Optimizing Weed Control for Progressive Reclamation: Literature Review

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Terms

Control

To inhibit the growth or spread, or to destroy noxious weeds.

Destroy (Eradicate)

A regulatory term from the *Weed Control Regulation* meaning to kill all growing parts of prohibited noxious weeds, or to render reproductive mechanisms non-viable.

NOTE: the plain language term "eradicate" is often used in place of "destroy" in the literature and so will be used in this report.

In-situ Developments

The combination of the central processing facility (the Enhanced Recovery In-situ Oil Sands or Heavy Oil Processing Plant in EPEA regulatory terms) and the field production facilities (the Oil Production Site in EPEA regulatory terms).

Noxious Weed

A plant designated in accordance with the *Weed Control Regulation* as a noxious weed and includes the plant's seeds.

Nuisance Weed

A weed class from the 2001 *Weed Regulation* that is no longer regulated.

Oil Sands Operations

For the purpose of this report, oil sands mines and in-situ developments.

Pesticide

As defined in the *Environmental Protection and Enhancement Act* (EPEA), it includes a herbicide:

> (i) a substance that is intended, sold or represented for use in preventing, destroying, repelling or mitigating any insect, nematode, rodent, predatory animal, parasite, bacteria, fungus, weed or other form of plant or animal life or virus, except a virus, parasite, bacteria or fungus in living people or animals,
>
> (ii) any substance that is a pest control product within the meaning of the *Pest Control Products Act* (Canada) or is intended for use as such a pest control product,
>
> (iii) any substance that is a plant growth regulator, a defoliant or a plant desiccant,
>
> (iv) a fertilizer within the meaning of the *Fertilizers Act* (Canada) that contains a substance referred to in subclause (i), (ii) or (iii), and
>
> (v) any other substance designated as a pesticide in the regulations.

Prohibited Noxious Weed

A plant designated in accordance with the *Weed Control Regulation* as a prohibited noxious weed and includes the plants' seeds.

Restricted Weed

A weed class from the 2001 *Weed Regulation*, equivalent to Prohibited Noxious.

Undesirable Plants

Plants that are incompatible with the ecosite and may impede land manager operability and/or management or the functioning of the native plant community (according to the 2010 Wellsite Criteria for Forested Land). This may or may not be a native species or a weed species listed in the *Weed Control Regulation*.

Weed

Vegetation defined as noxious or prohibited noxious by the *Weed Control Act*, as amended.

Weed Management

For the purposes of this report, all steps taken to prevent, control or destroy weeds.

Acronyms

The following acronyms are used in this report or the cited references.

AER	Alberta Energy Regulator
Al-Pac	Alberta-Pacific Industries Inc.
AWRAC	Alberta Weed Regulatory Advisory Committee
COSIA	Canada's Oil Sands Innovation Alliance
EPEA	*Environmental Protection and Enhancement Act*
FMA	Forest Management Agreement
GIS	Geographic Information System
IAPP	Invasive Alien Plant Program
LFH	Litter, Fibric, Humic
OSE	Oil Sands Exploration
PLA	*Public Lands Act*

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

Undesirable plant species in forested lands are those that spread rapidly and either slow or hinder the establishment of target desirable vegetation through competitive exclusion (Thompson and Pitt, 2011). In mining and in-situ oil sands operations, the greater the disturbance and traffic on industrial production facilities and roads, the higher the likelihood that undesirable species spread and become established. Weed species are a provincially regulated subset of undesirable plant species.

In Alberta, there are 75 regulated weed species (46 prohibited noxious and 29 noxious) listed in the *Weed Control Regulation* (Government of Alberta, 2010a) under the *Weed Control Act* (Government of Alberta, 2008) that need to be destroyed or controlled, respectively, as undesirable species. The concern with having weeds establish is the expectation that they will (1) out-compete and displace local native grasses, forbs, shrub and tree seedlings; (2) alter natural habitats and reduce local biological diversity; (3) hybridize with native species; and (4) change local nutrient cycling, water chemistry and hydrological regimes. Alberta Environment and Sustainable Resource Development (2012) describes the concern with weeds on industrial developments as:

- Fire hazards in non-vegetated areas;
- Competition with desirable plant species;
- Economic challenges of controlling the weeds both onsite and offsite; and,
- Non-compliant with the *Weed Control Act*.

Some of these concerns are more pertinent for the White Area and may be less of a risk for the Green Area, although there is currently no comprehensive documentation to support or refute this observation. However, the general nature of the regulated weed species is that they are fast-growing, often highly competitive species, and have the ability to spread rapidly (as shown in agricultural systems).

Observations from years of field work on disturbed and reclaimed forested sites has indicated that, at least some of the weeds currently regulated by the *Weed Control Act* may pose less risk to native plant establishment, succession and ultimately reclamation success in a boreal ecosystem.

> "Natural habitats in the boreal zone have a high degree of resistance to invasion [of non-native species] compared with those of other Canadian zones, likely owing to harsh climates, low light levels, poor soil nutrient availability, low soil pH, low productivity, and dense covering of the ground by plants, especially bryophytes" (Langor et al., 2014).

The issues with continuing to manage regulated weeds, which are interpreted to be of low risk, while aiming to achieve reclamation closure include the following:

- Increased time and resources spent on weed management;
- Increased herbicide application into the environment;
- Unintentional mortality of desirable native species from accidental herbicide overspray; and,
- A delay in reclamation certification application by at least one growing season (Government of Alberta, 2013).

- "The primary environmental concern [related to herbicide application in forested areas] is with the alteration of vegetation composition, structure and successional patterns that are known to be important for the provision of habitat and the maintenance of biodiversity in general" (Alberta Sustainable Resource Development, 2004).

The overall project goal is to attempt to assess whether noxious weeds managed in the boreal forest are significantly impacting boreal succession using publically available literature, available vegetation survey data and field experience of oil sands operations practitioners. The assessment is based on risk factors of individual weed species, growth dynamics with native vegetation, and site conditions. Current regulations require operators to control or eradicate noxious or prohibited noxious weeds, respectively. Presently, this is accomplished through the use of herbicides and manual labour (e.g., hand-pulling). This project aims to demonstrate whether, under certain site conditions, there is a third potential alternative – utilizing successional processes and forest vegetation development to better address some of the issues raised above.

Project objectives are

1. To compile current information on weed status and management programs in the boreal ecosystem, for both mining and in-situ oil sands operations.
2. To determine the risk factors of the regulated weeds that have been observed in the boreal ecosystem, with this objective being addressed by:
    a. Developing fact sheets summarizing key characteristics that have historically made these species problematic: their known distribution in Alberta and tolerance, known impacts to environment, and current management options.
    b. Completing a retrospective case study on available data sets where vegetation monitoring had occurred for at least three years to examine whether noxious weeds appeared to influence the development of woody vegetation and if these species were persistent over time.
    c. Developing a risk analysis framework based on the results from the literature review and retrospective case study and with consideration of a risk analysis tool - that was developed by Alberta Agriculture and Forestry (Alberta Agriculture and Forestry, nd).
3. To determine whether the current approach to weed management (i.e., active control and eradication) of these regulated weed species is necessary in boreal reclaimed sites or if other methods could be used (i.e. monitoring).
4. To identify whether there is enough evidence to reduce the number of weeds requiring active management in the boreal ecosystem.

1.2 LITERATURE REVIEW GOALS AND OBJECTIVES

The goal of this literature review component of the overall project is to compile the current information on weed status and management programs in the boreal ecosystem, for both mining and in-situ oil sands operations, including the following:

- Regulatory Framework – Legislation, authorizations, acts and approvals that outline how weeds are to be managed in the province; ground rules for forest management; and, regulatory methods for determining risks related to weeds.

- Information Sources for Weeds and Records of Occurrence – Publicly available information sources for identifying areas of weed occurrence within the boreal ecosystem.
- Current Practices in Weed Monitoring and Management at In-situ and Mineable Oil Sands Operations – Methods, strategies, costs, site types, observations trends, and learnings.
- Key characteristics that have historically made these species problematic: their known distribution in Alberta and tolerance, known impacts to environment, and current management options.

Information is used to understand whether the current approach to weed management (i.e., active control and eradication) of these regulated weed species is necessary in boreal sites or if other methods could be used (i.e. monitoring). By summarizing this information, the review aims to provide Canada's Oil Sands Innovation Alliance (COSIA) with a comprehensive understanding of the topic area, identifying specific knowledge gaps and potential risk factors and growth patterns associated with regulated noxious and prohibited noxious weeds in reclaimed areas in the boreal region, thus setting the foundation for future recommendations for potential changes in policy regarding weed control and eradication in the Green Area.

1.3 LITERATURE REVIEW METHODOLOGY

For this review, detailed searches through multiple resources including books; conference proceedings; electronic journals; industry, government and public reports; regulatory acts, standards and guidelines; and, the Internet were completed to find literature related to the themes within the scope of weed monitoring and management in Alberta and forested areas. An emphasis was placed on the collection of literature from peer-reviewed journal articles and industrial reports, provided directly from COSIA members. Searches on the Internet included the use of general search terms encompassing Boolean and iterative search strategies to capture a broad swath of literature. Once collected, resources and abstracts were reviewed to determine whether documents met the inclusion criteria.

Direct communication with policy makers and regulators (Alberta Environment and Parks, Alberta Energy Regulator, and Alberta Agriculture and Forestry) was conducted, to identify methodologies used for determining risks associated with weeds in the Province, and general perceptions on changing the status of weeds included in the *Weed Control Act* and *Regulation* for the Green Area. Interviews with COSIA member companies (including associated environmental service providers) were additionally conducted to compile information on the current status of weed monitoring, surveying and management on reclaimed oil sands operations.

Inclusion criteria: Due to the range of topics considered within this literature review, no specific key words were required as inclusion criteria. Documents discussing topics surrounding weed-related regulations, Alberta regulated weeds and their occurrence in the boreal forest, weed management in the boreal forest, weed management for reclamation certification, Alberta weed classification, weeds and forest succession, costs associated with weed control and eradication, and risks associated with Alberta regulated weed growth and development, were included within the review. Articles and information sources were included if they did not explicitly refer to Alberta regulated weeds but considered the relationships between weed growth, forest succession, and reclamation success/reclamation of terrestrial upland systems.

Exclusion criteria: Documents that were not in English, or documents related to weed monitoring and management but outside of the scope of forest reclamation were excluded from the review. Patents and conference abstracts were excluded from all searches. No documents were excluded based on the date

of publication; however, where literature was abundant, an emphasis was placed on the collection of literature from the most recent years (2015 to 2017).

The Internet and the Google scholar search engine were used to conduct general searches of peer-reviewed publications, reports, and book sections. More specific searches were conducted using Compendex (scientific and technical engineering research), ISI Web of Science (high impact scientific articles and conference proceedings), University of Alberta Education and Research Archive (repository for University-related intellectual property, such as OSRIN technical reports), and ProQuest (Master and Doctoral theses and dissertations) databases. Relevant technical reports were gathered from the following specific organizations: Alberta Energy Regulator (AER), Alberta Environment and Parks (AEP, formerly Alberta Environment and Sustainable Resource Development), Cumulative Environmental Management Association, and InnoTech Alberta (formerly Alberta Innovates – Technology Futures, and the Alberta Research Council).

Once appropriate and applicable articles were found, citation lists were reviewed to identify any relevant literature relevant to the topic area, missed within the primary literature search. Researchers identified to have large contributions to the field of interest were queried within electronic journals to locate earlier publications.

2.0 REGULATORY FRAMEWORK

Weeds are managed provincially through the *Weed Control Act* (Government of Alberta, 2008) and the *Weed Control Regulation* (Government of Alberta, 2010a). Environmental operating approvals issued by the Alberta Energy Regulator pursuant to the *Environmental Protection and Enhancement Act* (Government of Alberta, 2000a), and dispositions issued pursuant to the *Public Lands Act* (Government of Alberta, 2000b) may also contain weed management provisions. Classifications and characteristics of weeds included in the *Weed Control Act* and *Regulation* include the following (Posey, 2012):

Prohibited Noxious

Non-native species with currently restricted or local distribution in Alberta that present risks of spreading and causing significant economic or ecological impact. Examples: nodding thistle (*Carduus nutans*), yellow clematis (*Clematis tangutica*).

