatment should be to minimize the area of treatment while effectively controlling for undesirable species. It is important to note that plants may develop a resistance to herbicide following repeated herbicide application of the same group (ASRD, 2004). Therefore, an integrated vegetation management plan that uses several other controls (i.e. mechanical and/or cultural controls) in addition to herbicide is necessary to avoid plant adaptation to the chemicals.

For guidelines on herbicide use in forestry, herbicide selection, application rate, timing and restrictions, users should consult the *Forest Management Herbicide Reference Manual* and the most current *Crop Protection* guide (www.agriculture.alberta.ca/bluebook). Off-label use (not following product label use instruction) of any herbicide is not recommended, although a minor use permit maybe granted through Alberta Agriculture and Forestry under certain scenarios if deemed appropriate by minor-use coordinators.

Advantages

- highly cost-effective method to rapidly suppress weeds
- A wide range of herbicides is available (non-selective, selective to broad spectrum herbicides) that can provide adequate selective weed control.
- highly efficient and feasible to do in all scales (spot spraying in small patches to a tractor-pulled sprayer to aerial spraying for large areas)
- New herbicides tend to have low or no toxicity to the environment and human health, short residence time and lower concentration in active ingredients.
- Aerial application is not limited by the physical conditions of the site (uneven terrain, rockiness, trees).
- Some herbicides have residual activity to help control the weed population in the following years.
- Low rates of herbicide application on non-desirable plants can suppress certain species and alter community dominance, even if the non-desirable plants are not eliminated.
- Herbicide application can be used in conjunction with mechanical or biological control measures in an integrated vegetation management plan.

To minimize the effect on the surrounding vegetation, one of the goals of herbicide treatment should be to minimize the area of treatment while effectively controlling for undesirable species.

Limitations

- Herbicide spraying must be completed by individuals with pesticide applicator certificate.
- Herbicide-resistant weeds may develop after prolonged application of the same herbicide group.
- Some active ingredients and surfactants in the herbicides may impact soil microorganisms.
- cannot be used in or near riparian areas or aquatic environments
- The efficacy of herbicide depends on environmental conditions (rainfast requirements – length of time for the herbicide to dry or to be absorbed by plant tissues so that it will still be effective after rainfall or irrigation).
- Application of herbicide should be done under calm conditions to ensure little to no drift.
- Herbicide residue or carryover can have a phytotoxic effect on desirable species.

- Follow-up applications over multiple years may be required to obtain total weed eradication.

- Herbicide application may reduce species richness by creating plant community niches.

- Some herbicide efficacy and carryover may vary depending on the soil organic matter content of the soil.

- Some First Nations communities have communicated that the use of herbicides leads to the insufficient protection of wild plants for food, medicine and ceremonial purposes and also limits the sustainable development of non-timber forest products (for example, mushrooms and blueberries).

- Public opinion and perception of risks associated with herbicide use may require additional signage, public outreach or stakeholder engagement.

The result is a reduced population of a targeted non-native species over time.

Frequency and timing

- Herbicide applications are typically done before planting as part of site preparation activities or after planting, as needed.

- For maximum control, herbicide application should be done in early spring (i.e. May) for species that are early growers or early summer (June) during the late rosette, bolting or budding stage. Sometimes a second application is done in the fall to control the second flush of weeds.

- Spraying should occur prior to seed production to help deplete the seed bank in the soil and control undesirable annual species.

3.2 Biological control

Biological control includes the introduction of insects, bacteria or fungus to attack, infect and destroy a specific invasive, non-native species. These natural predators can include either non-self-sustaining (e.g. sterile males, biological chemicals or pathogens) or self-sustaining (populations that can reproduce) organisms. Typically, biological control agents must be host-specific to prevent adverse effects on non-target organisms; in some cases, feeding on closely related plant species is permitted. The result is a reduced population of a targeted non-native species over time.

The most commonly used biological control is the release of insects for invasive weed control. This can include seed head feeding, seed feeding, root-mining, foliar feeding, stem mining and gall-forming insects. The use of biological agents as a weed management control in reclamation is not widely practiced because biological control agents may present a risk to the environment by potentially being pests or carriers of pests. Furthermore, the efficacy of some of these control agents in a northern boreal setting may require additional validation.

Under the *Plant Protection Act* governed by the Canadian Food Inspection Agency (CFIA), the import, handling and release of biological agents are strictly regulated. Before a biological agent can be released into the Canadian environment for the first time, a petition and information on the safety of the organism must be filed with CFIA. A list of approved biological control agents from commercial sources on the CFIA website is exempt from the petition process (*inspection.gc.ca/plants/plant-pests-invasive-species/directives/imports/d-12-02/appendix-1/eng/1433209372739/1433209373489*). A list of tested biological control agents previously approved for use in Canada is provided in Table 3.

