Optimizing Weed Control for Progressive Reclamation: Risk Analysis on Regulated Weeds in the Boreal Region

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EXECUTIVE SUMMARY

The overall goal of this project was to attempt to assess whether noxious weeds managed in the boreal forest are significantly impacting boreal succession using publicly available literature, available vegetation survey data and field experience of oil sands operations practitioners. 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 aimed 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 were:

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.

A literature review was previously submitted under separate cover (Small et al. 2018). This report summarizes the results of a retrospective case study of oil sands data and development of a risk analysis framework.

A retrospective case study was conducted to quantitatively examine patterns in forest vegetation and non-native development using six oil sands data sets provided by the industry participants and existing research data managed by the authors and included data sets where vegetation monitoring had occurred for at least three years. Correlation analyses completed across the six reclamation sites did not find strong evidence of a negative association between woody cover and noxious weeds (by group or by species); this was measured across multiple years of measurement. The only significant correlations between these parameters were in fact positive associations. This analysis was supported by changes in relative dominance favoring woody vegetation as individual sites aged. However, the relative dominance of noxious weeds varied over time and there was no consistent trend amongst the sites. Though these results

collectively suggest that active noxious weed management may not be required as the species evaluated did not appear to hinder woody vegetation development, the analyses conducted in this report were not causal. Future studies are still needed to: (i) confirm that noxious species are not overtly competitive with woody vegetation recovery (or to identify specific thresholds that woody vegetation are able to tolerate) and (ii) to examine longer term site recovery to confirm that noxious species do consistently fall out of these sites.

A risk analysis framework was developed based on the results from the retrospective case study and with consideration of a currently available risk analysis tool (RAT) that was developed by Alberta Agriculture and Forestry. The risk analysis tool was not useful for determining effects thresholds though it has utility for its core purpose (which is to effectively triage and prioritize invasive species in terms of management considerations). The authors developed a conceptual risk analysis framework (RecRAT) using RAT as a starting point but using a more quantitative approach to evaluation. The proposed RecRAT is a two-part evaluation that first requires the user to provide data on relative dominance by vegetation category, site age, tree and shrub height, as well as management risk. It would then calculate an exposure risk (risk of site not becoming a forest) showing thresholds in relative dominance between vegetation cover types and stand age. The second part of the evaluation would include a short questionnaire that rated aspects of environmental risk to come up with a single number score. The exposure and environmental risk could then be plotted and conceptually the combined value would be expressed in the standard way risk-analysis are shown (green, yellow or red). Considerable research is required to support both components of RecRAT.

TABLE OF CONTENTS

LIST OF TERMS AND ACRONYMS

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.

AAF	Alberta Agriculture and Forestry
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 AND OBJECTIVES

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, 2010) 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 was to assess whether noxious weeds managed in the boreal forest are significantly impacting boreal succession using publicly available literature, available vegetation survey data and field experience of oil sands operations practitioners. The assessment was 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 aimed 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 were:

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:
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    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.

To achieve these objectives this study was separated into two key tasks: 1) a literature review to compile the current information on weed status and management programs in the boreal ecosystem, for both mining and in-situ oil sands operations; and 2) a risk analysis on regulated weeds in the boreal region of Alberta. A comprehensive literature review was completed by Small et al. (2018), the findings of which were used to inform the knowledge gaps and recommendations herein. The remaining objectives were the focus of this report.

2.0 RETROSPECTIVE CASE STUDY

The retrospective case study provided an opportunity to quantitatively examine patterns in forest vegetation and non-native plant (emphasizing noxious weed) development. The case study was completed utilizing six independent data sets: (i) CNRL Airstrip, (ii) ConocoPhillips / Nexen 2004 construction, (iii) ConocoPhillips Stockpile, (iv) CNRL Remote Sump, (v) CNRL Delineation Wells and (vi) Suncor Base Mine. These data sets were provided by the industry participants and existing research data managed by the authors and included data sets where vegetation monitoring had occurred for at least three years (**Tables A1-A2**).

Vegetation development patterns were examined by grouping individual species cover estimates into one of the following classes: woody, native forbs, non-native forbs, grasses or noxious weeds (**Table A3**). Individual noxious weed species were also analyzed individually to provide a closer examination of vegetation development patterns; as a second point of reference to understand non-native plant behavior, two additional groups (sweet clovers and perennial clovers) were also included as these agronomic species were prevalent through most of the case study data sets (**Table S3**).

2.1 METHODOLOGY

This analysis comprised measurements from six reclamation sites with multiple years of vegetation cover data collected after reclamation activities were completed (**Table A1**). The data were collected independently from each other, i.e., not part of the same study. Some data sets contained experimental treatments and measured vegetation cover response over time. Other data sets monitored vegetation cover over time with no additional treatments. For this analysis, all data sets were aggregated to the circular plot level (in the case where multiple quadrat-based measurements were taken in each circular plot to assess vegetation cover) and then either grouped by year after reclamation or by reclamation site (depending on the analysis) (**Table A2**).

All analyses, graphics and data manipulations were carried out using the R Language for Statistical Computing and the `*tidyverse*` package (R Core Team, 2018; Wickham, 2017). To assess the relationship between woody cover and cover types as well as individual noxious weeds and non-native undesirable species (**Table A3**), Pearson correlation coefficients were calculated, excluding zero percent cover values, using the `*cor.test()*` function in R (**Tables A4, A5**; for graphical representations see **Appendix C**). For this analysis, the data was examined for each reclamation site and the number of years since reclamation. To provide a more generalized summary of correlation trends across sites, the direction and significance of the correlation coefficients (positively or negatively different from zero) were plotted and the mean 'correlation' was graphically displayed (**Figure B1**).