Non-native species not currently established in Alberta but are present in neighbouring jurisdictions, cause significant economic or ecological impact in those jurisdictions, and are well adapted to Alberta conditions. Examples: yellow star-thistle (*Centaurea solstitialis*), salt-cedar (*Tamarix ramosissima*).

Noxious

Non-native species already widely distributed in the province that have significant ecological or economic impact, and that can spread easily from existing infestations onto adjoining properties (e.g., those with windblown seed or creeping roots). Examples: Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia esula*).

Non-native species that are relatively easy to control when a few individuals are found but that can easily get out of hand if left uncontrolled, and can have significant impacts when abundant. Example: scentless chamomile (*Tripleurospermum perforatum*).

Not Regulated

Exotic species that have been long established in Alberta and have not shown significant ecological or economic impact. Examples: knawel (*Scleranthus annuus*), cypress spurge (*Euphorbia cyparissias*).

Exotic species that are found virtually everywhere in the province, and control to prevent further spread is not likely to have a significant impact on its current distribution. Examples: stinkweed (*Thlaspi arvense*), wild buckwheat (*Polygonum convolvulus*).

2.1 LEGISLATION

2.1.1 *Weed Control Act*

The *Weed Control Act* (Government of Alberta, 2008), administered by the provincial Department of Agriculture and Forestry, prescribes specific management rules for two categories of regulated weeds (prohibited noxious and noxious) in Alberta. The distinction between the categories can be summarized as:

Alberta's prohibited noxious category includes 49 invasive plants that are problems in neighbouring provinces and states but are not yet established in Alberta. The 26 noxious weeds are already found within Alberta, but can still be controlled (Guenther, 2011).

The *Weed Control Act* empowers the Minister of Agriculture and Forestry to declare plants as "prohibited noxious" or "noxious", but does not provide guidance or criteria for listing plant species into the two different categories (McClay, 2013).

In a previous version of the *Weed Control Act* (Government of Alberta, 2000c) and its related *Weed Regulation* (Government of Alberta, 2001) there were three categories of weeds (restricted, noxious and nuisance); these old categories were replaced in 2010 by the amended *Weed Control Act* and the new *Weed Control Regulation* (Government of Alberta, 2010b; Kellett, 2015; Posey, 2012) – see Appendix 1 for the species currently in each category. The following quote provides insight on the rationale for dropping the nuisance weed category:

> The committee that drafted Alberta's *Weed Control Act* decided to drop the nuisance category altogether. "The main reason we got rid of the nuisance list was that in our old Act there was nothing you could do on a nuisance weed. You couldn't issue a notice on a nuisance weed. So it was just a list of very, very common weeds," explains Paul Laflamme, head of Alberta Agriculture and Rural Development's Pest Surveillance Branch (Guenther, 2011).

Key definitions and requirements in the *Weed Control Act* include:

> **1(c)**[1] "control" means
>
> (i) to inhibit the growth or spread, or
>
> (ii) to destroy;
>
> **(d)** "destroy" means
>
> (i) to kill all growing parts, or
>
> (ii) to render reproductive mechanisms non-viable;
>
> **(j)** "noxious weed" means a plant designated in accordance with the regulations as a noxious weed and includes the plant's seeds;
>
> **(m)** "prohibited noxious weed" means a plant designated in accordance with the regulations as a prohibited noxious weed and includes the plant's seeds;
>
> **2** A person shall control a noxious weed that is on land the person owns or occupies.
>
> **3** A person shall destroy a prohibited noxious weed that is on land the person owns or occupies.
>
> **4(1)** Subject to the regulations, a person shall not use or move anything that, if used or moved, might spread a noxious weed or prohibited noxious weed.

2.1.2 ***Weed Control Regulation***

The *Weed Control Regulation* (Government of Alberta, 2010a) provides authority for a municipality to change the designation of noxious weeds to prohibited noxious weeds, and to designate plants that are not listed as weeds in the *Weed Control Regulation*, through a by-law once approved by the Minister:

> **9(1)** The local authority of a municipality may designate a plant as a noxious weed or a prohibited noxious weed within the municipality by bylaw.
>
> **(2)** If the plant is designated as a noxious weed within a municipality by the Schedule, the local authority may designate it as a noxious weed or a prohibited noxious weed.

[1]Numbers and letters appearing at the start of the excerpt refer to a specific section of the referenced legislation.

(3) If the plant is designated as a prohibited noxious weed within a municipality by the Schedule, the local authority may only designate it as a prohibited noxious weed.

(4) A designation under this section is not effective unless it is approved by the Minister.

(5) The plants set out in a bylaw of a municipality are designated as noxious weeds or prohibited noxious weeds within that municipality in accordance with the bylaw.

(6) A designation as a prohibited noxious weed under this section prevails over a designation as a noxious weed under section 8.

The Regulation contains a provision designating two classes of regulated weeds: prohibited noxious weeds and noxious weeds:

8 Subject to section 9(6), the plants set out in the Schedule are designated as noxious weeds or prohibited noxious weeds in accordance with the Schedule.

The full listing of prohibited noxious weeds and noxious weeds is provided in Appendix 1 of this report.

2.1.3 **Public Lands Act**

The *Public Lands Act* (Government of Alberta, 2000b) requires disposition holders to undertake weed management:

63 A holder of a disposition shall with respect to the land contained in the holder's disposition

(a) use only first class seed that is free and clear of all noxious weeds and prohibited noxious weeds within the meaning of the *Weed Control Act*,

(b) cut, keep down and destroy all noxious weeds and prohibited noxious weeds to which the *Weed Control Act* applies,

2.1.4 **Environmental Code of Practice for Pesticides**

The Environmental Code of Practice for Pesticides (Government of Alberta, 2010c), issued pursuant to the *Environmental Protection and Enhancement Act*, provides specific details regarding the safe sales, handling, use and application of pesticides to ensure environmental protection. Pesticide applicators and other described pesticide users, pesticide services and pesticide vendors within the Province of Alberta must comply with these requirements. Section 11 of the Code provides requirements for Forest Management Pesticide Use:

11(2) A project proposal must be submitted to Alberta Sustainable Resource Development[2] for any proposed application of pesticides in a forest.

(a) A project proposal and written authorization from Alberta Sustainable Resource Development is not required for the control of noxious weeds in accordance with the *Weed Control Act*.

(b) Proposals for herbicide use must be in accordance with the *Forest Management Herbicide Reference Manual* (Alberta Sustainable Resource Development, 2004).

(3) The application of pesticides in a forest is restricted to the location, target area, pesticide, pesticide application method, pesticide application rate, and application time authorized in writing by a designated employee of Alberta Sustainable Resource Development.

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[2] Currently Alberta Agriculture and Forestry.

Section 12 of the Code provides additional conditions related to control of woody plants for roadsides, powerlines, pipelines and utility rights-of-way.

2.1.5 **Municipal Weed Designation Bylaws**

No municipal weed designation bylaws were found for the northeast boreal region.

2.2 REGULATORY AUTHORIZATIONS

Regulatory authorizations issued pursuant to the *Environmental Protection and Enhancement Act* or the *Public Lands Act* may contain provisions related to weed management, in addition to the general requirements of the *Weed Control Act*.

2.2.1 ***Environmental Protection and Enhancement Act* Approvals**

Oil sands mining approvals issued by the Alberta Energy Regulator pursuant to the *Environmental Protection and Enhancement Act* contain a single weed management provision and associated definition (Alberta Energy Regulator, 2015a)[3]:

> **1.1.2 (oooo)** "weeds" means vegetation defined as noxious or prohibited noxious by the *Weed Control Act*, as amended
>
> **3.6.20** The Reclamation Material Salvage Plan referred to in subsection 3.6.19 shall include, at a minimum, all of the following:
>
> > (d) the methods to be used to prevent and/or mitigate the presence of weeds on stockpiles;

Recent in-situ oil sands approvals contain more definitive weed management clauses (Alberta Energy Regulator, 2015b):

> **1. (bbb)** "weeds" means vegetation defined as noxious or prohibited noxious by the *Weed Control Act*, 2011, as amended;
> **6.** The topsoil stockpiles referred to in condition 5 of Schedule IX shall be:
>
> > (g) controlled for weeds.
>
> **7.** The subsoil stockpiles referred to in condition 5 of Schedule IX shall be:
>
> > (g) controlled for weeds.
>
> **39.** The approval holder shall maintain a weed control program until new vegetation is established and is self-sustaining.

2.2.2 ***Public Lands Act* Disposition Conditions**

Conditions that may be applied to public land dispositions are listed in the Master Schedule of Standards and Conditions (Government of Alberta, 2017a). The document also lists Desired Outcomes and Best Management Practices for the Vegetation component of an approval.

The majority of weed-related conditions relate to prevention (e.g., use only weed-free seed, clean vehicles), or provide a general requirement to "Manage all weeds as per the *Weed Control Act* (Condition 1101 or some variation thereof). Interestingly, there are some provisions that restrict weed management regardless of the requirements of the *Weed Control Act*, suggesting some

[3] Note that earlier approvals contain an older definition of weeds that does not reflect the removal of nuisance weeds from the *Weed Control Regulation*.

acknowledgement of the balance between control efforts and undesired impacts – for example (emphasis added):

> **1102** The Disposition Holder shall not conduct vegetation control including but not limited to mechanical mowing or brush removal during the following periods:
>
> > a) Between April 15th and August 15th within the Grassland and Parkland Natural regions except for the purpose of mowing vegetation no more than four (4) metres in width for vehicle access;
> >
> > b) Between May 1st and August 10th for all other Natural regions except for the purpose of mowing vegetation no more than four (4) metres in width for vehicle access, **notwithstanding the requirement to control weeds as per the *Weed Control Act*.**
>
> **1104** Vegetation control along pipelines is permitted to a maximum of three metres, centred on the pipeline, **notwithstanding the requirement to control weeds as per the *Weed Control Act*.**

A Desired Outcome for Vegetation is: Minimize negative effects of vegetation control activities.

Best Management Practices for Vegetation include:

> Mechanical vegetation control is the preferred form of vegetation management (trimming, cutting, mowing, etc.).
>
> Chemical control methods should be applied by spot application only.

2.3 RECLAMATION CERTIFICATION

Alberta Environment and Parks Land Policy 2015 No. 7 (Coal and Oil Sands Exploration Reclamation Requirements) states that:

> The Reclamation Criteria for Wellsite and Associated Facilities for … Forested, … and Peatlands (Wellsite Criteria) as outlined in this document are required for reclamation certification of … OSE programs (Alberta Environment and Parks, 2015).

The Reclamation Criteria for Wellsites and Associated Facilities for Peatlands (Government of Alberta, 2017b) requires that:

> Prohibited noxious and noxious weeds must be destroyed or controlled as per current provincial and municipal weed control regulations.

The Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands (Government of Alberta, 2013) contains a number of provisions related to weeds. Of particular relevance to this project:

> Ratings for noxious weeds onsite must be comparable to the control rating offsite, while no Prohibited Noxious weeds are allowed onsite.
>
> NOTE: On forested sites where weed issues arise resulting in a failure, applications can be submitted as Routine Applications provided they meet the following conditions:
> 1) The site is on Public Lands (excluding Provincial Parks and Protected Areas);
> 2) The site has met Criteria for all other parameters being assessed; but,
> 3) Fails the comparison for Controlled and/or Undesirable/Problem weeds as a result of a single source of weeds from offsite.
>
> Applications shall include data, photos, historical weed management, and supporting information clearly indicating that the weeds or invasive plants are from an offsite location and were not associated with/introduced from the operators' holdings.
>
> Persistent weeds require active management to control or eradicate, and are a barrier to the vegetation developing into the desired plant community.

NOTE: A minimum of one full growing season (including an overwintering period) is required following the use of herbicide before reassessing the weed control program and submitting a reclamation certificate application

The Cumulative Environmental Management Association developed a Criteria and Indicators Framework for Oil Sands Mine Reclamation Certification that was subsequently released by the government (Alberta Environment and Sustainable Resource Development, 2013). The Framework includes the following criteria related to weeds:

Indicator 2.5.1 Plant Community Composition – Weeds
No Prohibited Noxious weeds

The Framework also notes that an additional indicator, to be developed, would deal with other weeds through an assessment of plant community composition.