Table 3. Biological control agents

Plant species	Category	Biological control agents	Description	Application timing and rates
Canada thistle	Noxious	*Rhinocyllus conicus*	Seed feeding beetle	Spring (200 individuals)
		Urophora cardui	Stem gall-forming fly	Spring (50–100 individuals)
		Hadroplontus litura	Leaf and stem feeding beetle	Summer (200 individuals)
Dalmatian toadflax	Noxious	*Mecinus janthinus*	Stem mining beetle	Spring/mid-summer
		Rhinusa neta	Seed head feeding beetle	Late spring
Diffuse knapweed	Prohibited Noxious	*Agapeta zoegana*	Root feeding moth	Transfer as larvae, late fall/spring
		Cyphocleonus achates	Root feeding beetle	Late summer (50–100 individuals)
		Larinus minutus	Seed head feeding beetle	Summer (200 individuals)
		Larinus obtusus	Seed head feeding beetle	Summer (200 individuals)
		Metzneria paucipunctella	Seed head feeding moth	Spring; transfer infected plants
		Pterolonche inspersa	Root feeding moth	Spring; transfer infected plants
		Spehnoptera jugoslavica	Root feeding beetle	Summer (50–200 individuals)
		Urophora affinis	Seed feeding fly	Spring; transfer infected plants
		Urophora quadrifasciata	Seed feeding fly	Spring; transfer infected plants
Hound's tongue	Noxious	*Mogulones crucifer*	Root feeding beetle	April to May; wet-dry vacuum
Leafy spurge	Noxious	*Aphthona cyparissiae*	Root feeding flea beetle	Mid-summer (200–300 individuals)
Marsh thistle	Prohibited Noxious	*Rhinocyllus conicus*	Seed feeding beetle	Spring (200 individuals)
Meadow knapweed	Prohibited Noxious	*Agapeta zoegana*	Root feeding moth	Transfer as larvae, late fall/spring
		Cyphocleonus achates	Root feeding beetle	Late summer (50–100 individuals)
		Larinus obtusus	Seed feeding beetle	Summer (200 individuals)
		Metzneria paucinpunctella	Seed feeding moth	Summer (200 individuals)
		Urophora quadrifasciata	Seed feeding fly	Spring; transfer infected plants
Nodding thistle	Prohibited Noxious	*Rhinocyllus conicus*	Seed feeding beetle	Spring (200 individuals)
Plumeless thistle	Prohibited Noxious	*Rhinocyllus conicus*	Seed feeding beetle	Spring (200 individuals)
Purple loosestrife	Prohibited Noxious	*Galerucella calmariensis*	Foliar feeding beetle	Spring, summer (100–200 individuals)
		Galerucella pusilla	Foliar feeding beetle	Spring, summer (100–200 individuals)
		Hylobius transversovitaatus	Root feeding beetle	Mid-late summer (100–200 individuals)
		Nanophyes marmoatus	Flower feeding beetle	Summer (100–200 individuals)
Russian knapweed	Prohibited Noxious	*Aulacidea acroptilonica*	Gall wasp	Spring; transfer infected plants
		Jaapiella invannikovi	Gall fly	Spring; transfer infected plants
		Subanguina picridis	Nematode	Transfer to soil in fall
Scentless chamomile	Noxious	*Omphalapion hookeria*	Seed head feeding beetle	Spring/late summer (200 individuals)
		Micoplontus edentulous	Stem feeding beetle	Spring (100–200 individuals)
		Rhopalomyia tripleurospermi	Gall fly	Spring (50–100 individuals)

Table 3. Biological control agents (continued)

Plant species	Category	Biological control agents	Description	Application timing and rates
Spotted knapweed	Prohibited Noxious	*Agapeta zoegana*	Root feeding moth	Transfer as larvae, late fall/spring
		Cyphocleonus achates	Root feeding beetle	Late summer (50–100 individuals)
		Larinus minutus	Seed feeding beetle	Summer (200 individuals)
		Larinus obtusus	Seed feeding beetle	Summer (200 individuals)
		Metzneria paucipunctella	Seed feeding moth	Spring; transfer infected plants
		Pterolonche inspersa	Root feeding moth	Spring; transfer infected plants
		Sphenoptera jugoslavica	Root feeding beetle	Summer (50–200 individuals)
		Urophora affinis	Seed feeding fly	Spring; transfer infected plants
		Urophora quadrifasciata	Seed feeding fly	Spring; transfer infected plants
Tansy ragwort	Prohibited Noxious	*Botanophila seneciella*	Seed feeding fly	Early spring; maggots in sand
		Cochylis atricapitana	Root crown feeding moth	Transfer larvae; spring
		Longitarsus jacobaeae	Root feeding flea beetle	Late summer/fall (200 individuals)
		Tyria jacobaeae	Foliar feeding moth	Transfer larvae; growing season
Yellow toadflax	Noxious	*Mecinus janthinus*	Stem mining beetle	Spring/mid-summer
		Rhinusa neta	Seed head feeding beetle	Late spring
		Eteobalea seratella	Stem feeding moth	Mid-summer

Note:
- The table includes application timing and rates approved for use in Canada to control invasive plants commonly found in Alberta.
- "Prohibited Noxious" weeds must be destroyed, and "Noxious" weeds must be controlled. The table does not include biological control agents that are not permitted by the Canada Food Inspection Agency, have not been approved for establishment (based on sustained populations) and are currently under study.

Mode of action

Using specific insects or biological control agents to reduce the weed population by destroying developing seeds or by damaging leaves or flower heads

Advantages

- can be used to selectively control specific weed population on-site, depending on their similarities to the desirable species
- low environmental impact
- are not limited by the physical conditions of the site (uneven terrain, rockiness, trees)
- Once established, long-term management and monitoring can be cost-effective, permanent and self-sustaining.