The probability of presence was calculated using binomial regressions via the `*glm()*` function. Estimated marginal means for the probability estimates, as well as the 95% confidence limits, were calculated using the `*emmeans()*` function in the `*emmeans*` package (Lenth, 2018). The dependent variables were three (of five) noxious weeds (perennial sow thistle, scentless chamomile and Canada thistle) as well as two non-native undesirable species (sweet clover and perennial clovers (which represented species from the genus *Trifolium*)) and the independent variables were the six reclamation sites (**Table A1**). There was insufficient presence (too many zeros) to determine probabilities of presence for common tansy and tall buttercup. For this analysis, the data was presented by reclamation site (**Figure B2**).

Relative dominance was assessed at all reclamation sites over time. It was calculated as percent cover of vegetation cover types (see **Table A3** for definitions) as well as noxious weeds and undesirable species (**Table 3**) divided by the total cover in the measurement quadrat (at the plot level). Then the data was grouped by reclamation site and graphically displayed (**Figures B3 to B8**).

2.2 RESULTS AND DISCUSSION

A total of five noxious weed species were observed in at least one of the six study data sets evaluated, though all five species were never observed together on a single site (**Figure B1, Tables A4-A5**). Of these five species, only three (perennial sow thistle, Canada thistle and scentless chamomile) were observed at levels that allowed for statistical evaluations as common tansy and tall buttercup were rarely present (see for example, **Figure C15 and C45**). Perennial sow thistle was the most common to the study data sets (observed on 4 out of 6 data sets at > 10% occurrence, **Figure B2**). Suncor Base Mine had a notable mean occurrence exceeding 80% (**Figure B2**). Scentless chamomile was less commonly observed across the data sets though it occurred on average 50% of the time at the ConocoPhillips Stockpile (**Figure B2**). In addition, two other groups of non-native plants were included: sweet clovers and perennial clovers (**Table A3**) and these groups were present on all of the study sites (**Figure B2**). Although sweet clovers and perennial clovers are not considered noxious species, they are non-native and often prevalent on young reclamation sites thus may influence the development of native vegetation cover and provide another point of reference to understand vegetation competition dynamics in these sites.

2.2.1 **Correlation Analysis**

Correlation analysis was conducted between woody vegetation and each of the species noted above as well as four types of herbaceous vegetation cover (grasses, native forbs, non-native forbs and noxious weeds). The noxious weeds (whether grouped or examined individually) and woody vegetation showed no significant negative correlations (though some non-significant correlations were detectable) across the sites and years of measurements (**Tables A4-A5, Figure B1**). The only significant relationships observed between noxious weeds (whether grouped or examined individually) and woody cover were actually positive associations (**Tables A4-A5**) and these correlations were sporadic across sites and years of measurement. However, perennial clovers and sweet clovers were more often negatively correlated with woody cover (though it was only significant in year 2 at ConocoPhillips Stockpile) (**Table A5, Figure B1**). Although correlations cannot prove causal effects, these results do point towards a conclusion that, at least for the noxious species under study, there was limited evidence that their presence was inhibiting woody vegetation development.

Woody vegetation and native forbs were typically positively correlated, exclusively (and significantly) so in the first 2 years post reclamation (**Table A4, Figure B1**)**.** In contrast, woody vegetation and non-native forb cover varied over time for most of the sites studied but in general the correlation was positive in the first year, trended towards becoming negative in years 2-3 and was then highly variable across sites thereafter (**Table A4, Figure B1**). The correlation between woody vegetation and grass cover showed a similar pattern to that of woody vegetation and non-native forbs (**Table A4, Figure B1**). In the ConocoPhillips / Nexen 2004 construction data set, the negative correlation between grasses and woody cover increased over time, presumably in the longer time frame this was being driven by increasing woody canopy cover shading the grasses (rather than the grasses outcompeting the woody vegetation) (**Table A4, Figure B1**).

2.2.2 **Patterns of Relative Dominance**

Relative dominance varied for most vegetation groups as well as for the individual species evaluated; however, what stood out was that the relative dominance of woody vegetation consistently increased with time for every data set evaluated (**Table A6**, **Figures B3-B8**). This aligns with the often-stated assumption that eventually native forest trees and shrubs will overtop competing vegetation. Native and non-native forb groups tended to decline or were observed as variable patterns amongst the sites (**Table A6**, **Figures B3-B8**). Relative dominance of grasses increased in half of the data sets (CNRL Airstrip, CNRL Delineation Wells and Suncor Base Mine), varied with no consistent trend in two (ConocoPhillips Stockpile and CNRL Remote Sump) and declined in the Conoco / Nexen 2004 construction (**Table A6**, **Figure B3-B8**). It is notable that for all the sites where grass dominance increased with time there was a concurrent decline in relative dominance of non-native forbs but not necessarily noxious weeds (as a group) (**Table A6**). This may be due in part to the greater initial dominance (and absolute cover) in the non-native forbs therefore changes in vegetation over time would have been easier to detect. In addition, the overwhelming presence of sweet clover and perennial clovers in the non-native vegetation group and these species are often eventually outcompeted by grasses, a fact that was consistently observed in all data sets with exception of Suncor Base Mine which did not vary (**Table A6**).

The relative dominance of noxious species (as a group) was variable amongst sites with two sites showing an increasing trend (CNRL Airstrip and ConocoPhillips Stockpile), two sites showing a declining trend (CNRL Remote Sump and CNRL Delineation Wells) and two sites showing no consistent pattern or change (Conoco / Nexen 2004 construction and Suncor Base Mine) (**Table A6, Figures B3-B8**). It is important to note that the relative dominance (and absolute cover) of this vegetation group was typically the lowest of all vegetation cover groups (with the exception of Suncor Base Mine (**Figure B8a**) and peak relative dominance values ranged from <1% for the Conoco / Nexen 2004 construction (**Figure B4a**) to 13% (peak in year 3 where year 5 showed relative decline) at the Suncor Base Mine (**Figure B8a**). Suncor Base Mine was the only data set from the mineable oil sands and this may have made some of the vegetation patterns somewhat unique. The CNRL Remote Sump data set visually shares the most similarity in terms of relative dominance patterns to Suncor Base Mine which may be partially explained by the site history[1]. The sites where increased relative dominance of the noxious species group was observed over time were associated with increased dominance in perennial sow thistle (CNRL Airstrip and ConocoPhillips Stockpile, **Figure 3a, 5a**) and in Canada thistle (CNRL Airstrip only, **Figure B8b**).