2.4 Forest Management Agreement Ground Rules

Forest Management Agreements (FMA) such as the one for Alberta-Pacific Industries Inc. (Al-Pac) in northeast Alberta (Alberta-Pacific Forest Industries Inc. and Alberta Environment and Sustainable Resource Development, 2014) require weed management "To minimize the impact of non-native, restricted, and noxious weeds, in the Green Area". In the Al-Pac FMA Ground Rule 10.2.1 states:

> **10.2.1** Forest companies shall follow Alberta's requirements (Directive 2001-06) for weed management related to timber operations (see Appendix 3).

The purpose of the *Weed Management in Forestry Operations* Directive referred to in clause 10.2.1 is "To implement effective weed management programs administered by holders of *Forests Act* dispositions engaged in forestry operations" (Alberta Sustainable Resource Development, 2001). While the policy applies only to *Forests Act* dispositions the provisions provide context for weed management in oil sands operations. The guidelines describe the four essential aspects of weed management: goals, prevention, inventory and control. The following guidelines are of particular relevance to this project:

> As some areas within which weeds are managed consist of a large land base, control throughout the entire area is not feasible. Specific areas should be targeted each year, based on priorities.
>
> Target restricted weed infestations over noxious weed infestations. Control of restricted weeds should be implemented immediately following their discovery.
>
> Target infestations in highly traveled areas over those in isolated areas, thereby limiting the threat of seeds or plant parts being translocated.
>
> Target small infestations before large ones, as it is easier to gain control of small infestations. This also applies to outlying pockets of larger infestations, which should be controlled prior to tackling the larger infestation. When dealing with a large infestation, a "contain and control" strategy (targeting outlying pockets, and/or the perimeter of the infestations) is an excellent option when resources are not available to control an entire infestation.
>
> To prevent their establishment, target weed species that are less abundant on a regional basis. When controlling infestations, target the weed species with the greatest ecological impacts.

2.5 Regulatory Methods for Determining Risks Posed by Weed Species

2.5.1 Regulatory Methods from 1980 to 2009

Previous to 2010, plant species were listed on the *Weed Control Act* through an internal decision-making process (not well documented or recorded in publically available literature). As such, the lists remained fairly consistent over time, with a focus on those species of economic importance to the agriculture industry (McClay, 2013).

2.5.2 **Regulatory Methods in 2010**

With the intent of becoming more transparent and accountable in the decision-making process, as well as to incorporate the latest knowledge on weeds and adaptive management outcomes both within and outside of Alberta, the Alberta Weed Regulatory Advisory Committee[4] (AWRAC) was formed (2009) and the *Weed Control Act* was re-opened for review (2010) (Sieusahai, 2018). At this time, it was requested that the prohibited noxious and noxious lists incorporate those species that are not only invasive in agricultural end land uses, but additionally invasive in natural ecosystems and other non-agricultural habitats (McClay, 2013). AWRAC was tasked with advising the Minister of Agriculture and Rural Development on (1) the listing of weeds, (2) issues related to weed regulation in Alberta, and (3) the development of a risk management framework and assessment tool (Government of Alberta, 2010d; McClay, 2013; Posey, 2012)[5]. The intent was to capitalize on expert knowledge through collaboration with the AWRAC to help coordinate and align provincial and national efforts on assessing terrestrial and aquatic invasive species (Government of Alberta, 2010d).

The process for redeveloping the prohibited noxious and noxious weeds list was initiated as a blank slate, and included the following steps (McClay, 2013):

- Review of introduced plant species to Alberta, British Columbia, Saskatchewan, Manitoba, Northwest Territories and Montana (owing to similar habitats and potential for transportation corridors) on the USDA PLANTS database – resulting in 779 species
- Flagging of plant species considered weedy within a number of government, textbook and peer-reviewed literature sources – resulting in 387 species
- Review of the reduced list by AWRAC, using the following criteria – resulting in 152 species
    - Current presence and abundance in Alberta;
    - Adaptability to Alberta climate conditions;
    - Species outside of the scope of the *Weed Control Act* (e.g., aquatic species);
    - Potential for ecological impact; and,
    - Potential for economic impact.
- Ranking of reduced list by AWRAC into the following categories, determined through consensus
    - Prohibited noxious
    - Noxious
    - Do not regulate
    - Uncertain

[4]The Alberta Weed Regulatory Advisory Committee (AWRAC) is a technical group comprised of representatives of the Association of Alberta Agriculture Fieldmen, Alberta Agriculture and Rural Development, municipal governments, Canadian Food Inspection Agency, the Landscape Alberta Nursery Trades Association, the Prairie Shelterbelt Program, the Alberta Invasive Plants Council, the Alberta Native Plants Council, and some unaffiliated individuals (Posey, 2012). No herbicide companies are represented in AWRAC (Sieusahai, 2018).

[5]The AWRAC is not part of the Alberta Government, but solely make recommendations to the Alberta Government. The Minister of Agriculture and Forestry looks at the AWRAC recommendations and if determined to have merit, the Alberta Government conducts a more detailed assessment (Sieusahai, 2018).

- Review of species categorized as 'uncertain' or species that resulted in disagreement by outside consultants, including a summary of the following for each plant species
    - Biology;
    - Distribution;
    - Likely impacts;
    - Current status in Alberta; and,
    - Recommended regulatory category (i.e., prohibited noxious, noxious, or do not regulate).

It is important to note that a full risk assessment was not conducted on each individual species due to time and cost constraints; species with insufficient information were not regulated but placed on a watch list for periodic review (McClay, 2013).

2.5.3 **Regulatory Methods Post-2010**

The intent of the *Weed Control Regulation* was to keep the weeds lists under continual review to permit adaptive management as new information becomes available and invasive plant problems evolve (McClay, 2013). As such, AWRAC recommended amendments to the Schedules in the *Weed Control Regulation* to be made on a semi-regular basis (Alberta Invasive Species Council, 2014). Most recently, AWRAC hired a subcontractor to compile risk assessment information on each of the 75 regulated species. The types of information gathered for each species will include: general description; current distribution; regulatory status in Alberta and adjacent provinces as well as plant ecology (i.e., habitat requirements, description of life cycle, environmental tolerances, distribution vectors, herbivory, and symbiotic and parasitic relationships). Additionally, ecological and economic risks and benefits for each species will be reviewed, this will include new information and research conducted examining the change in colonization of these regulated species and impacts observed in ecosystem diversity, stability as well as on end land uses. Lastly, any new information on detection and control methods will be amassed for review.

AWRAC has additionally developed a process that allows outside individuals, companies or organizations to propose changes to the species currently listed under the *Weed Control Regulation* (McClay, 2013). Any large recognized organization can make a recommendation, provided there is reasonable rationale for a change in the regulation (e.g., data to verify changes in ecological impact of a specific species in Alberta) (Sieusahai, 2018). Recommendations can include the following:

- Elevated status (e.g., Noxious to Prohibited Noxious),
- De-elevated status (e.g., Prohibited Noxious to Noxious), or
- Removal.

Moving forward, the Alberta Government would hold public consultation to seek opinions and support from non-government organizations and other stakeholders on future changes to the *Weed Control Act* as well as to enhance public awareness, and better develop and distribute information on invasive plant species (Government of Alberta, 2010b; Sieusahai, 2018).

Despite the vast difference between the White and Green Areas of the province, the weed regulations are the same across the province. When asked if weeds should be managed differently in the Green and White Areas, the Alberta Pest Regulatory Officer interviewed was intrigued and noted the comment as an area of interest and further exploration. If desired, it was requested that the issue be brought up through stakeholder engagement and public consultation as a potential area to explore further

(Sieusahai, 2018). Once raised, it is possible for the *Weed Control Regulation* to be re-opened for review provided there is enough (*undefined*) push by the public or ***industry***.

3.0 PUBLIC RECORDS OF WEED OCCURRENCE IN THE BOREAL FOREST

3.1 WEED OCCURRENCE

3.1.1 **Alberta**

Weed surveys in Alberta were initiated by Agriculture and Agri-Food Canada in the 1970s, with the original intent of documenting shifts in weed species over time. The surveys were also intended to relate weed composition to changes in weed management practices (Alberta Agriculture and Forestry, 2007). More recently, these surveys have expanded to document the abundance and distribution of persistent weed species. The last weed survey in Alberta was completed in 2017 by Agriculture and Agri-Food Canada; however, only the results from the 2010 weed survey are currently public. The 2010 survey did not include much of northern Alberta, but rather encompassed the dryland agricultural areas and provided results for several additional regions including the Athabasca Plain Ecodistrict and Beaver River Plain Ecodistrict within the Boreal Transition Ecoregion, encompassing Bonnyville, Lac La Biche and Athabasca counties (Leeson et al., 2010). Three weed species identified in annual crops within the two Ecodistricts are Canada thistle (ranked 6th in Athabasca with 22% frequency of occurrence and 2nd in Beaver River with 52% occurrence), scentless chamomile (16th in Athabasca at 9% and 21st in Beaver River at 3.9%) (AAAF 2016) and perennial sow thistle (12th in Athabasca at 17.7% and 9th in Beaver River at 15.5%) (Leeson et al., 2010).

McClay et al. (2004) summarized the occurrences of invasive plant species in the Green Area from inventories by ASRD staff, 1998 – 2003. The most frequent noxious weed species occurrences were:

Scentless chamomile	1,429
Canada thistle	969
Tall buttercup	685
Perennial sow-thistle	561
Oxeye daisy	476
Common tansy	269

In 2009, the Regional Municipality of Wood Buffalo noted the presence of the same noxious weeds within the Municipality (Regional Municipality of Wood Buffalo, 2009).

The Alberta Biodiversity Monitoring Institute has prepared species profiles for scentless chamomile (Alberta Biodiversity Monitoring Institute, 2018a) and perennial sow thistle (Alberta Biodiversity Monitoring Institute, 2018b) based on surveys from 2003 to 2016 in forested sites. These profiles predict species relative abundance, and examine species responses to vegetation and soil types, and human footprint in Alberta.

Fragmented dry boreal mixed-wood areas within north-central Alberta were surveyed by Gignac and Dale (2007). Over 20 non-native species were recorded. The most abundant weed species were predominantly nuisance weeds, including smooth brome (*Bromus inermis*), alfalfa (*Medicago sativa*), dandelion (*Taraxacum officinale*) and alsike clover (*Trifolium hybridum*). The three noxious weeds identified included Canada thistle, cleavers (*Galium aparine*), and perennial sow thistle.

A survey of grass and sedge meadows within Wood Buffalo National Park has also recorded the presence of Canada thistle and perennial sow thistle (Hamilton, 2004; Wein et al., 1992).

From the limited information available on weed occurrence within the boreal forest, it can be noted that the predominant regulated weeds are all noxious, including:

- Canada thistle;
- Perennial sow thistle;
- Scentless chamomile; and,
- Oxeye daisy.

Prohibited noxious weeds are not predominant in terms of their presence or cover, based on the publically available information.

Alberta does not have a centralized spatial database to record and monitor weed and/or invasive plant distribution (McClay, 2013); however, Alberta Agriculture and Forestry is in the process of developing a map of regulated species found across the province. This will collate observational information compiled by the surveys and inspections conducted by the Association of Alberta Agriculture Fieldmen into a GIS format. Currently, only the occurrence of regulated weed species is tabulated. Additional technical information on each of the regulated prohibited noxious (Alberta Agriculture and Forestry, 2013) and noxious weeds (Alberta Agriculture and Forestry, 2015) is available. Some information on weed occurrence and distribution is based on informal or anecdotal information, which has been identified in some cases, to significantly underestimate weed levels (McClay, 2013).