Limitations

- limited to smaller areas
- can be expensive depending on the selection of biological control agent
- Efficacy and persistence may be limited because of various factors (i.e. presence of other antagonistic pests, climate).
- Biological control agents may require testing to prove effectiveness, risk and benefits. Approval and additional on-going monitoring may be requested by Alberta Environment and Parks and the CFIA (*Plant Protection Act*).
- Biological control agents are often difficult to obtain for use and are not currently available for all invasive plant species. Many species approved for use in the United States are not approved for use in Canada.
- There is uncertainty around the level of control achieved because of a lack of predator-prey systems for imported species, in addition to recent climatic changes.
- Agents can take from 2 to 10 years to become established enough to damage target plants.
- Several agents may be required to make a measureable impact on invasive plant vigour and population.

- Specialized equipment and expertise are required for the transportation, release, distribution and monitoring of biological control agents. Therefore, the cost is higher than for other controls.

- There is uncertainty about whether biological control agents will impact native plants and fauna because some agents do cause non-target damage to desirable species.

Frequency and timing

- The application time and rates of applicable biological control agents are listed in Table 3.

3.3 Soil fumigation

Soil fumigation is typically used as part of site preparation prior to planting or seeding as a chemical method of controlling pre-emergent weeds. This technique is often implemented for smaller and confined areas that are away from sensitive areas (i.e. surface water bodies). The technique is ideal for soils borrowed from sites that are known to contain a high volume of undesirable seeds in the seed bank.

Mode of action

Soil fumigation involves incorporating liquid solutions or granules into the soil during the soil reconstruction stage (before planting) to eliminate weeds. The chemical added to the soil will be decomposed by microbes and produce gaseous compounds such as methyl-isothiocyanate. The gases will be transported throughout the soil where they impact the resident weed. Several factors affect the efficacy of soil fumigants (Table 4). Because of the combination of conditions required for success, it is worthwhile to evaluate the efficacy of soil fumigants in the northern boreal region. Soil fumigants available for use in Canada are listed in Table 5. Similar to pesticide application, a pesticide applicator certificate is required for soil fumigation.

Table 4. Factors affecting soil fumigation

Factor	Explanation	Recommendations for use
Soil texture	• Fine-textured soils (silts and clays) restrict gas diffusion because of smaller pore spaces and discontinuity among the pores.	• Use on coarse-textured soils
Soil moisture	• Moisture is required for gas diffusion. However, too much soil moisture can dilute the concentration of gases and restrict the movement within the soil pores.	• Soils should be moist. • Fumigate in the spring or fall when it is easier to achieve ideal soil moisture levels.
Soil temperature	• Increased temperature improves water solubility and gas diffusion. • Increased temperature increases fumigant degradation rate because of higher biological activity.	• The ideal soil temperature is ~13 to 15.5°C. • Fumigate in the spring or fall when soils are warm.
Organic matter content	• Organic matter content reduces the ability for soil fumigation to be successful and results in increased adsorption and absorption and less soil-air diffusion (which is required for success). • Too much organic debris can inactivate fumigants.	• Remove organic debris on top of the soil prior to application. • Minimize using fumigation on soil that has high organic matter content (greater than 10%).
Soil microbiota	• Biologically active soil will accelerate fumigant biodegradation.	• Apply fumigant concentration based on target species and label rates.
Chemical application concentration and timing	• Efficacy is correlated to chemical concentration at the time of application.	• Calculate and apply a biologically effective concentration (based on concentration and exposure time). • Do not plant or seed for 14 to 20 days after application (more than 20 days if the soil is cold and wet).
Chemical application technique	• Shallow soil application can result in loss of fumigant to the air. • Covering soil with tarps can improve fumigation effects.	• If possible, use polyethylene tarp after application. • Till the soil 6 to 8 inches deep, 7 to 10 days before treatment and again immediately after treatment. • Apply liquid fumigants by using hand or power-operated sprayers or injectors. • Apply granules fumigants with a fertilizer spreader.

Table 5. Soil fumigants

Fumigant	Name	Formulation	Supplier
Metham sodium	Vapam	solution	Nufarm
Dazomet	Basamid	granule	Dow Chemical Company
Chloropicrin	Chloropicrin	solution	Drexel Chemical Company
1, 3-dichloropropene	Telone II	solution	Dow Agrosciences

Note: These fumigants are available in Canada for weed control.

Advantages

- non-selective control for weeds and weed seeds in the soil
- may provide control for plant-feeding nematodes, soil pathogens or insects

Limitations

- Soil fumigation may be completed only by individuals with a pesticide applicator certificate.
- Soil fumigation may negatively impact soil microorganisms, which may in turn impact long-term soil health.
- cannot be used around riparian areas or sensitive areas
- Some fumigant residue or carryover can be poisonous to desirable species. It is necessary to follow appropriate wait times after application to plant or seed.
- The efficacy of soil fumigation depends on soil texture, moisture, temperature, organic matter content, microbial activity, type of fumigant, rate and application technique (Table 4).
- may not be appropriate for all soil types
- limited to small areas
- only used for site preparation, not after planting

Frequency and timing

- applied once, during site preparation
- apply under ideal soil moisture and temperature conditions (Table 4)

3.4 Steam treatment

Steam is an effective physical tool for eradicating undesirable plants and seeds that accumulate on or near the soil surface. Steam treatment has no residual effects and does not require chemicals or biological agents. Therefore, it may be appropriate for localized, environmentally sensitive areas.