[1] The site had been reclaimed and seeded to native grasses, allowed to grow for 2 years and was then deep ripped with a McNabb RipPlow and immediately planted with a mixture of native trees and shrubs. This site prep activity resulted in substantially knocking back the grass community (for at least 2 years) and therefore, it may have to some degree regenerated in an atypical way (as the initial flush of agronomic seed that seems to be nearly universally present in these sites (and for which perennial clovers tend to show the greatest relative dominance on all of the other sites aside from these two) likely germinated following the initial reclamation work.

3.0 DEVELOPMENT OF A RISK ANALYSIS FRAMEWORK

The risk analysis framework was developed based on the results from the retrospective case study and with consideration of a risk analysis tool (RAT) that was developed by Alberta Agriculture and Forestry (AAF; Alberta Agriculture and Forestry, nd). This section is divided into two components, the first is an evaluation of the AAF tool for conducting risk assessments of alien species and the second section is focused on the development of a reclamation-reforestation specific tool that could be applied in the Boreal region of Alberta.

3.1 TESTING THE PROVINCIAL RISK ASSESSMENT TOOL (ALBERTA AGRICULTURE AND FORESTRY)

The AAF Risk Assessment Tool (RAT) scores the potential exposure and effects (environmental, economic and social) of a species. This tool is meant to be used as a guide to prioritize the management of invasive species (including other biota, not just plants). The primary drivers for the tool are questions related to potential exposure and the potential effects. The exposure potential is weighted the highest while the effects (combined) are weighted together.

Using the ConocoPhillips Stockpile site as an example, the three noxious species observed on this site (perennial sow thistle, Canada thistle and scentless chamomile) were scored with this tool. The inputted answers to the 57 question online survey are shown in **Table A7** and the graphical output of the effect vs exposure graph is presented in **Figure B9**. The maximum score that can be achieved is a 3 for effect and 4 for exposure. The scores for each species were similar (all had the same effect = 0.8) with small variation in exposure (**Figure B9**). A major limitation is that it is difficult to interpret this tool outside of its primary purpose for relative ranking of risk as there is no indication of what thresholds should be in place to trigger a management response. What this tool effectively suggests is that, at least for this site, management efforts could focus on reducing Canada thistle ahead of sow thistle or scentless chamomile. However, because there is little emphasis on the actual quantity / presence of individual species, this tool does not capture the site reality which is that the Canada thistle is sporadically distributed (at low coverage) across the site while both sow thistle and scentless chamomile are more widespread, a fact that is well illustrated by difference in presence at this site (**Figure B2**).

3.2 DEVELOPING A RECLAMATION-FOCUSED RISK ASSESSMENT TOOL

Given the limitations noted above in utilizing the risk analysis tool (RAT) to determine threshold risk levels in noxious weeds, we developed a modified list of questions (hereafter called modified reclamation RAT or RecRAT) to consider when assessing risk that was more tailored to forest reclamation outcomes. This section describes a conceptual framework for a quantitative rating tool that could be developed in collaboration with the Government of Alberta to eventually be used as a true risk or hazard assessment for existing noxious weeds (species that are already regionally present as 'newly' introduced species are likely to require specialized management interventions and they will not have been validated in the RecRAT) in the Boreal region of Alberta.

When developing the RecRAT framework we worked with the assumption that the primary goal of reclamation efforts in the Boreal region is to return the disturbed site to a young forest. The RecRAT is proposed to have two components, a quantitative assessment to identify the degree of exposure risk and a qualitative assessment to understand the environmental risks. The results of the retrospective case study showed that using relative dominance appeared to be a reasonably robust approach to understanding changes in vegetation composition in young reclaimed sites. Relative dominance metrics

formed a key component of the questions posed below in the exposure risk section. Site age and height of woody vegetation was also considered. RecRAT also examines the counter-risk of active management (which would likely be hand-pulling or spraying weeds) in an effort to better understand the wholistic effect of the practice (thereby asking the question: is managing for this single noxious species worth the risk of not achieving the primary objective?).

For the exposure risk, the six RecRAT questions are:

#	Question
1	What is the post-reclamation age of the site?
2	What is the relative dominance of the species in the assessment area?
3	What is the relative dominance of all *other herbaceous* species in the assessment area?
4	What is the relative dominance of the woody species in the assessment area?
5	What is the average height of individual woody species in the assessment area?
6	What is the counter-risk (i.e., reduction in the relative abundance of target tree / shrub species) of engaging in active management of the species in question?

The exposure risk questions would require inputting data values, which would be tabulated to determine if the specific species is posing undue risk to forest development. To effectively evaluate the responses, this assessment would need to have pre-determined thresholds that account for 'normal' vegetation development patterns over time. The following lists the type of information that would have to be known over a general range of environmental conditions:

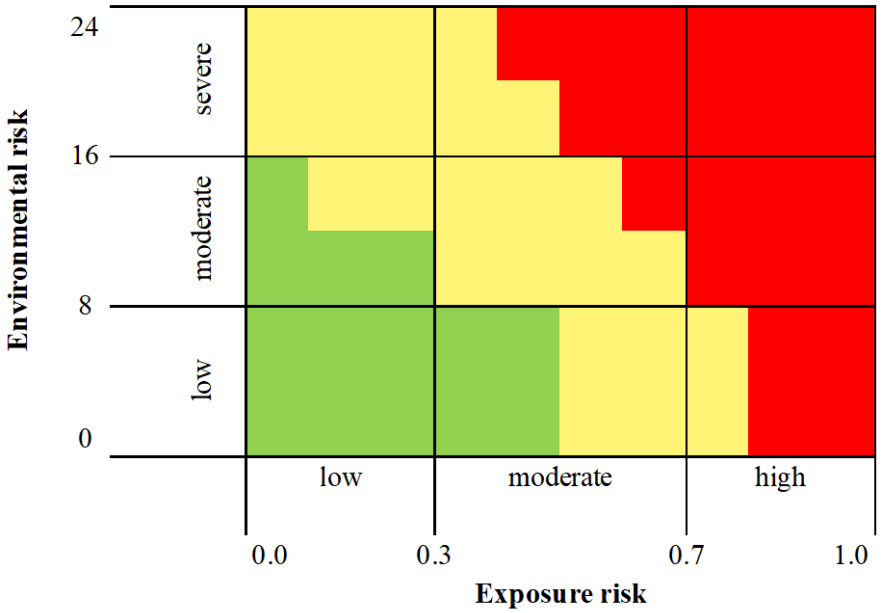
1. The assessment would recognize that noxious species may be present, but that there were known relationships to support that given the age of the site, the current levels of relative dominance would not pose a serious risk to development of forest vegetation and that the noxious species are expected to dissipate over time (due to competition). This assessment would recognize 'normal' or 'expected' patterns of woody vegetation development (and increasing dominance) where at any given age, a relative dominance value for woody vegetation would have an appropriate range of values.
2. Previous modelling efforts to predict tree growth (Welham 2010, Welham and Seely 2011, 2013) could be utilized to feed information into the exposure calculation to further support the assertion that forest canopy development was on track. This information would need to be species specific.
3. A quantitative understanding of the level of mortality or reduction in different groups of vegetation (particularly woody vegetation) expected by different types of active vegetation management (question 6).

The answers to question 1-6 would then be worked into a probability (0-1 scale with low < 0.3, moderate ≥0.3 to 0.7 and high > 0.7) of the site not developing into a forest.

For the environmental risk evaluation, the six RecRAT questions are:

#	Question	Weighting	Max score
1	Is the species a host or vector for known diseases, parasites, or pests that will cause harm to stable or abundant native species?	0.5	1.5
2	Is the species a host or vector for known diseases, parasites, or pests that will cause harm to vulnerable or "at risk" species?	0.5	1.5
3	Is the species able to hybridize with stable or abundant native species?	1.5	4.5
4	Is the species able to hybridize with vulnerable or "at risk" species?	1.5	4.5
5	What is the potential level of effect on abiotic or ecosystem processes?	2.0	6.0
6	Is there an environmental concern to actively managing the species?	2.0	6.0

For each of the questions above, the range of responses could include: no effect (score = 0), low effect (score = 1), moderate effect (score = 2), severe effect (score = 3) or unknown (score = 2). Combining each of these components, a graphical view of this approach is shown below:



The specific thresholds (shown by differing colors) would also have to be identified based on more detailed assessment of the trade-off between environmental risk and exposure risk. In the absence of obtaining an outright waiver or permission to simply not actively manage noxious species, the RecRAT concept described above could provide an alternative option (which of course would require government and stakeholder approval). The strength of the RecRAT is that it would be an evidence-based assessment tool (rather than a qualitative opinion based on practitioner experience) to rationalize the need for noxious weed management.

4.0 SUMMARY OF KEY FINDINGS

4.1 LITERATURE REVIEW

Refer to Small et al. (2018) for more information; this section presents the key findings.

4.1.1 **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. Given the legislated requirement to destroy prohibited noxious weeds there is likely no option to reduce management requirements for these species. 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.

4.1.2 **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. 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 (though it is notable this is actually a native and likely desirable species in Boreal forest), 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.

4.1.3 **Nature of Weed Growth in Forest Ecosystems**

It is important to distinguish between (1) the intensity of competition, and (2) the importance of competition. 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. 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. 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 could negatively impact tree growth and development.

4.1.4 **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. The top four noxious weeds managed for in oil sands operations are perennial sow thistle, scentless chamomile, Canada thistle and common tansy. It is believed that these species are predominantly transported to sites via equipment and machinery.

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). 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.

4.2 RISK ANALYSIS

4.2.1 **Retrospective Case Study**

Correlation analyses completed across the six reclamation sites did not find strong evidence of a negative association between woody cover and noxious weeds (whether examined as a group or by species); this was measured across multiple years of measurement. The only significant correlations between these parameters were in fact positive associations (**Tables A4-A5, Figure B1**). This analysis was further supported by changes in relative dominance favoring woody vegetation as individual sites aged while the relative dominance of noxious weeds was site specific and increased, decreased or showed no consistent trend or change over time. The variable pattern was likely driven by the particular mixture and absolute coverages of the vegetation community in that site. It is noteworthy that even with relatively high noxious weed occurrence (>50%, though not necessarily coverage) for two of the data sets examined (ConocoPhillips Stockpile and Suncor Base Mine), woody vegetation development progressed steadily.

If perennial clovers could be considered generally representative of the non-native plant group (inclusive of noxious species), the results of this study showed a very clear pattern of declining relative dominance over time (on 5 of 6 data sets measured). This pattern may be more apparent relative to other non-native species as this species grouping was often commonly occurring (higher coverage), thereby making the shifts in vegetation easier to detect. Nevertheless, as none of the analyses conducted in this report are causal, future studies are still required to: (i) confirm that noxious species are not overtly competitive with woody vegetation recovery (or to identify specific thresholds that woody vegetation are able to tolerate) and (ii) to examine longer term site recovery to confirm that noxious species do consistently fall out of these sites as the data sets in the current investigation were often 5 years or less in age (ConocoPhillips / Nexen 2004 construction had 10 years of measurement but it never did have a sizeable population of noxious species).