3.1.2 **Saskatchewan**

There is very limited weed survey data available from Saskatchewan. The last weed survey was completed during the 2014-2015 growing season by Agriculture and Agri-Food Canada. They conducted this survey in 2,242 fields across the province, categorized by both type of crop grown and ecodistrict (i.e., mixed grassland, moist mixed grassland, aspen parkland and boreal transition). For the boreal transition ecodistrict, the top three weed species, evaluated based on relative abundance and frequency, included predominantly nuisance weeds, including wild buckwheat (*Polygonum convolvulus*), shepherd's purse (*Capsella bursa pastoris*), and narrow-leaved hawk's-beard (*Crepis tectorum*) (Leeson, 2014).

An earlier survey conducted by Sumners and Archibald (2007) within mature mixedwood boreal forest in northern Saskatchewan also noted the predominance of non-native nuisance species dandelion and Canada bluegrass (*Poa compressa*). In comparison to native species, their presence was recorded as 'low in density'.

3.1.3 **British Columbia**

The most abundant non-native species within the boreal zone located in British Columbia, accounting for around 95% of the non-native plant records within the Invasive Alien Plant Program (IAPP)[6] database include Canada thistle, scentless chamomile, oxeye daisy, perennial sow thistle, caraway (*Carum carvi*), bull thistle (*Cirsium vulgare*), hawkweed (*Hieracium* spp.), and common tansy (Langor et al., 2014; ISC 2014a; ISC 2014b).

There are currently three prohibited noxious hawkweed species within Alberta, including orange hawkweed, mouse-ear hawkweed and meadow hawkweed. The type of hawkweed reported was not described further. Bull thistle is not a regulated weed in Alberta.

[6] See https://www.for.gov.bc.ca/hra/plants/application.htm

4.0 THE NATURE OF WEED GROWTH IN FOREST ECOSYSTEMS

This section is a compilation of theories and observations on weed growth, development and infestation in forest ecosystems from both in-field monitoring and experimental research and development, found in the publically available literature.

4.1 THEORY OF COMPETITION AND FOREST MANAGEMENT

In a developing forest stand, tree growth is influenced by both inter- and intra-specific competition; the level of which can depend on the stage of stand development (Nambiar and Sands, 1993).

Competition for Nutrients and Water

At juvenile stages of stand development, weeds have the capacity to compete with tree seedlings for space, water and nutrients owing to the volume of area occupied by their root systems within the upper soil horizons (Herrero and Gutierrez, 2006; Langor et al., 2014). However, trees have the capacity to develop deep and/or far reaching lateral roots, giving them an advantage over shallow rooted herbaceous weeds over the long term (Bell et al., 2000). Trees that are genetically well-adapted to dry climates have the capacity to quickly allocate more resources to belowground biomass production, additionally reducing competition for resources in the upper soil horizons (Herrero and Gutierrez, 2006). Therefore, the ability of a tree to compete with weeds for nutrients and water is directly related to tree root morphology (i.e., the size and geometry of the root system), physiology of the tree (with respect to resource allocation), and location of the roots within the soil profile (e.g., upper or lower soil horizons and/or beyond the range of the weed population).

Competition for Light

If weeds are present at reforested sites and have the opportunity to outgrow newly planted and/or juvenile trees in terms of height, the shade provided by weeds during early tree growth stages may affect ongoing tree growth and development (Herrero and Gutierrez, 2006). While jack pine and black spruce seedlings require full sunlight to reach their maximum height potential, white spruce seedlings only require 45 to 100% full sunlight (Bell et al., 2000; MacDonald and Thompson, 2003). Stemwood productivity, measured through stem diameter, is most impacted by the absence of light, as it is directly related to leaf area and the amount of intercepted radiation (or light availability) (MacDonald and Thompson, 2003; Nambiar and Sands, 1993). Therefore, it is anticipated that light occlusion by weeds may inhibit aboveground biomass production by common boreal tree species, increasing the success of competition by weeds. Conversely, if trees have the opportunity to grow to heights greater than that of surrounding weeds, the light occlusion by trees will increase tree competition with understory herbaceous species (Bell et al., 2000). This can lead to the competitive displacement of weeds.

4.2 THEORY OF DRIVERS AND PASSENGERS

Emerging research has debated whether invasive plants represent the sole cause of ecosystem change, through a reduction in native plant diversity (Bauer, 2012; Davis, 2003; Gurevitch and Padilla, 2004; Sax and Gaines, 2008). Research focusing on species competition has shown the potential for dominant non-native species to lower resource availability by having either (1) a superior competitive ability, or (2) increased population numbers, thereby suppressing, constraining or excluding other desirable native species (MacDougall and Turkington, 2005). However, it has been noted that relationships between the success of invasion and competition by dominant non-native species have not been confirmed experimentally for many species. In addition, competition is not always the primary limiting factor impacting native species growth and development post-disturbance (MacDougall and Turkington, 2005). Other confounding factors can include methods of soil salvage and storage, methods of soil

reconstruction, soil quality, on-going vegetation management, etc. As such, the literature has categorized invasive non-native species into the following descriptors, to better understand the methods in which they can impact community change (Bauer, 2012; Didham et al., 2005; Grarock et al., 2013; Hart and Larson, 2014; MacDougall and Turkington, 2005; Masters, 2014; Wilson and Pinno, 2013):

Drivers: Drivers are the primary cause of ecosystem alteration and the decline in native plant species within the community[7]. Drivers prevent recolonization by native species and alter successional trajectories; coinciding changes can include the modification of soil biotic communities, directly impacting ecosystem function (e.g., nutrient cycling, soil structure, soil biota) (Langor et al., 2016). In the long-term, communities dominant in drivers are considered to be of low-diversity.

Back-seat Drivers: Back-seat drivers require an ecosystem change or disruption to first occur (e.g., over-browsing, forest fires, etc.), which allows them to establish and further contribute to changes in ecosystem structure or function (e.g., production of allelochemicals that suppress native plant growth), including the decline of native species and/or species diversity. Back-seat drivers are considered to require the most comprehensive management strategies to recover native species, including the correction of both the initial ecosystem disruption and removal of the established invaders.

Passengers: Invasive plants in this group benefit from or take advantage of disturbance and/or changes in the landscape, to which native plants are not well adapted (e.g., compacted soils, change in soil moisture content or nutrient availability, etc.). Passengers are described as 'symptoms of disturbance'. As such, changes to the landscape are the primary cause that leads to an initial decline in native plant species within the community, not the ingress of invasive plants. Passengers often represent annuals, short-lived perennials, or early-successional species.

Facilitative Passengers: Passengers that facilitate native species or native ecosystem services (e.g., erosion control in the absence of ground cover). These invasive plant species may maintain ecosystem function while native plants are suppressed.

4.3 THEORY OF WEED EXISTENCE IN THE BOREAL FOREST

Non-native species tend to be those that are less tolerant of, or intolerant of, shading (Medvecka et al., 2018). Therefore, it has been theorized that non-native invasive plants do not proliferate within mature forest stands with closed canopies owing to insufficient resources required for growth and development, including light and available nutrients (Brothers and Spingarn, 1992; Honnay et al., 2002; Langor et al., 2014). Mature trees have also been reported to influence both the chemical and structural properties of the soil and residing understory vegetation creating conditions that are not ideal for non-native plant species (Barbier et al., 2008).

Evidence to support this theory includes vegetation survey data collected from mature forest ecosystems spread across Canada. When surveyed, invasive non-native species were absent from the following (Langor et al., 2014):

- Boreal forest stands in Quebec (De Granpre et al., 2003);

[7] Plant extinctions caused solely by competition with invasive species have been reported as rare (Bauer, 2012; Davis, 2003; Gurevitch and Padilla, 2004; Sax and Gaines, 2008). Roughly 10% of invasive species, reported globally, have had the capacity to alter ecosystem function in their new environment (Richardson et al., 2000).

- Uncut aspen stands in northwestern Quebec and northeastern Ontario (Haeussler et al., 2007);
- The understory of western balsam fir and paper birch forests in southwestern Quebec (Legare et al., 2001);
- Unharvested white spruce and aspen forests in northern Saskatchewan (Peltzer et al., 2000); and,
- Undisturbed northern boreal forests in Wood Buffalo National Park (Wein et al., 1992).

The factors that typically facilitate invasion include: disturbance, fragmentation, propagule pressure, and availability of nutrients (Medveck et al., 2018). In the absence of these factors, the intensity of invasion is likely to be low.

Within old-growth forest fragments, Honnay et al. (2002) noted that non-native invasive species predominantly exist at forest edges; in a monitoring study, non-native species did not extend past 1 m into disturbed forested area. Previous weed surveys in the Athabasca boreal forest have also noted that non-native nuisance and noxious weed species richness was greatest in fragmented forested areas (typically between 5 to 20 m from the fragmented edges) (Gignac and Dale, 2007). Conversely, very low non-native species richness was observed more than 30 m from the fragmented edges (Gignac and Dale, 2007). This further corroborates the theory that a mature forested environment does not support the continued growth and development of non-native species.

5.0 WEED MONITORING AND MANAGEMENT AT IN-SITU AND MINEABLE OIL SANDS OPERATIONS IN THE BOREAL FOREST

This section is a summary of information pertaining to weed management and monitoring at oil sands in-situ and mine sites in the boreal forest. The information was obtained predominantly through industry reports, and anecdotal evidence through interviews with both industry vegetation management specialists and environmental consultants (Alberta Environment and Sustainable Resource Development, 2012; Alberta Sustainable Resource Development, 2001, 2004; ALCES Alberta Historical Landuse and Landscape Data Library, 2012; Bradley, 2003; British Columbia Ministry of Forests, 2010; Burke, 2018; Campbell, 1990; Fabel, 2000; Girard, 2018; Langor et al., 2014; Malik and Vanden Born, 1986; McClay et al., 2004; McDonald, 2017; Paragon, 2017; Smreciu, 2018; Stackhouse, 2018; Trefy, 2018; Vassov, 2018; Wells, 2018; Wittenberg and Cock, 2001).

5.1 OCCURRENCE AND BEHAVIOR OF WEEDS ON IN-SITU AND MINE SITES

5.1.1 **Predominant Weeds Observed on In-Situ and Mine Sites**

The predominant noxious weeds identified across multiple mine and in-situ sites within the boreal forest, in varying population sizes, include the following (Burke, 2018; Girard, 2018; McDonald, 2017; Paragon, 2017; Smreciu, 2018; Vassov, 2018; Wells, 2018):

- Perennial sow thistle (*Sonchus arvensis*)
- Scentless chamomile (*Tripleurospermum inodorum*)
- Canada thistle (*Cirsium arvense*)
- Common tansy (*Tanacetum vulgare*)
- Oxeye daisy (*Leucanthemum vulgare*)
- Tall buttercup (*Ranunculus acris*)
- Hound's-tongue (*Cynoglossum officinale*)
- Yellow toadflax (*Linaria vulgaris*)
- White cockle (*Silene latifolia*)
- Field bindweed (*Convolvulus arvensis*)

Of these, perennial sow thistle, scentless chamomile, Canada thistle and common tansy are managed for the most as they have been found to be the most frequent, abundant and prolific across sites (Burke, 2018; Paragon, 2017; Wells, 2018). Those that require the most effort and cost for control include Canada thistle and common tansy (Wells, 2018). White cockle has been managed the least, because it is minimally found throughout the region (Burke, 2018). Fact sheets describing the characteristics and distribution in the boreal of the top four species are provided in Appendix 2. A brief summary of information pertaining to the occurrence, behavior, dispersal, habitat and management of the predominant noxious species (Table 1), less common noxious and prohibited noxious species (Table 2) and nuisance agronomic species (Table 3) on in situ and mine sites in the boreal forest is provided below.

Table 1. Information pertaining to the occurrence, behaviour, dispersal, habitat, and management of predominant noxious weeds on in situ and mine sites in the boreal forest.