Mode of action

When applied directly to plants, high-temperature steam (55 to 95°C) can be effective in eliminating plants. Weed seeds and propagules in the soil can also be controlled by steam at temperatures greater than 50°C. The effectiveness of steam treatments depends on several local site factors including soil texture, soil moisture and soil temperature (Table 6).

Table 6. Efficacy of steam treatment

Factors	The effect	Recommendations for use
Soil texture	• Pore space distribution in soils affects steam dispersion. • Fine-textured soils (silts and clays) restrict steam diffusion because of smaller pore spaces and discontinuity among pores.	• Use on coarse-textured soils.
Soil moisture	• Too much soil moisture can restrict the movement of steam within the soil pores.	• Soil should be drier to reduce the use of hot water and energy required for treatment. • Apply the treatment in the drier summer months and during the middle of the afternoon.
Soil temperature	• Increased temperature reduces application time to reach the target temperature.	• Apply the treatment in the summer months when soils are warmest or complete fumigation in the afternoon when the soil temperature is highest.
Treatment application and technique	• Can provide 80 to 99% control of annual weed species if soil temperatures are raised to 70°C or higher. • Efficacy is correlated to soil temperature and steam exposure time at the time of application.	• Application time can range from 1 to 12 seconds per plant to reach the target temperature. • Adjust the steam intensity based on the specific weed species, the size and existing field conditions.

Advantages

- It is a non-chemical method for weed eradication, suitable for sensitive areas, protected habitats, permeable soils, buffer zones and near open water bodies.
- Although steam treatment is non-selective, the applicator can be set manually to target specific non-desirable plant species in the field.
- Application does not require a pesticide applicator licence.
- Successfully controls annual weeds, and repeated applications can eliminate well-established perennial plants.

Limitations

- The efficacy of this technique depends on the soil temperature, texture and moisture and the type of weed species (Table 6).
- more effective on weed seeds that have a water-permeable coat and a palea (an inner leaf attached to the seed) than on those with water-impermeable seed coats
- Perennial weeds may re-sprout, requiring multiple treatments for complete eradication.
- not an efficient method for large areas
- The effective depth is limited, hence, below ground propagules may be protected and unaffected, resulting in continued weed growth.
- Steam treatment is costly and energy-intensive; it also requires specialized equipment and personnel with appropriate training.

Frequency and timing

- One to four applications per year are required for routine site maintenance (in the summer months) or four to six times per year for well-established perennial plants.
- Time the treatment application with seed germination and production cycles.
- Operating steam of more than 50°C with speeds from 0.3 to 0.5 km/hr have been observed to kill weed propagules and achieving 90% weed seed mortality. Increasing the temperature (greater than 100°C) or the duration (longer than 12 seconds per plant) of the treatment does increase mortality rates.

4. Cultural controls

Overview

Cultural control methods present an alternative approach to vegetation management relative to the more conventional methods of chemical and mechanical control.

Conventional approaches to reforestation often lead to sites being dominated by non-native species, which compete with and often significantly suppress and delay growth of desirable, native species. Establishment of both native woody and herbaceous species is a key objective of reclamation of industrial sites. Conventional reforestation practices, however, often lead to spatially inconsistent establishment of required native understory species and does not guarantee that target plant densities will meet reclamation requirements. Consequently, it often takes considerable time to achieve desirable native species cover and considerable expense to manage non-native species.

The goal of cultural control methods is to simultaneously manage undesirable vegetation while promoting establishment of desirable native vegetation. An early and dense cover of native woody and/or herbaceous species is assumed to prevent establishment or reduce the abundance of undesirable, often non-native species. Therefore, cultural controls methods target the intentional addition of desirable species, both woody and herbaceous, to a site.

Cultural control methods include seeding and planting herbaceous and woody species in a variety of methods. This chapter explains three methods:

- cover cropping
- hitchhiker planting
- cluster planting

These methods can also be used for stockpile management, i.e. planting and/or seeding of desirable species to enhance establishment of native vegetation and to prevent weed establishment. Some of the presented methods are still experimental and have not been proven over a wide scale or for a long term in land reclamation; this is indicated within each method overview.

4.1. Cover cropping

Cover cropping involves establishing (usually by seed) one or more native herbaceous species concurrently with planted trees and shrubs. The purpose of cover cropping is to rapidly occupy physical space (both above-ground and below ground) with desirable species while concurrently preventing the establishment of non-native, undesirable species.

Also, the cover crop species should be selected and deployed at a density that will not negatively affect the growth of target tree species. Some studies have suggested that removing invasive species is not a viable option. Instead, developing a competitive plant community is more effective at preventing the invasion of non-native species. The term “cover cropping” in this guidebook does not refer to the traditional cover crop of annual and/or agronomic species.

The goal of cultural control methods is to simultaneously manage undesirable vegetation while promoting establishment of desirable native vegetation.

Selecting suitable cover crop species (and developing suitable seed deployment methods and protocols) is critical and will include species that can rapidly occupy a site without competing for above-ground or below ground resources with planted target species. Native herbaceous species of potential use in reclamation include those that fix nitrogen or require very few nutrients (e.g. fireweed, goldenrod, asters and sedges), which are abundant following natural disturbances.

Cover crops are typically broadcast-seeded on the soil surface or hydro-seeded in a slurry. However, establishment rates for many native forb species from broadcast seeding are very low. To be successful, native forb cover crops need to reach high densities that dominate significant portions of a reclamation site. Moreover, few native species are presently commercially available; for many others, wild seed collections have to be mounted.