4.2.2 **Development of a Risk Analysis Framework**

The original AAF RAT (risk analysis tool) was not useful for determining effects thresholds though it has utility for its core purpose (which is to effectively triage and prioritize invasive species in terms of management considerations). The authors developed a conceptual risk analysis framework (RecRAT) using RAT as a starting point but employing an evidence-driven approach to evaluation. The proposed RecRAT is a two-part evaluation that first requires the user to provide data on relative dominance by vegetation category, site age, tree and shrub height, as well as management risk. It would then calculate

an exposure risk (risk of site not becoming a forest) based on previously known data sets (which do not currently exist) showing thresholds in relative dominance between vegetation cover types and stand age. The second part of the evaluation would include a short questionnaire (a preliminary list of questions were developed) that rated aspects of environmental risk to come up with a single number score. The exposure and environmental risk could then be plotted and conceptually the combined value would be expressed in the standard way risk-analyses are shown (green, yellow or red).

5.0 KNOWLEDGE GAPS AND RELEVANT RESEARCH QUESTIONS

The table below summarizes key knowledge gaps as well as suggestions for further work to fill these gaps. The term “noxious weeds” in the table refers to the main weeds found on in situ and mine sites, and in particular on the two species (perennial sow thistle and scentless chamomile) that were determined to be of low risk to the development of a reclaimed self-sustaining forest ecosystem and therefore for potential exemptions from the *Weed Control Regulation*. There was strong evidence that Canada thistle was problematic for woody cover development but some anecdotal descriptions suggested this species may be more persistent, even with canopy cover development.

Gap #	Section	Knowledge Gap	Suggestions for Further Work
1	Literature review and Retrospective case study	Quantitative evidence detailing the level of long-term persistence of noxious weeds. It is anticipated that they will be outcompeted (due to successional theory) but local data is lacking. The data sets in the case study represented young sites (all 5 years or less with exception of 1 data set which had 10 years of measurement). The long-term persistence (or lack thereof) was not confirmed by these analyses and future research should examine older sites (10-40 years of age would be ideal or 10+ years post forest canopy closure).	Review data from CEMA's long term monitoring plots to compare "weeds" and tree/shrub data. There are 100s (possibly 1000s) of reclaimed and certified oil and gas sites in northern Alberta; many of which will have records relating to the presence of noxious weeds and other major vegetation at the time of certification. These sites could be remeasured to create a strong, province-wide analysis which would demonstrate the long-term persistence (or lack thereof) of noxious weeds.
2	Literature review	Improved understand of noxious weed physiology (capacity for competing with woody species) in a reclamation setting.	Conduct competition study between select noxious weeds and woody species (focusing on range of species morphologies); this could be done in an outdoor but controlled (in terms of other vegetation) plot study and/or potentially in a greenhouse container trial (providing sufficiently large containers). This study should also compare 'competition' that woody species would normally be exposed to in reclamation setting to provide context around competition exposure (e.g., ask the question, are perennial sow thistles or perennial clovers more of a competition issue for survival and growth of white spruce?).

3	Literature review and Retrospective case study	The literature review found little evidence that many of the noxious weeds currently under management are actually problematic for forest development. Similarly, the retrospective case study also found little to no evidence that noxious plant species were inhibiting forest tree and shrub cover. The case study analysis was limited to correlations and observations of relative dominance over time. There still remains a need to explore, in an experimental setting, thresholds in noxious plant cover in relation to woody vegetation development to confirm that these species do not pose a significant risk to forest development.	Following from the suggestion in (2) the same (or similar) study could also look at threshold rates of competing noxious weed competition to ask the question – how much cover (or number of plants) is too much (are too many) for woody species?
4	Retrospective case study	In addition, this analysis coarsely examined overall woody vegetation development but did not examine species-specific patterns or potential constraints in growth due to noxious weeds.	More specifically to the points above, attention should be given to provide confirmatory evidence that most woody species follow the general patterns observed in this work.
5	Risk analysis framework	The risk analysis framework developed here was conceptual, based on the original RAT and considering key vegetation parameters identified in the retrospective case study. However, the RecRAT would require substantial additional data input (and likely model development) to provide quantitative and robust risk ratings.	Clear threshold level data would need to be provided as guidance on risk ratings (for the exposure risk). It would also need to be validated to identify what regions are truly 'green', 'yellow' or 'red'. Example study sites would be needed that represent the range of possible conditions to validate this chart.

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APPENDIX A: TABLES

Table A1. Data sets analyzed in the study with data file origin, the first year measured since reclamation and the number of measurement points conducted. Note that not all studies were measured annually. *Vegetation surveys were conducted and compiled by NAIT staff.

Reclamation site	Origin	Year first measured	Number of measurement points	Post-reclamation age (years) of measurement points
CNRL Airstrip*	CNRL	2015	4	1-4
ConocoPhillips / Nexen 2004 construction	ConocoPhillips	2005	6	1-5, 10
ConocoPhillips Stockpile*	ConocoPhillips	2016	3	1-3
CNRL Remote Sump*	CNRL	2012	5	1-5
CNRL Delineation Wells*	CNRL	2012	4	1-4
Suncor Base Mine	Suncor	2014	3	1, 3, 5

Table A2. Number of plot replicates at each reclamation site pooled by years since reclamation.

	Years since reclamation						
Reclamation site	1	2	3	4	5	10	Total
CNRL Airstrip	375	525	525	525			1950
ConocoPhillips / Nexen 2004 construction	400	400	400	400	400	400	2400
ConocoPhillips Stockpile	222	277	282				781
CNRL Remote Sump	30	135	135	135	135		570
CNRL Delineation Wells	18	18	18	18			72
Suncor Base Mine	145		194		194		533

Table A3. List of individual species (or genus's of closely related species in the case of clovers) and vegetation cover types analyzed in this study.