Weed Species	Classification	Nature of Occurrences on In situ/Mine Sites	Degree and Cost of Management	Observed Behaviour	Dispersal	Habitat	Weed Management Intensity and Forest Succession
Perennial sow thistle (*Sonchus arvensis*)	Noxious	Frequent, abundant and prolific across sites (predominant weed species)	Highly managed; cost unknown	Foliage cover not dense, not aggressive with native species, specialist on poor sites	Unlikely to spread far from current locations, relatively contained to non-ideal growth conditions	Poor sites (low soil nutrients, harsh conditions)	May not require management as competition with native vegetation tends to diminish its population
Scentless chamomile (*Tripleuro-spermum inodorum*)	Noxious	Frequent, abundant and prolific across sites (predominant weed species)	Highly managed; cost unknown	A single plant can produce up to half a million seeds, seeds drop roughly 1 to 2 inches from the plant	Localized within a small area; soil seed bank often rich with scentless chamomile; equipment and machinery	Roadsides	Does not cause delays in tree development, with the exception of early stages when infestations are dense
Canada thistle (*Cirsium arvense*)	Noxious	Frequent, abundant and prolific across sites (predominant weed species)	High cost and effort for management	Wind-blown seed, produces large quantity of seed, somewhat shade tolerant once established	Wind dispersion; presence in the soil seed bank; equipment and machinery	Bare soil, established plants can survive in forest understory, grows with grass communities when established before or at same time as grass species	Grows quickly within grass dominated communities both are establishing at the same time; conduct two consecutive years of Canada thistle treatment before planting
Common tansy (*Tanacetum vulgare*)	Noxious	Frequent, abundant and prolific across sites (predominant weed species)	High cost and effort for management	Quickly establishes deep roots, produces large quantity of wind-blown seed	Widespread across mine sites; wind dispersion; potential for the soil seed bank to be rich with common tansy; equipment and machinery; upstream untreated infestations near the Athabasca River	Forest edges, near open water bodies	Growth inhibited by light, does not compete well with established vegetation; keeping populations at low density until trees mature is important in avoiding delays in canopy closure

Table 2. Information pertaining to the occurrence, behaviour, dispersal, and management of less common noxious and prohibited noxious weeds found on in situ and mine sites in the boreal forest.

Weed Species	Classification	Nature of Occurrences on In situ/Mine Sites	Degree and Cost of Management	Observed Behaviour	Dispersal	Weed Management Intensity and Forest Succession
Oxeye daisy (*Leucanthemum vulgare*)	Noxious	Individual occurrences	No information provided	No information provided	For weed species, regardless of classification, equipment and machinery, inadequate stockpile management, and wind, water, and fauna (depending on seed type) are typical dispersal mechanisms on mines and in situ sites	For weed species that have not yet established a patch or stand, regardless of classification, infestations are limited within developing forests as maturing native vegetation can outcompete weeds; newly reclaimed forests are more vulnerable to weeds than mature forests; openings in the forest present an opportunity for weed invasion due to persistence in the soil seed bank
Tall buttercup (*Ranunculus acris*)	Noxious	Individual occurrences	No information provided	No information provided		
Hound's-tongue (*Cynoglossum officinale*)	Noxious	Individual occurrences	No information provided	No information provided		
Yellow toadflax (*Linaria vulgaris*)	Noxious	Individual occurrences	No information provided	No information provided		
White cockle (*Silene latifolia*)	Noxious	Not commonly found	Not highly managed; cost unknown	No information provided		
Field bindweed (*Convolvulus arvensis*)	Noxious	Individual occurrences	No information provided	No information provided		
Leafy spurge (*Euphorbia esula*)	Noxious	Syncrude mines	No information provided	Lacks shade tolerance (not found in tree stands), survives in aggressive grass communities and often found at the edges of tree lines		
Purple loosestrife (*Lythrum salicaria*)	Prohibited noxious	Syncrude boat launch (one occurrence)	Plants were hand-pulled and were no longer observed in the same area nor along further extents of the shoreline	No information provided		
Russian knapweed (*Thaponticum repens*)	Prohibited noxious	Imperial Kearl mine site (one occurrence)	Plants were hand pulled and not observed again	No information provided		

Table 3. Information pertaining to the occurrence, behaviour, dispersal, habitat, and management of escaped agronomic and nuisance species creating vegetation management challenges on in situ and mine sites in the boreal forest.

Weed Species	Classification	Nature of Occurrences on In situ/Mine Sites	Degree and Cost of Management	Behaviour	Dispersal	Habitat
Non-native forages: White sweet clover (*Melilotus albus*), yellow sweet clover (*Melilotus officinalis*), and alfalfa (*Medicago sativa*), orchard grass (*Dactylis glomerata*), timothy (*Phleum pratense*)	Escaped agronomic and nuisance species	Tend to occur more frequently and in higher abundance than noxious and prohibited noxious weeds	No information provided	May fix nitrogen; may create a moderating climate within the understory; often considered early successional species; aggressive growth; propagation by seed or creeping roots; drought and cold tolerant; seed can persist in soils with excessive surface moisture	Introduced via approved seed mixes for highways (approved for highways, not permitted on mines); equipment and machinery,	Disturbed habitats where resources are available but competition limited (e.g., roads, fence lines, well sites, grazing areas, waste areas, riparian zones, and natural areas)
Wild buckwheat (*Polygonum convolvulus*)	Escaped agronomic and nuisance species	Tends to occur more frequently and in higher abundance than noxious and prohibited noxious weeds	Must be controlled due to aggressive growth	Vine-like growth, wraps around trees and native vegetation creating a blanket	Thought to occur naturally in soil seed bank, not the result of other natural transport vectors or equipment and machinery	Sandy soil

5.2 CURRENT WEED MANAGEMENT STRATEGIES

Within a developing forest on reclaimed sites, sites are continually monitored for prohibited noxious and noxious weeds. As weeds are identified, weed control programs are planned to identify best management practices that meet the needs of the species and the location (Wells, 2018). If native vegetation is growing in the area, an assessment is performed to determine whether control is necessary and if it might impact the desired vegetation. The costs and benefits are analyzed and, in most cases, the least impactful methods are employed. In special cases, where the risk arising from management is too high or deemed relatively low, management may not occur, or management may be deferred (Burke, 2018). Weed populations that have yet to establish a patch or stand in developing forested sites, have been observed to be outcompeted by native vegetation and may just be monitored with time. As the forest matures on reclaimed sites, the natural ingress of native species increases and weeds tend to naturally diminish within the plant community (Burke, 2018; Smreciu, 2018).

Most of the weed control programs occur within lease boundaries, which can include active and undisturbed areas. Every time there is bare ground the seed bank has an opportunity to express itself; if it is full of weed seeds, weeds will be the first to grow and establish (Girard, 2018). If there are locations on a lease adjacent to reclamation areas that are infested with weeds, the adjacent area will usually be treated as a proactive approach to avoid spreading (Burke, 2018). Newly reclaimed forested areas with juvenile vegetation are at greatest risk; management in the first few growing seasons is most important. Planting soil immediately after placement has been found to be one of the most successful passive tactics for weed control. If left unmanaged, weeds can easily overtake areas that have been newly seeded or planted (Burke, 2018).

Areas that require the most weed management are site-specific. Some mines prefer to focus on infestations within active areas, where vehicle or equipment traffic is the highest by volume. Others focus management on reclamation or forested areas, noting that the disturbed areas with weeds are likely to be disturbed again (e.g., buried, dug up for sumps, used for infrastructure placement, etc.) (Burke, 2018). Based on Suncor's monitoring results, oil sands exploration (OSE) sites appear to require the most weed management, followed by roads at operating facilities (Wells, 2018). Active facilities (or plants) are usually last on the list as total vegetation control herbicides are typically employed to control all growth around facilities (fire hazard) (Burke, 2018). Therefore, minimal weed growth is found.

A number of control methods are available to help manage weed species while continuing to support the growth and establishment of desirable species, including: chemical, physical/mechanical and biological control (Langor et al., 2014; Malik and Vanden Born, 1986). Selecting the appropriate weed management method(s) is based on the desired plant community, existing weed populations on- and off-site, site conditions and regulatory requirements. The best time to control weeds depends on a number of variables including weed emergence timing, weed densities, the competitive ability of weeds compared to seedlings, and environmental factors (Alberta Sustainable Resource Development, 2004). Glyphosate is the most commonly used herbicide for forest management in Alberta (ALCES, 2012), which is consistent with historical use across Canada (Campbell, 1990), however a variety of products are available for weed control and have been reported to be used at mine and in situ sites (Table 4). Often an integrated approach is used to increase the overall effectiveness of the weed management program to achieve the reclamation objectives. A summary of the weed control methods used for management of weeds at in situ and mine sites in the boreal forest is provided in Table 5.

Table 4. Chemical herbicides reported to have been used across mine and in situ sites (in no specific order).

Herbicide Product Trade Name	Common name; Formulation	Herbicide Group; Class; Mode of Action*	Targeted Species/ Species Group
Lontrel 360	Clopyralid; salt	Group 4; Benzoic acid; Auxin mimic[1]	Broadleaf weeds
Banvel II	Dicamba; salt	Group 4; Benzoic acid; Auxin mimic[1]	Scentless chamomile
Roundup Weathermax	Glyphosate[3]	Group 9; EPSP inhibitor	Non-selective herbicide; effective on most broadleaf and grass weeds
Milestone	Aminopyralid	Group 4; Pyridine carboxylic acid; Auxin mimic[1]	Broadleaf weeds (particularly thistle and knapweed)
Clearview	Aminopyralid (potassium salt and metsulfuron - methyl	Group 4; Pyridine carboxylic acid; Auxin mimic[1]	Broadleaf weed and shrub control
2,4-D Amine 600	2,4-D;LV ester ± amine	Group 4; Phenoxy acid/ phenoxyalkanoic acid; Auxin mimic*	Common Tansy; scentless chamomile; Broad leaf weeds
MCPA Ester/Amine 600	MCPA; 2-ethylhexyl ester	Group 4; Phenoxy acid; Auxin mimic[1]	Broadleaf weeds
Pinestick	Surfactant blend	n/a	Common Tansy; scentless chamomile
Telar XP	Chlorsulfuron	Group 2; sulfonylurea; ALS inhibitor[2]	Selective herbicide, can affect both broadleaf weeds and grasses; Common tansy
Tordon	Picloram; salt	Group 4; Phenoxy acid/ phenoxyalkanoic acid; Auxin mimic[1]	Broad spectrum control on grass and broadleaf weeds; and select control on woody species
Esplandade	Indaziflam	Cellulose biosynthesis inhibitor	Broad spectrum control on grass and broadleaf weeds
Overdrive	Sodium salt of diflufenzopyr and dicamba	Group 4; Benzoic acid; Auxin mimic[1]	Broad spectrum of broadleaf weeds
Hasten	Ethyl and methyl esters of canola oil	Surfactant used in combination with other herbicides that require an adjuvant[3]	Dependent on herbicide combined with; particularly Tordon
Gateway	Paraffinic oil	Surfactant used in combination with other herbicides that require an adjuvant	Dependent on herbicide combined with
Torpedo	Flumioxazin and pyroxasulfone;	Group 14; disrupts plant cell growth and ALS inhibitor	Broadleaf weeds such as: common lamb's quarters, red root pigweed, dandelion, kochia, etc.

Source: Burke, 2018; McDonald, 2017; Paragon, 2017; Wells, 2018; Hall et al. 1999

[1] Auxin is a plant growth regulator that controls cell enlargement and plant development through the plant life cycle

[2] ALS is a key enzyme in the synthesis of branched-chain amino acids and is located in the chloroplasts of green tissue; most active in young meristematic regions of a plant

[3] Any substance in a herbicide formulation or added to the spray tank to improve herbicidal activity or application characteristics

Table 5. Weed control methods used to manage weeds on in situ and mine sites in the boreal forest. Source: Burke, 2018; Wells, 2018; Girard, 2018.