Figure 3. Cover crop of native grasses

Note: shown in September following surface broadcasting in late June on a sandy reclamation site

It is necessary to develop improved mechanisms for deploying native forb seed (e.g. improve direct seeding) for reclamation, which is currently being explored at the NAIT Boreal Research Institute.

Mode of action

Cover crops are often established prior to planting trees and/or shrubs on-site but these activities can be done concurrently if cover crop deployment does not use machinery. Seed-based deployment is the most common strategy for grasses. However, successful establishment of non-grass species may require deployment by other strategies (such as planting or further manipulations to seeds) because direct seeding has generally been less successful to date.

Advantages

- suppresses undesirable and invasive weed species
- protects planted trees from extreme soil and air temperatures compared to bare soil
- reduces the potential of soil erosion
- reduced insect damage through direct protection (e.g. visually hiding trees) or indirect protection of trees (e.g. providing an alternate, readily available food source) from herbaceous species

Figure 4. Test plot of Indian paintbrush *(Castellja miniata)*

Note: sown as a cover crop species

- potential cost reductions for future treatments (i.e. fewer vegetation management treatments required)
- increases the amount of spring moisture that is available because the herbaceous canopy catches snow

Limitations

- Cover crops may compete with planted trees for site resources (e.g. soil moisture and nutrients) and thus may increase mortality and reduce growth of target species.
- Cover crops may not suppress invasive weed species if they are deployed at incorrect rates.
- risk of introducing weed species, especially if non-certified seed mixes are used
- risk of seedling predation and girdling by mice and voles that are attracted by the seed production of grasses
- may require two planting programs with different equipment needs – trees and cover crop

Figure 5. Native herbaceous plant *(Solidago candensis)*

(a) **(b)**

Note: planted as nursery stock seedling to be a cover crop species: (a) first growing season, (b) second growing season

4.2. Hitchhiker planting

Hitchhiker planting is a term that describes the production of multiple species within the same nursery stock container. This is a form of companion planting, which is a type of polyculture and is the practice of growing different species in the same space.

Hitchhiker planting of multiple species, both overstorey and understorey species, emulates natural mixed-species forest ecosystems and addresses the reclamation objective of establishing diverse communities of native forest plants.

In reclamation, the objective of hitchhiker planting is to improve the growth of both plants (e.g. a tree and native forb) and to locally displace undesirable vegetation by occupying physical space around the woody species. Facilitative (i.e. positive) interactions between two companion plants can be direct (e.g. increasing nutrient availability) or indirect (e.g. displacing undesirable species).

Selecting suitable plant species is critical and will depend on the management objectives, e.g. suppression of competitive weeds.

Common facilitative interactions found in mixed-species systems include

- modification of the microclimate
- increases in the availability of nutrients (e.g. by avoiding nutrient leaching)
- increases in the availability of water (e.g. reduced evaporation)
- indirect reduction of the competitive effects from undesirable species

Figure 6. Hitchhiker stock, first season

Note: white spruce (*Picea glauca*) in the first growing season with fireweed (*Chamerion angustifolium*)

Hence, gardeners and horticultural nurseries often use companion planting to aid in pest management, increase poor soil nitrogen by using green manure, increase height growth or suppress weeds, etc.

However, testing potential applications of the hitchhiker planting concept in forest land reclamation is still in its pilot stages. Preliminary results from recent field studies being conducted at the NAIT Boreal Research Institute show promise but further testing is required. Hitchhiker planting will be best suited within an integrated weed management program (see the "Integrated vegetation management" chapter).

Selecting suitable plant species is critical and will depend on the management objectives, e.g. suppression of competitive weeds. Factors that will influence the interactions between two plants include their respective resource requirements, size and age.

Figure 7. Hitchhiker stock, second and third season

(a) **(b)**

Note: white spruce (*Picea glauca*) in the (a) second and (b) third growing season with showy aster (*Aster conspicuous*)

Mode of action

Hitchhiker planting consists of growing a native woody species with a native understory species in the same nursery container.

Advantages

- provides shade for later successional, shade-tolerant woody species
- occupies physical space, thus suppressing undesirable species (i.e. non-native or invasive species)
- potentially reduces planting costs by growing and out-planting two target species at the same time
- potential use of a companion plant by the Indigenous community

Limitations:

- Companion plants may compete for resources and thus limit the growth and survival of one or both species.
- Success of companion planting strongly depends on the selection of compatible species. Knowledge of suitable species, nursery propagation and field establishment methods is limited.
- Companion planting may not be suitable for species that are difficult to propagate in a greenhouse.
- Currently, this method is not a standard nursery production practice for forestry and land reclamation. Hence it could be more costly to produce two seedling per plug in the nursery. However, field planting costs could be reduced because each plug carries multiple species that would otherwise be planted separately.

4.3. Cluster planting

Cluster planting involves the high-density planting of woody plant species in closely spaced clusters across a site. The cluster planting approach was developed in Europe for reforesting sites with adverse environmental site conditions and has been occasionally used in high elevation restoration areas and in afforestation projects. Cluster planting has recently seen renewed interest. However, there are limited field studies that can provide planting guidelines for successful establishment of trees in clusters, especially in the context of land reclamation.

On reclaimed sites, conventional planting has seen mixed results because the bare soil between planted trees is often rapidly colonized by undesirable species.