Noxious weeds
Perennial sow thistle (*Sonchus arvensis*)
Canada thistle (*Cirsium arvense*)
Scentless chamomile (*Tripleurospermum inodorum*)
Tall buttercup (*Ranunculus acris*)
Common tansy (*Tanacetum vulgare*)
Non-native species presented alongside noxious weeds
Sweet clover (*Melilotus* spp.)
Perennial clovers (*Trifolium* spp.)
Vegetation Cover Types
Woody (all trees and shrubs)
Native forbs
Non-native forbs (excludes noxious weeds)
Grasses (native and non-native species grouped)
Noxious weeds (only those species on the noxious weed list)

Table A4. Correlation coefficients for woody species vs. cover types (native forbs, non-native forbs, grasses and noxious weed cover) at six reclamation sites over a period of ten years since reclamation. Black font color denotes positive correlations, red font color denotes negative correlations. "---" = no measurements taken; "ZC" = zero cover for woody or cover type but present in different year. Bold correlation coefficients were significant at $P < 0.05$.

	Years since reclamation					
	1	2	3	4	5	10
Native forb cover						
CNRL Airstrip	**0.35**	**0.27**	0.05	**0.13**	---	---
ConocoPhillips / Nexen 2004 construction	0.07	**0.33**	0.02	0.07	**-0.18**	**-0.16**
ConocoPhillips Stockpile	**0.45**	0.05	**0.48**	---	---	---
CNRL Remote Sump	ZC	0.32	-0.04	**0.6**	**0.65**	---
CNRL Delineation Wells	ZC	**0.61**	-0.43	0.45	---	---
Suncor Base Mine	**0.2**	---	0.02	---	0.01	---
Non-native forb cover						
CNRL Airstrip	-0.08	**0.14**	-0.08	-0.1	---	---
ConocoPhillips / Nexen 2004 construction	0.76	-0.24	0.03	0.03	0.17	**-0.2**
ConocoPhillips Stockpile	0.1	**-0.28**	-0.12	---	---	---
CNRL Remote Sump	ZC	**-0.73**	-0.18	**0.54**	0.04	---
CNRL Delineation Wells	ZC	**-0.63**	-0.37	-0.42	---	---
Suncor Base Mine	0.04	---	-0.11	---	-0.16	---
Grasses						
CNRL Airstrip	-0.1	-0.03	-0.09	-0.07	---	---
ConocoPhillips / Nexen 2004 construction	0.04	0.02	**-0.17**	**-0.27**	**-0.23**	**-0.4**
ConocoPhillips Stockpile	**0.33**	0.1	**0.28**	---	---	---
CNRL Remote Sump	ZC	**-0.46**	-0.06	**0.59**	-0.02	---
CNRL Delineation Wells	ZC	<0.01	-0.27	-0.41	---	---
Suncor Base Mine	**0.21**	---	<0.01	---	**-0.16**	---
Noxious weed cover						
CNRL Airstrip	0.66	0.13	**0.28**	<0.01	---	---
ConocoPhillips / Nexen 2004 construction	ZC	0.12	ZC	-0.28	0.06	0.33
ConocoPhillips Stockpile	0.26	0.13	0.08	---	---	---
CNRL Remote Sump	ZC	-0.12	-0.05	0.07	0.61	---
CNRL Delineation Wells	ZC	ZC	ZC	0.66	---	---
Suncor Base Mine	**0.25**	---	0.07	---	-0.02	---

Table A5. Correlation coefficients for woody species vs. noxious weeds and non-native forb species at six reclamation sites over a period of ten years since reclamation. Black font color denotes positive correlations, red font color denotes negative correlations. "---" = no measurements taken; "ZC" = zero cover for woody or cover type but present in different year; "n < 3" = not enough finite observations to perform Pearson's correlation test; "NP" = not present at any time point. Bold correlation coefficients were significant at $P < 0.05$.

	Years since reclamation					
	1	2	3	4	5	10
Perennial sow thistle						
CNRL Airstrip	n < 3	**0.38**	-0.07	0.04	---	---
ConocoPhillips / Nexen 2004 construction	ZC	0.14	ZC	-0.28	0.06	**0.85**
ConocoPhillips Stockpile	0.41	0.01	0.04	---	---	---
CNRL Remote Sump	ZC	-0.12	-0.12	0.07	ZC	---
CNRL Delineation Wells	ZC	ZC	ZC	0.66	---	---
Suncor Base Mine	**0.24**	---	0.07	---	-0.01	---
Canada thistle						
CNRL Airstrip	0.65	-0.04	**0.55**	0.05	---	---
ConocoPhillips / Nexen 2004 construction	ZC	ZC	ZC	ZC	ZC	n < 3
ConocoPhillips Stockpile	n < 3	n < 3	n < 3	---	---	---
CNRL Remote Sump	ZC	ZC	-0.2	ZC	ZC	---
CNRL Delineation Wells	ZC	n < 3	n < 3	ZC	---	---
Suncor Base Mine	-0.26	---	-0.04	---	-0.14	---
Scentless chamomile						
CNRL Airstrip	ZC	ZC	ZC	-0.11	---	---
ConocoPhillips / Nexen 2004 construction	ZC	ZC	n < 3	ZC	ZC	ZC
ConocoPhillips Stockpile	0.3	0.16	-0.05	---	---	---
CNRL Remote Sump	NP	NP	NP	NP	NP	---
CNRL Delineation Wells	NP	NP	NP	NP	---	---
Suncor Base Mine	NP	---	NP	---	NP	---
Tall buttercup						
CNRL Airstrip	NP	NP	NP	NP	---	---
ConocoPhillips / Nexen 2004 construction	ZC	n < 3	ZC	ZC	ZC	ZC
ConocoPhillips Stockpile	NP	NP	NP	---	---	---
CNRL Remote Sump	NP	NP	NP	NP	NP	---
CNRL Delineation Wells	NP	NP	NP	NP	---	---
Suncor Base Mine	NP	---	NP	---	NP	---