	Chemical Methods	Physical/ Mechanical Methods	Biological Methods
Description	Herbicide application is considered one of the most effective and efficient weed control methods	Techniques that break up soil and root systems and bury, damage or destroy weeds through pulling, cutting or mowing	Establishment of upper trophic level organisms (such as insects, bacteria, or fungi) to attack, infect, and destroy a specific non-native species (Alberta Sustainable Resource Development, 2001)
Is it commonly used? And where?	Predominant control method; widespread use on in situ and mine sites; aerial spraying most common method of application in forest operations (Mihajlovich et al., 2012), hand spraying in oil sands operations	Used commonly when chemical control not feasible or not recommended in sensitive areas, near open water or for small infestations	Release of insects most common, but biological control rarely used for mines and in situ
When is it used?	Applied annually, sometimes twice in a growing season. Timing depends on a number of variables including weed emergence timing, weed densities, the competitive ability of weeds compared to seedlings, and environmental factors	Hand pulling in developing forests and within 30 m of open water, mowing used for annual weeds in fields	Depends on which plant part is attacked: e.g., seed head-feeding, seed feeding, root-mining, foliar feeding, stem mining, and gall-forming insects (B.C. Ministry of Forests, 2010; Fabel, 2000).
Species of note	• Common tansy: 2,4-D Amine 600, Telar XP, and Pinestick • Scentless chamomile: Banvel, 2-4D Amine 600, and Pinestick • Canada thistle: chemical control twice per year to limit seed production and therefore dispersion	• Common tansy and scentless chamomile: control small populations with hand pulling • Russian knapweed: hand pulling effective • Canada thistle: hand pulling effective for plants in first growing season	Not commonly used on species in boreal mines and in situ
Considerations	Must balance over spraying (damage to native plants, environmental concerns) with under spraying (ineffective weed control)	Mechanical techniques that expose soils and microsites are most effective when immediately followed by planting; hand pulling should be done prior to seed set to limit dispersal	Biological control can be non-self-sustaining (e.g., sterile males, pathogens, etc.) or self-sustaining (populations that can reproduce) (Wittenberg and Cock, 2001)

5.3 LEARNINGS AND BEST PRACTICES

5.3.1 General Control and Eradication

The early detection of prohibited noxious and noxious weeds is the standard best management practice and ultimately, the most cost-effective. A number of preventative measures can be taken by on-site staff and contractors (Alberta Environment and Sustainable Resource Development, 2012) including:

- Avoid moving equipment through infested areas;
- Washing equipment clean of soils and weeds before moving to a new site;
- Using certified seed only that is free of weeds; and,
- Seeding or planting soil stockpiles and bare soils with native species.

When prohibited noxious and noxious weeds appear within the community, prompt weed control limits the spread of infestations and cost of management; this additionally provides better growing conditions for desirable vegetation to establish. A combination of chemical and physical management is almost always the best approach because it controls all types of weeds including creeping perennials, annuals, winter annuals, etc.

Although chemicals represent an easy method of control, it is not always reliable; a one-time spray does not guarantee that an infestation will be removed from an area (Vassov, 2018). Therefore, continuous monitoring is required. However, it is important to ensure that individuals with the right skill set are selected for conducting plant identification prior to the development of a control and eradication plan; many plants are often misidentified increasing costs and harm to native vegetation (Smreciu, 2018).

Best management practices identified to date are provided in Table 6 in addition to considerations to achieve the desired results.

5.3.2 Noxious Weeds of Less Concern

The noxious weeds that may be of low risk include perennial sow thistle and scentless chamomile. Observations suggest the perennial sow thistle may not require management because it is not an aggressive species and it does not tend to spread across a site (Vassov, 2018; Wells, 2018). Although the plant appears plentiful to the eye, it does not have dense foliage. As such, it does not appear to inhibit the growth and development of other native plants. Therefore, it is considered to be of lowest priority in terms of management (Vassov, 2018; Wells, 2018). Perennial sow thistle has been observed to decrease in abundance around 5 years post-seedling planting (Wells, 2018). Others have reported that infestations disappear within 2 to 3 years once other vegetation becomes established (Girard, 2018). As such, perennial sow thistle may be a good example of a species that is on the weed list but has not been observed to cause any adverse effects on reclamation sites (Girard, 2018). If perennial sow thistle were to no longer be controlled, it would likely cut a weed control program in half, in terms of budget and time (Burke, 2018).

Since scentless chamomile seeds have not been found to spread far from the main plant, and is mainly associated with roads, it is less of a concern and existing populations tend to be localized (Girard, 2018).

Table 6. Best management practices (BMPs) for controlling weeds on in situ and mines in the boreal forest.

Best Management Practices (BMPs)	Achieving BMPs	Considerations
Prevention	• Avoid moving equipment through infested areas • Wash equipment clean of soil and weeds before moving to a new site • Use certified seed that is free of weeds • Seed soil stockpiles and bare soils with native species	• Managing stockpiles is important in preventing the spread of weeds when the stockpiled material is moved and spread on the land • Washing is difficult to enforce, especially for everyday traffic of light duty vehicles; implementation of on-site washing stations would be very time consuming and costly
Early Detection	• Weed monitoring/surveys conducted annually May through June • Monitoring often completed as part of a vegetation survey documenting location, species present, population size, vegetation health and growth stage • Incidental observations during reclamation performance surveys and from reported employee and contractor sightings in addition to direct weed surveys and vegetation community composition surveys • Agronomic nuisance species also surveyed, monitored and listed in annual reports • If weeds identified, management plans developed	• Continuous monitoring by qualified individuals required for early detection and correct species identification • A good monitoring program should include annual monitoring of all sites and soils
Integrated weed management	• Includes prevention and early detection • Combination of chemical and physical management often best for controlling different weed types • Keep weed populations small because re-disturbance of the land is likely on mine sites • Establish woody species to facilitate canopy development • Direct placement of LFH material controls weeds by providing an opportunity for native vegetation from the seed bank to establish quickly • Reclamation with peat is effective because the material is generally initially weed-free	• Specific species (determines the type of control and timing of control) • Site-dependent factors (e.g., proximity to a water body, regulations, access) • Available methods of control (e.g., chemical, physical or biological) including equipment and products • Cost of control method • Client input (e.g., approved control methods, prioritization of specific species or locations) • Previous use of controls (e.g., avoidance of using herbicides from the same group for more than 3 consecutive years) • Previous control success

6.0 SUMMARY, CONCLUSIONS AND NEXT STEPS

6.1 REGULATORY FRAMEWORK

Regulatory requirements and policy guidance for the construction, operation, reclamation and certification of oil sands operations defer to the *Weed Control Act* and *Weed Control Regulation* for management of weeds, though it is notable that the mine approval clauses are different than those for in-situ developments. Of particular note, clause 39 in recent in-situ approvals seems to suggest that pre-revegetation management can be different than post-revegetation (**39.** The approval holder shall maintain a weed control program until new vegetation is established and is self-sustaining.) Requirements and policy guidance for undesirable vegetation management on public lands in general, and within FMA areas in particular, appear to provide more flexibility and, in some instances, go so far as to say "do X … notwithstanding the requirement to control weeds as per the *Weed Control Act"*. ***This suggests an opening to initiate discussions with the regulators about flexibility in management of weeds on oil sands operations*** (i.e., confirm intent and timing of clause 39 and adopt some of the FMA-type approaches to weed management).

Given the legislated requirement to destroy prohibited noxious weeds there is likely no option to reduce management requirements for these species. With sound monitoring and ecological impact information, it is likely that there are potentially noxious weed species that should be considered for reduced or no management.

For those noxious weed species that are determined to be of low risk to the development of a reclaimed self-sustaining forest ecosystem (e.g., perennial sow thistle and scentless chamomile), industry or any large organization can request that the *Weed Control Regulation* be re-opened for review. Once opened, recommendations can be made for a change in the regulated status of individual species in a specified region.

6.2 PUBLIC RECORDS OF WEED OCCURRENCE

Few reports were found on the abundance and distribution of weed species within the boreal forest regions of Alberta, Saskatchewan and British Columbia. Aside from increased oil and gas related activities in the boreal forest, the change in crop rotation, farming practices as well as herbicide use patterns in the agricultural areas has changed the weed spectrum significantly over the past 20 years (Leeson et al., 2010). Undoubtedly, this has also had an impact on the weed spectrum in the boreal regions.

The weed survey data in the Boreal Transition Ecoregions may provide some indication of current or future risk of invasions into the Athabasca oil sands mining and in-situ areas. More specifically, there are a number of noxious and nuisance weeds reported in the Alberta Boreal Transition Ecoregion including Canada thistle, perennial sow thistle, scentless chamomile, oxeye daisy, common tansy, spreading dogbane, cleavers, and tall buttercup. In terms of weed cover, it is likely that the presence and cover of nuisance weeds is greater than that of noxious weeds, depending on the area. It is unlikely, based on the weed survey data, that noxious weeds have ingressed from Saskatchewan; however, Canada thistle, scentless chamomile, oxeye daisy, perennial sow thistle and common tansy have been reported within the boreal zone of British Columbia. As such, the most likely vector of transport is likely through transport from vehicles and equipment travelling across western Canada.

6.3 NATURE OF WEED GROWTH IN FOREST ECOSYSTEMS

It is important to distinguish between (1) the intensity of competition, and (2) the importance of competition (Herrero and Gutierrez, 2006; Nambiar and Sands, 1993). A strategic vegetation

management plan should assess the influence of a noxious weed on a native population, and then aim to suppress the influence only to the extent that it significantly interferes with the growth and development of the desired native plant (Nambiar and Sands, 1993). This requires a thorough understanding of the relative competitiveness between noxious weeds and native vegetation, how the interactions change over time, and how the ultimate species composition aligns with end land use goals (Bell et al., 2000; Cannell and Grace, 1993). If the size of the infestation is small in height and extent, it is unlikely that the weeds will have a competitive advantage over the growing trees, inhibiting tree growth and development. Alternatively, if the weeds occupy the majority of the soil surface and extend well above the height of the trees, it is likely that the weeds will have a competitive advantage over available nutrients, water and light. This can negatively impact tree growth and development.

Further research is required to identify the threshold of significant interference of light, nutrients and water as they drive forest development (Nambiar and Sands, 1993).

Passengers and facilitative passengers become replaced, over time, by diverse native communities through succession or ecological restoration, becoming subordinate in or lost from the plant community. The removal of passengers or facilitative passengers from an invaded area is not anticipated to have significant benefits for the native ecosystem; consequences include the invasion of a new species or a failure to eradicate the original invasive species of concern – ***resulting in increased and unnecessary costs for weed management***.

By understanding plant community dynamics, appropriately categorizing invasive plant behaviour can aid in separating out those that pose a threat to native plant biodiversity (Bauer, 2012), and ultimately reclamation success. This means shifting the focus away from locality of origin (i.e., native or non-native) and towards understanding impacts (Hart and Larson, 2014). If competition is not identified to be the primary limiting factor of native species growth and development, then the eradication of invasive species is anticipated to have minimal impact (MacDougall and Turkington, 2005). This presents an opportunity area for future work including:

- Understanding the structure and function of plant communities within a boreal forest environment post-reclamation, in terms of both the causes and consequences of invasion of noxious weeds;
- Identifying relationships between invasion probability, invasion success, and competitive ability of noxious weeds; and,
- Building the weight-of-evidence to support conclusions negating impacts to native systems, in terms of boreal forest succession and reclamation success.

It is expected that non-native plants exist in greater diversity and abundance within disturbed areas that have yet to be re-vegetated, at forest edges, in soil stockpiles, replaced soil seedbanks, and/or within juvenile forest communities (Gignac and Dale, 2007). As a result, it is expected that if site preparation is conducted to support native forest regeneration, and the appropriate revegetation plans are prepared and executed, reclaimed areas on the trajectory towards developing closed-canopy forest communities may not be threatened by non-native plant species. Non-native plants that are of greatest concern will likely include species that are highly adaptable in terms of their requirements for temperature, moisture, soil pH and light; such species will likely also be found throughout closed-canopy forests (Medvecka et al., 2018). Therefore, understanding the physiology of noxious weed species will aid in the evaluation of impact during forest succession.

6.4 Weed Monitoring and Management at In Situ and Mineable Oil Sands

Noxious weeds are more prevalent within in situ and mineable oil sands sites than prohibited noxious weeds. Of those designated in the 2010 *Weed Control Regulation*, the top four noxious weeds managed for in oil sands operations include perennial sow thistle, scentless chamomile, Canada thistle and common tansy. These species are predominantly transported to sites via equipment and machinery. The movement of salvaged or stockpiled soil infested with noxious weed populations, is the major cause of spreading infestations over large areas.

Noxious weed species are identified throughout the season through vegetation surveys and are typically managed in the summer months mainly through chemical control and hand pulling, depending on the size and growth stage of the population.