Conventional planting, as used in the forest industry, typically targets uniform spacing at rates of 1,500 to 5,000 stems/ha, e.g. low density with significant space between individuals. The range in planting densities is attributable to wide ranging starting conditions because some sites have greater expectations of natural recovery than others. Uniform spacing has the underlying goal of optimizing productivity of individual trees intended for merchantable timber harvest. Reclamation criteria, however, target the establishment of functional, native vegetation communities with less focus on merchantable timber (although this may still be an objective). On reclaimed sites, conventional planting has seen mixed results because the bare soil between planted trees is often rapidly colonized by undesirable species.

Cluster planting is an alternative approach to conventional planting methods used on reclaimed industrial sites. Cluster planting aims to establish rapid occupancy of portions of a site (i.e. high density clusters) with target native species to outcompete non-native species, within and adjacent to the planted tree clusters, during the early establishment period. Cluster planting has been shown to increase natural regeneration within the gaps between clusters as well as increase species richness in clusters, when compared to uniform planting.

Mode of action

Cluster planting is conducted by planting woody species at high densities in closely spaced groups. Localized densities (in clusters) would be close to 10,000 stems/ha, but the overall site-level density would remain 1,500 to 5,000 stems/ha.

Potential advantages

- rapid site occupancy
- faster canopy closure
- out-compete non-native and weed species and reduce the need for additional weed control methods
- potential increase in the overall plant species richness
- coarse woody material inputs (through tree mortality) that will contribute to the site during the stem exclusion phase within the clusters of trees

Limitations:

- Ultimately, not all of the planted trees within clusters will survive. They will eventually fall out of the site as the canopy develops. This result may not be desirable for some operators that would like to see every seedling planted grow into a merchantable trees.
- There are no long-term field studies available to provide planting guidelines for successful establishment of trees in clusters in a reclamation context.
- Some training will be required for planting staff to overcome traditional planting guidelines.

Figure 8. Cluster planting after two growing seasons

Note: a cluster of 10 aspen (*Populus tremuloides*) seedlings planted at 25 cm spacing after two growing seasons

Figure 9. Cluster planting after one growing season

Note: three deciduous species (Paper birch [*Betula papyrifera*], Balsam Poplar [*Populus balsamifera*] and Aspen) in a 7.5 x 7.5 m cluster with 75 cm spacing after one growing season

5. Integrated vegetation management

Integrated vegetation management (IVM) includes a combination of preventive and control practices with the goal to optimize control of undesirable species (including regulated weeds) while enhancing the establishment of desirable species.

IVM recognizes that no single method of vegetation control will be effective in controlling the high number of undesirable plant species of varying growth forms (e.g. annual versus perennial). Instead, IVM integrates several methods to increase the effectiveness of the vegetation management program and to ultimately better support reclamation objectives.

Occupying physical growing space with desirable species is an important part of IVM. This is particularly important for management techniques that disturb the soil (e.g. cultivation) because many non-native, undesirable species would readily occupy the bare soil.

IVM is best used as a management strategy from the very onset of reclamation. This chapter will illustrate examples of how IVM could be developed and used in an operational setting. Several methods will be selected as part of the IVM plan, including mechanical controls ("Mechanical controls" chapter), chemical controls ("Chemical and biological controls" chapter) and cultural controls ("Cultural controls" chapter).

Integrated vegetation management plan

Key components of an integrated vegetation management plan include the following six steps, outlined here and in Figure 10 IVM decision matrix:

1. **Prevent** weeds from becoming established (e.g. clean equipment prior to entering a site, perform regular weed inspections, and train operators to recognize weed species and understand the available treatment options).

2. **Assess** (identify and map) all undesirable and regulated species on and in direct proximity to the target site.

3. **Define management thresholds** of plant abundance for undesirable species based on species type (undesirable versus regulated weeds) and economic threshold (e.g. eradication is not necessarily the goal for all species). Thresholds will be species- and site-specific and may vary based on the species and with overall management objectives.