Table A5 continued

	Years since reclamation					
	1	2	3	4	5	10
Common tansy						
CNRL Airstrip	NP	NP	NP	NP	---	---
ConocoPhillips / Nexen 2004 construction	NP	NP	NP	NP	NP	NP
ConocoPhillips Stockpile	NP	NP	NP	---	---	---
CNRL Remote Sump	NP	NP	NP	NP	NP	---
CNRL Delineation Wells	NP	NP	NP	NP	---	---
Suncor Base Mine	n < 3	---	n < 3	---	n < 3	---
Sweet clover						
CNRL Airstrip	0.01	0.1	**0.16**	-0.1	---	---
ConocoPhillips / Nexen 2004 construction	n < 3	ZC	ZC	ZC	ZC	n < 3
ConocoPhillips Stockpile	0.16	**-0.17**	-0.13	---	---	---
CNRL Remote Sump	ZC	0.71	-0.16	**0.58**	0.13	---
CNRL Delineation Wells	ZC	n < 3	ZC	n < 3	---	---
Suncor Base Mine	-0.01	---	-0.09	---	-0.04	---
Perennial clovers						
CNRL Airstrip	0.07	**0.13**	<0.01	-0.11	---	---
ConocoPhillips / Nexen 2004 construction	ZC	-0.02	0.05	-0.25	-0.18	**-0.42**
ConocoPhillips Stockpile	0.04	**-0.19**	-0.1	---	---	---
CNRL Remote Sump	ZC	ZC	-0.26	**0.97**	-0.32	---
CNRL Delineation Wells	ZC	-0.45	-0.21	-0.68	---	---
Suncor Base Mine	-0.46	---	0.53	---	0.23	---

Table A6. Table summary illustrating trending increase or decrease in relative dominance of vegetation cover groups, noxious weeds and clovers over time by site type. Symbols indicate increasing (↑), decreasing (↓), no change (–) or highly variable (≅) trends in relative dominance over time. *Denotes trends that are visible, but the magnitude of the change was very small (<2%). NP = not present.

	CNRL Airstrip	**Conoco / Nexen 2004 construction**	**ConocoPhillips Stockpile**	**CNRL Remote Sump**	**CNRL Delineation Wells**	**Suncor Base Mine**
Woody	↑	↑	↑	↑	↑	↑
Native forbs	–	↓	≅	–	↓	↓
Non-native forbs	↓	↑*	↓	↑	↓	↓
Grasses	↑	↓	≅	≅	↑	↑
Noxious weeds	↑	–	↑*	↓	↓*	↓*
Perennial sow thistle	↑*	↓	↑	↓	↓*	≅
Canada thistle	↑*	NP	–	↓	NP	NP
Scentless chamomile	–	NP	–	NP	NP	NP
Sweet clover	≅	–	↓	↑	–	–
Perennial clover	↓	↓	↓	↓	↓	–

Table A7. Alberta Agriculture and Forestry risk assessment tool questions and inputted responses for the three commonly occurring noxious weeds (sow thistle, Canada thistle and scentless chamomile) observed from the case study data.

#	Question	Sow thistle	Canada thistle	Scentless chamomile	Potential responses					
EXPOSURE RISK										
1	Is the species present in the assessment area?	Confirmed	Confirmed	Confirmed	Not present	Likely Not present	Likely Present	Confirmed	Unknown	
2	What is the abundance of the species in the assessment area?	Scattered	Scattered	Abundant	No abundance	Rare / Trace	Occasional	Scattered	Abundant	Unknown
3	How is the species distributed within the assessment area?	Widespread	Localized	Widespread	No distribution	Isolated	Localized	Widespread	Unknown	
4	What are the potential invasion pathways into the assessment area?	Combination of natural and anthropogenic pathways	Combination of natural and anthropogenic pathways	Combination of natural and anthropogenic pathways	Only natural pathways	Only anthropogenic pathways	Combination of natural and anthropogenic pathways	Unknown		
5	What is the likelihood of re-introduction from the source of the invasion?	Continuous / ongoing re-intro possible	Continuous / ongoing re-intro possible	Sporadic	Unlikely, original intro one-time occurrence	Sporadic	Continuous / ongoing re-intro possible	Unknown		
6	How likely is the organism to survive in transit?	likely to survive but number of individuals originally transported is reduced	likely to survive but number of individuals originally transported is reduced	likely to survive but number of individuals originally transported is reduced	will not survive	limited survival	likely to survive but number of individuals originally transported is reduced	likely to survive with no negative effect the number of individuals being transported	Unknown	
7	What is the likelihood of detecting the organism along its invasion pathway(s) into the assessment area?	likely to be missed	likely to be missed	likely to be missed	easy to detect	somewhat difficult to detect, mechanisms for detection exist	somewhat difficult to detect, no mechanisms for detection exist	likely to be missed	Unknown	
8	If introduced, how many individuals are likely to be released?	few individuals, multiple introduction events	few individuals, multiple introduction events	few individuals, multiple introduction events	one	few individuals, one introduction event	few individuals, multiple introduction events	many individuals, one or multiple introduction events	Unknown	
9	How much habitat is available for the species within the assessment area?	Less than half of the area	Less than half of the area	Less than half of the area	No available Habitat	Less than half of the area	Majority of the area	Entire area	Unknown	
10	How can the climate (i.e. weather) within the assessment area affect the survival of the species?	No limiting effect	No limiting effect	No limiting effect	Prevents survival	Limits survival	No limiting effect	Promote survival	Unknown	
11	Does the species have a broad tolerance to environmental conditions?	can establishes in a broad range of environmental conditions	can establishes in a broad range of environmental conditions	can establishes in a broad range of environmental conditions	establishes only in a narrow range of environmental conditions	rarely establishes in less than ideal conditions	sometimes establishes in less than ideal conditions	can establishes in a broad range of environmental conditions	Unknown	
12	Has the organism demonstrated the ability to colonize undisturbed or natural communities?	does not invade natural/undisturbed communities	colonizes natural communities (infrequently) but prefers communities with major disturbances (frequently)	colonizes natural communities (infrequently) but prefers communities with major disturbances (frequently)	does not invade natural/undisturbed communities	colonizes in communities with major disturbance only	colonizes natural communities (infrequently) but prefers communities with major disturbances (frequently)	often colonizes natural or undisturbed communities	Unknown	