It has been noted that the age of a reclaimed area determines the general risk of forest succession inhibition; juvenile native vegetation can be outcompeted for light causing delays in growth. However, once the trees grow above the height of weed infestation, many noxious weed species begin to die-off due to shade intolerance (with the exception of Canada thistle). As such, it is most common to find noxious weed populations at the edges of forests or in re-disturbed forest areas.

Those noxious weed species observed to be of low risk to a developing forest community include perennial sow thistle and scentless chamomile as they are not aggressive, tend to be localized, and begin to disappear from the community once other vegetation becomes established.

6.5 Next Steps

Canopy closure is currently thought to be the answer to weed eradication, but to date, it is unknown whether this is actually the case (Smreciu, 2018). To date, there has been little research conducted on the competitive interactions between noxious weed species and native species within the Alberta boreal forest. Knowledge gaps in weed management include some of the following (Smreciu, 2018; Vassov, 2018; Wells, 2018):

- Empirical evidence indicating whether noxious weeds remain within the vegetation community after canopy closure;
- Length of forest succession delay, including both native woody and understory species, with the growth of noxious weeds;
- Determining whether noxious and/or prohibited noxious weeds actually cause long-term negative impacts on forest succession and canopy closure; and,
- Better understanding of the impacts of current management practices (which largely focus on herbicide-based control) on forest development and asking the question: which is the worse? Allow noxious species to persist or control sites but potentially loose some native species to overspray?

These knowledge gaps can be addressed with an in-field long-term trial; to date, there have been no trials that have been designed to answer similar questions (Smreciu, 2018; Vassov, 2018).

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APPENDIX 1: CHANGES IN WEED DESIGNATION AFTER 2010

The *Weed Control Regulation* (Government of Alberta, 2010a) contains two schedules listing prohibited noxious weeds and noxious weeds. The previous *Weed Regulation* (Government of Alberta, 2001) contained one Schedule with three weed categories (restricted, noxious and nuisance; the scattering or spreading of nuisance weeds were to be prevented). The two sets of designations are compared in the tables below:

Table A-1. Weed designations in the 2001 *Weed Regulation* (adapted from McClay, 2013).

Restricted (7 species)		**Noxious (24 species) continued**	
Cardus nutans L.	Nodding thistle	*Galium aparine* L.	Cleavers
Centaurea diffusa Lam.	Diffuse knapweed	*Galium spurium* L.	Cleavers
Centaurea stoebe L. Ssp. *Micranthos* (Gugler) Hayek	Spotted knapweed	*Knautia arvensis* (L.) Coult.	Field scabious
Centaurea solstitialis L.	Yellow star thistle	*Leucanthemum vulgare* Lam.	Oxeye daisy
Cuscuta spp.	Dodder	*Linaria vulgaris* Mill.	Yellow toadflax
Myriophyllum spicatum L.	Eurasian water milfoil	*Lolium persicum* Boiss. & Hohen.	Persian darnel
Odontites serotina	Red bartsia	*Lythrum salicaria* L.	Purple loosestrife
Noxious (24 species)		*Cerastium vulgatum* L.	*Ranunculus acris* L.
Apocynum androsaemifolium L.	Spreading dogbane	*Rhaponticum repens* (L.) Hidalgo	Russian knapweed
Cardaria spp.	Globe-podded hoary cress	*Scleranthus annuus* L.	Knawel
	Heart-podded hoary cress	Silene alba	White campion
	Lenspodded hoary cress	*Silene cucubalus* Wibe	Bladder campion
Cirsium arvense (L.) Scop.	Canada thistle	*Sonchus arvensis* L.	Perennial sow thistle
Convolvulus arvensis L.	Field bindweed	*Tanacetum vulgare* L.	Common tansy
Cynoglossum officinale L.	Hound's-tongue	*Tripleurospermum inodorum* (L.) Sch. Bip.	Scentless chamomile
Echium vulgare L.	Blueweed		
Erodium cicutarium (L.) L'Her.	Stork's bill		
Euphorbia cyparissias L.	Cypress spurge		
Euphorbia esula L.	Leafy spurge		

Nuisance (36 species)			
Agropyron repens (L.) Beauv.	Quack grass	*Linaria dalmatica* (L.) Mill.	Dalmatian toadflax
Amaranthus retroflexus L.	Redroot pigweed	*Malva rotundifolia* L.	Round-leaved mallow
Avena fatua L.	Wild oats	*Neslia paniculata* (L.) Desv.	Ball mustard
Bromus tectorum L.	Downy brome	*Polygonum convolvulus* L.	Wild buckwheat
Campanula rapunculoides L.	Creeping bellflower	*Polygonum persicaria* L.	Lady's-thumb
Capsella bursapastoris (L.) Medic.	Shepherd's purse	*Potentilla norvegica* L.	Rough cinquefoil
Cerastium arvense L.	Field chickweed	*Raphanus raphanistrum* L.	Wild radish
Cerastium vulgatum L.	Mouse-eared chickweed	*Salsola pestifer* A. Nels.	Russian thistle
Convolvulus sepium L.	Hedge bindweed	*Saponaria vaccaria* L.	Cow cockle
Crepis tectorum L.	Narrow-leaved hawk's beard	*Setaria viridis* (L.) Beauv.	Green foxtail
Descurainia pinnata (Walt.) Britt.	Green tansy mustard	*Silene cserei* Baumg.	Biennial campion
Descurainia sophia (L.) Webb	Flixweed	*Silene noctiflora* L.	Night-flowering catchfly
Erucastrum gallicum (Willd.) O.E. Schulz	Dog mustard	*Sinapis arvensis* L.	Wild mustard
Erysimum cheiranthoides L.	Wormseed mustard	*Sonchus oleraceus* L.	Annual sow thistle
Fagopyrum tataricum (L.) J. Gaerta	Tartary buckwheat	*Spergula arvensis* L.	Corn spurry
Galeopsis tetrahit L.	Hemp nettle	*Stellaria media* (L.) Vill.	Common chickweed
Lamium amplexicaule L.	Henbit	*Taraxacum officinale* Weber.	Dandelion
Lappula echinata Gilib	Bluebur	*Thlaspi arvense* L.	Stinkweed

Table A-2. Weed designations in the 2010 *Weed Control Regulation* (adapted from McClay, 2013).

Prohibited Noxious (46 species)		**Noxious (29 species)**	
Aegilops cylindrica Host	Jointed goatgrass	*Arctium lappa* L.	Great burdock
Alliaria petiolata (M. Bieb.) Cavara & Grande	Garlic mustard	*Arctium minus* (Hill) Bernh.	Lesser burdock
Berberis vulgaris L.	Common barberry	*Arctium tomentosum* Mill.	Woolly burdock
Berteroa incana (L.) DC.	Hoary alyssum	*Bromus japonicus* Thunb.	Japanese brome
Butomus umbellatus L.	Flowering rush	*Bromus tectorum* L.	Downy brome
Carduus acanthoides L.	Plumeless thistle	*Campanula rapunculoides* L.	Creeping bellflower
Carduus nutans L.	Nodding thistle	*Cirsium arvense* (L.) Scop.	Canada thistle
Centaurea × moncktonii C. E. Britton	Meadow knapweed	*Clematis tangutica* (Maxim.) Korsh.	Yellow clematis
Centaurea × psammogena Gáyer	Hybrid knapweed	*Convolvulus arvensis* L.	Field bindweed
Centaurea diffusa Lam.	Diffuse knapweed	*Cynoglossum officinale* L.	Hound's-tongue
Centaurea jacea L.	Brown knapweed	*Echium vulgare* L.	Blueweed
Centaurea macrocephala Puschk. Ex Willd.	Bighead knapweed	*Euphorbia esula* L.	Leafy spurge
Centaurea nigra L.	Black knapweed	*Gypsophila paniculata* L.	Common baby's breath
Centaurea nigrescens Willd.	Tyrol knapweed	*Hesperis matronalis* L.	Dame's rocket
Centaurea solstitialis L.	Yellow star thistle	*Hyoscyamus niger* L.	Black henbane
Centaurea stoebe L. Ssp. *Micranthos* (Gugler) Hayek	Spotted knapweed	*Knautia arvensis* (L.) Coult.	Field scabious
Centaurea virgata Lam. Ssp. Squarrosa (Willd.) Gugler	Squarrose knapweed	*Lepidium appelianum* Al-Shehbaz	Globe-podded hoary cress
Chondrilla juncea L.	Rush skeletonweed	*Lepidium chalepense* L.	Lens-podded hoary cress
Cirsium palustre (L.) Scop.	Marsh thistle	*Lepidium draba* L.	Heart-podded hoary cress
Crupina vulgaris Pers. Ex Cass.	Common crupina	*Lepidium latifolium* L.	Broad-leaved pepper-grass
Cyperus esculentus L.	Yellow nutsedge	*Leucanthemum vulgare* Lam.	Oxeye daisy
Elaeagnus umbellata Thunb.	Autumn olive	*Linaria dalmatica* (L.) Mill.	Dalmatian toadflax
Fallopia × bohemica (Chrtek & Chrtková) J. P. Bailey	Hybrid Japanese knotweed	*Linaria vulgaris* Mill.	Yellow toadflax
Fallopia japonica	Japanese knotweed	*Ranunculus acris* L.	Tall buttercup

Prohibited Noxious (46 species)		**Noxious (29 species)**	
Fallopia sachalinensis (F. Schmidt Petrop.) Ronse Decr.	Giant knotweed	*Silene latifolia* Poir. ssp. a*lba* (Miller) Greuter & Burdet	White cockle
Halogeton glomeratus (M. Bieb.) C.A. Mey.	Saltlover	*Sonchus arvensis* L.	Perennial sow thistle
Heracleum mantegazzianum Sommier & Levier	Giant hogweed	*Tanacetum vulgare* L.	Common tansy
Pilosella aurantiaca L.	Orange hawkweed	*Tripleurospermum inodorum* (L.) Sch. Bip.	Scentless chamomile
Pilosella caespitosa Dumort.	Meadow hawkweed	*Verbascum thapsus* L.	Common mullein
Pilosella officinarum L.	Mouse-ear hawkweed		
Hypericum perforatum L.	Common St. John's wort		
Impatiens glandulifera Royle	Himalayan balsam		
Iris pseudacorus L.	Pale yellow iris		
Isatis tinctoria L.	Dyer's woad		
Jacobaea vulgaris Gaertn.	Tansy ragwort		
Lythrum salicaria L.	Purple loosestrife		
Myriophyllum spicatum L.	Eurasian water milfoil		
Odontites vernus (Bellardi) Dumort	Red bartsia		
Potentilla recta L.	Sulphur cinquefoil		
Rhamnus cathartica L.	Common buckthorn		
Rhaponticum repens (L.) Hidalgo	Russian knapweed		
Taeniatherum caput-medusae (L.) Nevski	Medusahead		
Tamarix chinensis Lour.	Chinese tamarisk		
Tamarix parviflora DC.	Small flower tamarisk		
Tamarix ramosissima Ledeb.	Salt cedar		
Tribulus terrestris L.	Puncturevine		

APPENDIX 2: FACT SHEETS

The following fact sheets provide brief descriptions of the characteristics, boreal forest and oil sands experience, environmental impacts and management options for the top four noxious weeds in the boreal forest and/or oil sands operations identified through this review:

- Perennial sow thistle (*Sonchus arvensis*)
- Scentless chamomile (*Tripleurospermum inodorum*)
- Canada thistle (*Cirsium arvense*)
- Common tansy (*Tanacetum vulgare*)

Perennial Sow Thistle *Sonchus arvensis* L.

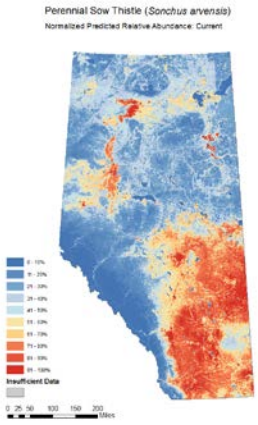
Description: An early successional perennial plant, most commonly 60 to 150 cm tall (although they range from 30 to 180 cm tall), that reproduces both by seed and rhizomes. Flowers have both male and female organs but are generally self-incompatible, and are pollinated by insects.