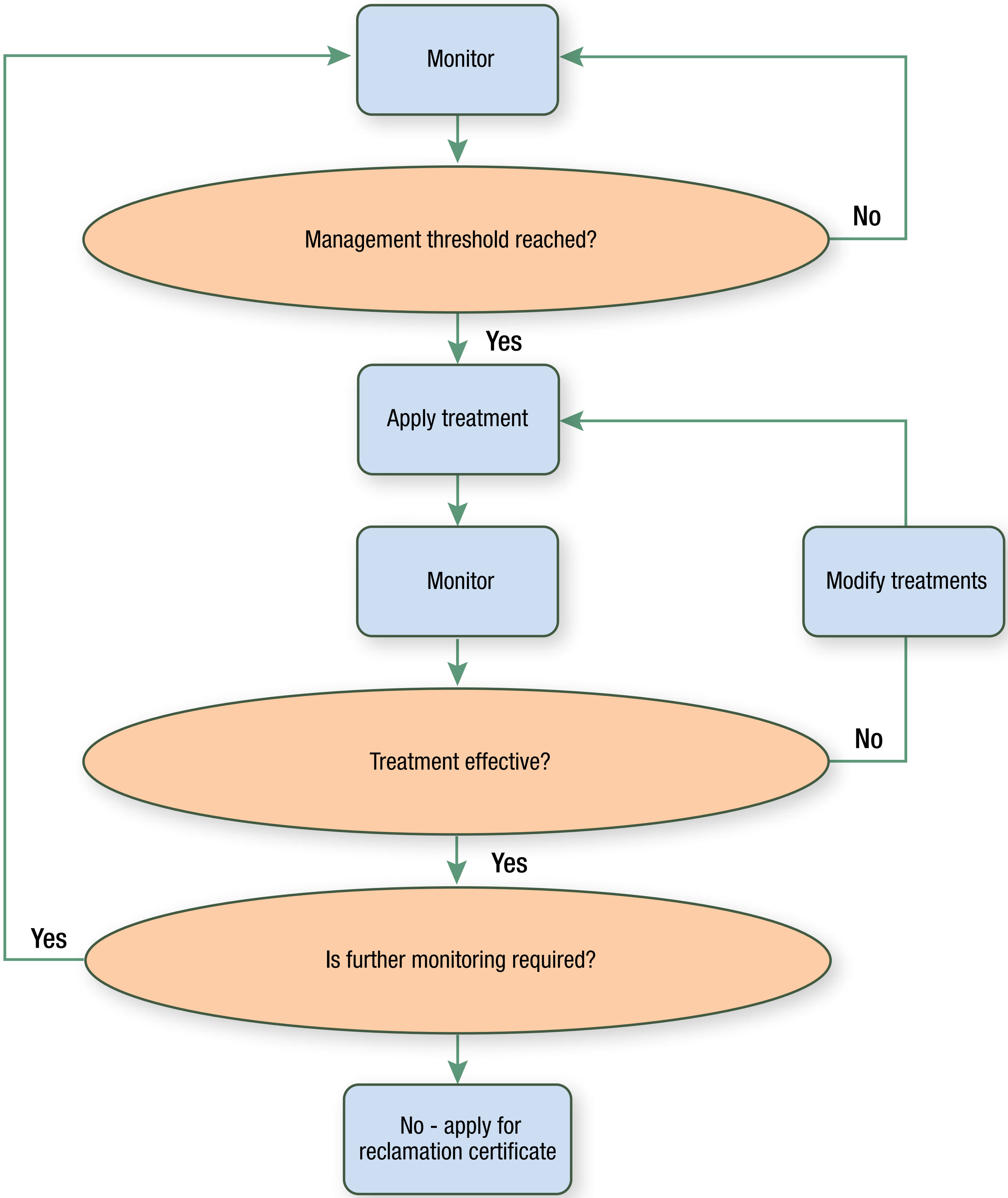
4. **Select an appropriate combination of methods** to control undesirable species to acceptable levels.

5. **Determine effective timing** for specific treatments. For example, some treatments, such as cultural controls, are most effective when used to control emergent plants as opposed to well-established plants.

6. **Monitor sites annually** to determine when management thresholds are reached (and action is required), to evaluate the effectiveness of control methods in reaching vegetation management goals and to assess whether follow-up treatments are required. Timely monitoring (including aspects of weed growth stages and locations) allows for prompt and proactive treatment interventions and can increase cost-effectiveness.

This chapter will illustrate examples of how IVM could be developed and used in an operational setting.

Figure 10. IVM decision matrix



IVM plans will often require several steps over several seasons to effectively control undesirable species and shift the plant community toward the target. The following key principles and steps should be considered when selecting treatment type and timing:

- Promptly control regulated weeds that are listed under the *Weed Control Act*; these species must be controlled regardless of their size and number. Concentrate control efforts toward species that will adversely affect your target plants. Plants that have little or no impact on target plants can be overlooked (e.g. small populations of some non-native annual species and non-native perennial species may not pose any risk to target plants). Non-native annual species include Chenopodium album, Chenopodium capitatum and Trifolium arvense. Non-native perennial species include Taraxacum officinale, Trifolium hybridum and Trifolium pretense.

- Generally, control of undesirable species is most efficient when populations are sparse (e.g. single plants) and during early growth stages (i.e. early vegetative stage) before weeds become densely established.

- Control methods are specific to the type of weed (graminoid versus forbs) and the respective growth form (annual versus biannual or perennial) and need to be selected accordingly.

- Ensure the sequence of treatments does not compromise long-term treatment effectiveness, e.g. initials treatments should not adversely affect later treatments.

- Select treatments that will minimize negative outcomes for non-target species and the environment.

- Ensure effective site preparation to control undesirable species prior to planting woody species because the latter are highly susceptible to competition with weed species during the early establishment phase.

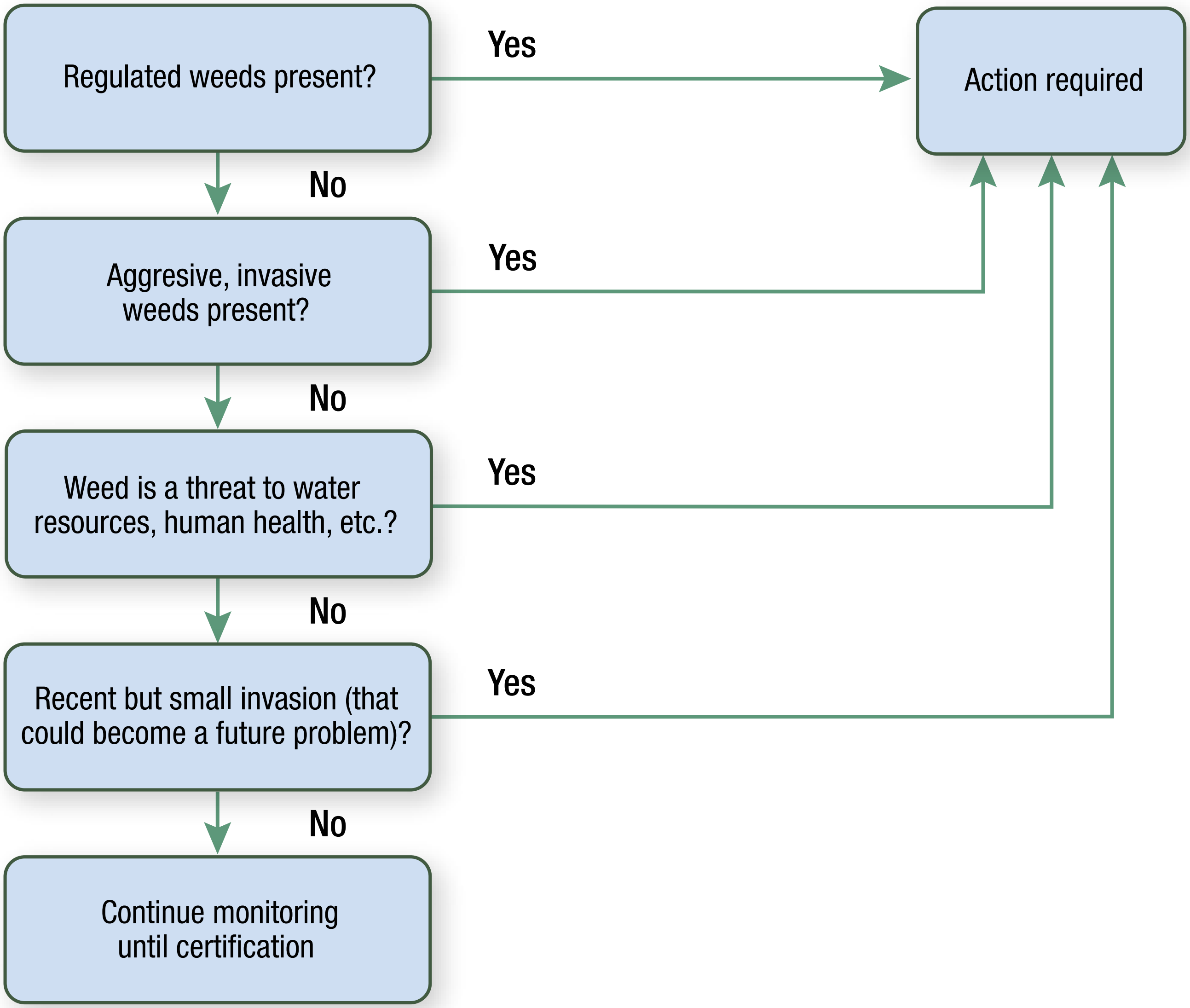
- Strive for cost-effectiveness in a treatment plan, where possible. Costs will vary with remoteness of the site, type and size of weed populations, treatment objectives and the contractor employed.

Promptly control regulated weeds that are listed under the *Weed Control Act*; these species must be controlled regardless of their size and number.

Treatment priorities

Situations that will increase the priority for treatment of a weed population are outlined in **Figure 11.**

Figure 11. IVM management priorities



Treatment example

Site conditions – This is a 5+ year old sump site that was remediated, and reclamation activities were completed over a wet summer (year 1). The primary goal for this site was to establish a native forest community. A series of vegetation management treatments were imposed on this site as part of a larger IVM plan.

Year 1 – The site was broadcast-seeded with native grasses following replacement of subsoil and topsoil. The purpose of the grass was to provide fast, early occupancy of physical space, thereby not allowing room for ingression and development of undesirable species.

Year 2 – The site was spot-sprayed to control any noxious weed species present. Because the native grasses were seeded the previous summer, they had fully developed into mature plants by the second year. A mixture of native tree and shrub seedlings was produced in a commercial nursery for planting at the site the following year.

Year 3 – The native grasses were well-established, so there was little growing space available for nursery seedlings. Consequently, the entire site was disturbed with a plow to reduce the cover volume of grass, create microsites and reduce the compaction level of the soil. Nursery seedlings were planted at a total density of 5,000 stems/ha throughout the site. Spot-application of post-emergent herbicide was used to control ingression of noxious weed species.

Year 4–6 – No additional vegetation treatments were deployed because the native grasses redeveloped over time, and the native tree and shrub species also contributed to physical occupancy of the site. The site was monitored annually and noxious weed species were spot-sprayed or hand-pulled.

Conclusion

- Because of ongoing monitoring and management, noxious weeds were never at problematic levels across the site. Early intervention (spraying by hand) and establishing other desirable vegetation kept these species from overtaking the site.

- Similarly, other undesirable species (clovers) that are common on newly reclaimed sites were not a major concern. This is because the initial establishment of native grasses immediately following reclamation resulted in the germinating clover never having an opportunity to fully develop.

- Because the use of broadcasting herbicides was limited, the planted trees and shrubs were able to grow and persist, allowing for excellent early growth and contributing to the primary objective (creating a native forest community).

The primary goal for this site was to establish a native forest community.

Figure 12. Site after the fourth growing season

Note: a site in year 6, following site plowing and nursery stock planting

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Notes