Boreal Forest and Oil Sands Experience: Recorded in a 2007 survey of fragmented dry boreal mixed-wood areas within north-central Alberta, a 2009 survey of the Regional Municipality of Wood Buffalo, and a 2010 survey of agricultural fields in the Boreal Transition Region. Alberta Biodiversity Monitoring Institute surveys from 2003 to 2016 show greater relative abundance in white spruce and pine forests and none in black spruce.

Problem Characteristics: Vertical roots can penetrate 1.5 to 3 m deep. Horizontal roots, frequently 2.5 to 5 mm in diameter (rarely exceeding 10 mm), are found 5 to 10 cm below the soil surface and can reach 0.9 to 1.8 m in length in a single growing season. Chemicals from decaying plants inhibit seed germination of other species.

Seed production is highly variable; a single plant can produce up to 4,000 seeds, however seeds are relatively short-lived. Seeds are mostly wind dispersed (up to 10 m from the plant) and can germinate in spring or fall. Seed dormancy suggests that some seed may remain viable for 3 or more years in cultivated soils. Seedlings survive best in areas with protective plant cover or litter and high moisture compared with open cultivated soil.

Distribution: Reported in all Canadian provinces with the exception of Nunavut Territory. Ranks among the top 20 most abundant weeds in western Canada. Predicted relative abundance based on ABMI data as of 2012 show limited distribution in forested regions (see figure).



Tolerances: Adapted to a wide range of conditions (it is mentioned most often in the literature in relation to saline habitat types); does best in moist, fertile soils with full sunlight. Appears to prefer fine-textured soils and does not thrive on dry, coarse-textured sand. Plants are likely to survive and persist on burned areas, even after high-severity fire, and the limited available data on post-fire response indicate little difference in abundance between burned and unburned sites.

Impacts: An aggressive agricultural weed that can invade both natural and disturbed sites. Can become a serious problem in riparian areas. Not especially palatable to livestock, though sheep and cattle will eat new growth and sometimes roots. Considered "excellent" forage for rabbits.

Management Options: Seedlings can be easily hand-pulled.

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Scentless Chamomile *Tripleurospermum inodorum* (L.) Sch. Bip.

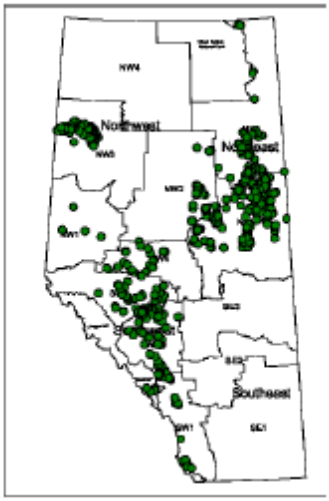
Description: An annual to perennial plant that grows to 1 m tall from extensive, fibrous root systems that do not run or creep. Reproduces only by seed, which is spread by wind or water.

Boreal Forest and Oil Sands Experience: Recorded in a 2007 survey of fragmented dry boreal mixed-wood areas within north-central Alberta, a 2009 survey of the Regional Municipality of Wood Buffalo, and in the Boreal Transition Region in a 2010 Agriculture and Agri-Food Canada weed survey. ABMI surveys from 2003 to 2016 found decreasing relative abundance from pine to black spruce to white spruce forests and the lowest abundance in deciduous and mixedwood forests. Found mostly on roadsides; enters sites on equipment and machinery.

A single plant can produce up to half a million seeds which tend to drop roughly 1 to 2 inches from the plant. Therefore, infestations are typically localized within a small area; within that area, the seed bank is often rich with scentless chamomile seeds. Migration of infestations occurs through the spreading of soil containing scentless chamomile seeds, such as the spreading of salvaged soil or movement of soil from roadsides.

Banvel, 2-4D Amine 600, and Pinestick have been used for the control of scentless chamomile at sites managed by CNRL; spring and fall spraying of a heavily-infested stockpile at Syncrude was conducted for three years – stockpiled soil was spread over 40 ha in 2018 and monitoring will determine if the seedbank still contains viable seed. Hand pulling is effective for small infestations.

Problem Characteristics: Buried seed can remain viable up to 15 years. One flower head can have as many as 300 seeds. A single plant can produce as many as a million seeds. In a dense stand, as many as 1.8 million seeds/m^2 may be produced. The seeds develop quickly and are viable as soon as the flower is formed. Has an indeterminate flowering habit; therefore, flowers and seed are continually formed, which makes eradication difficult. Generally unpalatable to grazers but its seeds can survive digestion.



Scentless chamomile

Distribution: Located in every province except for Nunavut Territory. Mainly present in central and northern Alberta. Most frequently reported noxious weed in ASRD Green Area surveys from 1998 – 2003 (see figure). Found around campsites, access roads, cut blocks, gravel pits, grazed areas, pipelines, well sites, and storage areas. Transportation networks such as road and railway systems serve as a major means of spread. Once plants are established, ditches and watercourses can also spread the seed.

Tolerances: Well adapted to heavy/clay soils and does best in wet soils (more prevalent on Solonetzic soils in areas of higher moisture, such as around sloughs and in depressions). Does not tolerate competition.

Impacts: If it becomes established on bare soil or in weak plant stands, it can become very aggressive. As it spreads into more northern areas it has the potential to disrupt successional patterns in areas that have been disturbed by oil, gas, or forestry operations. Can serve as an alternate host to insect species that may damage other crops or be vectors for diseases of other crops.

Management Options: Pulling the first plants in an area before the flowers are fully formed is the most effective method (pulled plants should be burned or bagged and sent to the landfill). Spot treatment in

and around these small initial infestations with a residual selective herbicide will help prevent establishment in new areas. Burning infestations that have finished blooming can prevent seed spread. Dense stands tend to fade out after a few years as they are outcompeted by perennial species, but they leave a large seed bank in the soil that will re-infest if the ground cover is disturbed again at a later date. Frequent shallow tillage will aid in the germination and destruction of seedlings. Deep cultivation should not be used because it buries the seed and slow germination over several years will result. Several herbicides are effective at controlling scentless chamomile when applied to actively growing plants up to the flowering stage. Two insects are being reared and made available for use in Canada as biological control agents.

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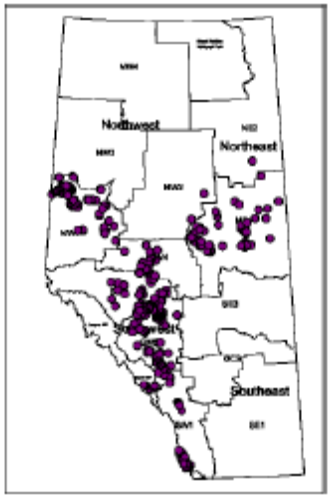
Canada Thistle *Cirsium arvense* (L.) Scop

Description: A colony-forming, aggressive perennial growing to 1.5 m tall, that spreads primarily by its creeping root system. Does best in disturbed areas – found along roads and pipelines, on well sites, grazing leases, cut blocks, and recreation areas in the forested areas of Alberta. Not usually found in undisturbed forested areas as it doesn't tolerate shade, but has the potential to colonize a wide variety of forest habitats following overstory removal and soil disturbance.



Canada thistle

Boreal Forest and Oil Sands Experience: Second most common weed in ASRD forest surveys from 1998 to 2003 (see figure); also found in other surveys in and near boreal forest regions. One of the most frequent, abundant and prolific weeds in oil sands development likely arising from equipment and machinery transported to sites.

Grows faster than planted trees and shrubs and can therefore impact seedling performance in early reclamation stage. Remains in seed bank and establishes quickly upon soil disturbance.

One of two species requiring the most effort and control in oil sands developments; if left uncontrolled it is suspected that it would grow aggressively and inhibit the growth of other native vegetation. Requires two herbicide applications (spring and fall) for a minimum of two years; spraying after sites have been planted with shrubs and deciduous trees will result in mortality of desired vegetation. Spot-spraying with knowledgeable staff is critical to minimizing unintentional spraying. Hand pulling of plants germinated from seed is very effective; once established however the extensive root system makes hand pulling ineffective.

Problem Characteristics: Produces 1,000 to 1,500 wind dispersed seeds/flowering shoot, which can lie dormant for up to 20 years. Seeds mature quickly and most are capable of germinating 8 to 11 days after the flowers open, even if the plants are cut when flowering.

Roots can regenerate from small pieces (0.6 cm long) and root fragments have sufficient reserves to survive for 100 days under adverse conditions. Most roots are in the top 0.2 to 0.6 m of soil, but can extend as deep as 6.5 m.

In one year, a single plant may extend over a circular area up to 6 m in diameter. May produce phytotoxins that inhibit the growth of other plants.

Tolerances: Thrives in a wide range of soil types. Best adapted to rich, heavy loam, clay loam, and sandy loam. Tolerates saline conditions and wet, but not waterlogged, soils. Adapted to survive fire on site, and to colonize recently burned sites with exposed bare soil.

Impacts: Extremely competitive. Capable of crowding out and replacing native grasses and forbs, decreasing the species diversity of an area, and changing the structure and composition of some habitats. Rated as a moderately invasive but widespread problem in natural areas. Dense riparian infestations can impact wildlife by reducing food, and access and nesting cover for waterfowl.

Management Options: Focus control on vegetative reproduction rather than seed production. Eradication of established populations in natural areas is not often a practical goal. Reducing infestations to manageable levels is a more viable objective.

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Common Tansy *Tanacetum vulgare L.*

Description: A perennial that reproduces by both seed and short rhizomes. There are many branched, erect stems per plant and can grow up to 1.5 m tall. Common tansy flowers from July to October; there are 20 to 200 flower heads per plant that can produce up to 50,000 seeds. Listed as #10 in a listing of Canada's top ten invasive horticultural plants.

Boreal Forest and Oil Sands Experience: During growth and development, common tansy quickly establishes deep roots. Oil sands vegetation surveys conducted in 1993 did not include the presence of common tansy; however, now the species can be observed across mine sites. Described in weed surveys in the Green Area from 1998 to 2003, in the Regional Municipality of Wood Buffalo in 2009, and in the Boreal Transition Ecoregion in an agricultural land survey in 2010.

Plants have been found to grow very well at the edges of forests. Plants have also been identified near open water bodies, such as along the Athabasca River and areas where there is pooling water around tailings pond structures. Along rivers or lake shores, dense monotypic common tansy populations are common.

Common tansy produces a large quantity of seed which have been found to be readily wind-blown, rapidly spreading across sites. Because of this behaviour, there is some concern that the common tansy will have a large presence within the natural seed bank.

Landowners and managers in Alberta's forested areas reported that common tansy spread has been minimal even though populations have been present for more than 60 years.

Problem Characteristics: Grows in dense stands. Common tansy plants along roadsides and in riparian areas produce "tightly coiled" rhizomes with diameters of 1.0 to 2.7 cm and "extremely woody" roots with diameters that averaged 0.4 cm. Roots extended more than 130 cm below ground. Dense patches of dried common tansy stems burn "very hot and fast".

Distribution: Reported in all Canadian provinces with the exception of Nunavut and the Yukon. Grows best in full sun and fertile, well-drained soil in uncultivated land (pastures, riparian areas, rights of way, parks, and natural areas). In recent years it has also been spreading rapidly into the forested areas of northern Alberta.

Tolerances: Common tansy will not establish on sites with high cover (shade intolerant).

Impacts: Plants contain alkaloids that are toxic to both humans and livestock if consumed in large quantities – though it is unpalatable to cattle and horses, sheep and goats are reported to graze on it. Common tansy displaces native plant communities.

Management Options: Control of seed dispersal is more important than control of vegetative spread. Chemical control options for common tansy are limited because it often grows near water bodies and in remote locations that are difficult and expensive to access. The most effective control method combines mowing or hand cutting with chemical control and encouraging competition from native vegetation. Repeated stem removal depletes the food energy stored in roots. Several herbicides are registered for use on common tansy. Work is ongoing to identify potential biological control species.

The total estimated annual cost of the measures of controlling common tansy applied by municipal agencies and a small sample of sixteen private landowners was $9.70/hectare in 1993.

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