13	Are the organism's specific requirements for reproduction available in the assessment area?	species requires no specific requirements, or all requirements are available.	species requires no specific requirements, or all requirements are available.	species requires no specific requirements, or all requirements are available.	specific requirements not available	some specific requirement(s) are available	most requirements for reproduction are available	species requires no specific requirements, or all requirements are available.	Unknown	
14	What is the frequency of sexual reproduction?	Once per year	Once per year	Once per year	Almost Never	Less than once a year	Once per year	More than once per year	Unknown	
15	What is the rate of growth to reproductive maturity?	Rapid growth	Rapid growth	Rapid growth	Slow growth	Moderate growth	Rapid growth	Unknown		
16	How many viable offspring can the organism produce at one time?	Many	Many	Many	Very few or none	Few	Moderate	Many	Unknown	
17	Is asexual reproduction (e.g. vegetative reproduction or self-fertilization) an important aspect of this organism's reproduction?	None	Moderately Important	None	None	Not important	Moderately Important	Highly important	Unknown	
18	Does the opportunity exist to hybridize naturally with species present in the assessment area?	no close relatives, little to no chance of hybridization	no close relatives, little to no chance of hybridization	no close relatives, little to no chance of hybridization	no close relatives, little to no chance of hybridization	one or two hybridization opportunities but likelihood of occurrence is low	many hybridization opportunities exist but likelihood of occurrence is low	many hybridization opportunities exist and likelihood of occurrence is high	Unknown	
19	Are there known natural control agents, including predators, in the assessment area?	Unknown	Unknown	Unknown	Predators and/or control agents are or have the potential to severely to completely restricting population growth	Predators and/or control agents are present and are or have the potential to minimizing population growth	Predators and/or control agents are present but are not or do not have the potential to affecting population growth	No known control agents present	Unknown	
20	To what degree can the organism disperse naturally?	Local dispersal	Local dispersal	Local dispersal	No potential	Local dispersal	Regional dispersal	Provincial dispersal	Unknown	
21	To what degree will anthropogenic mechanisms assist the dispersal of this species within the assessment area?	Several mechanisms	Several mechanisms	Several mechanisms	No mechanisms	Few mechanisms	Several mechanisms	Many mechanisms	Unknown	
22	What is the rate of dispersal once the species is released or disperses into a new area?	Moderate rate of dispersal	Moderate rate of dispersal	Slow rate of dispersal	Does not disperse	Slow rate of dispersal	Moderate rate of dispersal	Rapid rate of dispersal	Unknown	
ENVIRONMENTAL RISK										
23	Is the species known to compete for resources with desired non-native species?	Moderate effect	Moderate effect	Moderate effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
24	Is the species known to compete for resources with secure or abundant native species?	Mild effect	Mild effect	Mild effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
25	Is the species known to compete for resources with vulnerable or "at risk" species?	Moderate effect	Moderate effect	Moderate effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
26	Is the species a predator or parasite of desired non-native species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	

27	Is the species a predator or parasite of secure or abundant native species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
28	Is the species a predator or parasite of vulnerable or "at risk" species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
29	Is the species a host or vector for known diseases, parasites, or pests that will cause harm to desired non-native species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
30	Is the species a host or vector for known diseases, parasites, or pests that will cause harm to secure or abundant native species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
31	Is the species a host or vector for known diseases, parasites, or pests that will cause harm to vulnerable or "at risk" species?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
32	Is the species able to hybridize with desired non-native species?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
33	Is the species able to hybridize with secure or abundant native species?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
34	Is the species able to hybridize with vulnerable or "at risk" species?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
35	What is the potential level of effect on abiotic or ecosystem processes?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
ECONOMIC										
36	What are the expected effects of the species on the crop industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
37	What are the expected effects of the species on the livestock industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
38	What are the expected effects of the species on the dairy farm industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
39	What are the expected effects of the species on the greenhouse industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
40	What are the expected effects of the species on the aquaculture industry?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown	
41	What are the expected effects of the species on the commercial and recreational fishing industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown	

42	What are the expected effects of the species on the food processing industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
43	What is the potential risk to the forestry industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
44	What is the potential risk to the non-timber forest product industry?	Unknown	Unknown	Unknown	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
45	What will be the expected effects on the tourism industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
46	What will be the expected effects on the energy industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
47	What are the expected effects of the species on infrastructure?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
48	What will be the expected effects on the health care industry?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
49	What will be the expected effects on Alberta's exports?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
SOCIAL											
50	What will be the expected effects on human health and well-being?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
51	What will be the expected effects on recreation activities?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
52	What will be the expected effects on aesthetic values?	Mild effect	Mild effect	Mild effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
53	What will be the expected effects on the urban environment?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
54	To what extent will the species decrease scientific research opportunities?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
55	What will be the expected effects of the species on places of traditional value or cultural value?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
56	To what extent will the species lead to reduced or lost traditional habitats or food supplies?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
57	To what extent will the species decrease nature-based educational opportunities?	No effect	No effect	No effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		
58	Will the species affect the perception that something of natural value will continue to exist?	Mild effect	Mild effect	Mild effect	No effect	Mild effect	Moderate effect	Severe effect	Unknown		

APPENDIX B: FIGURES

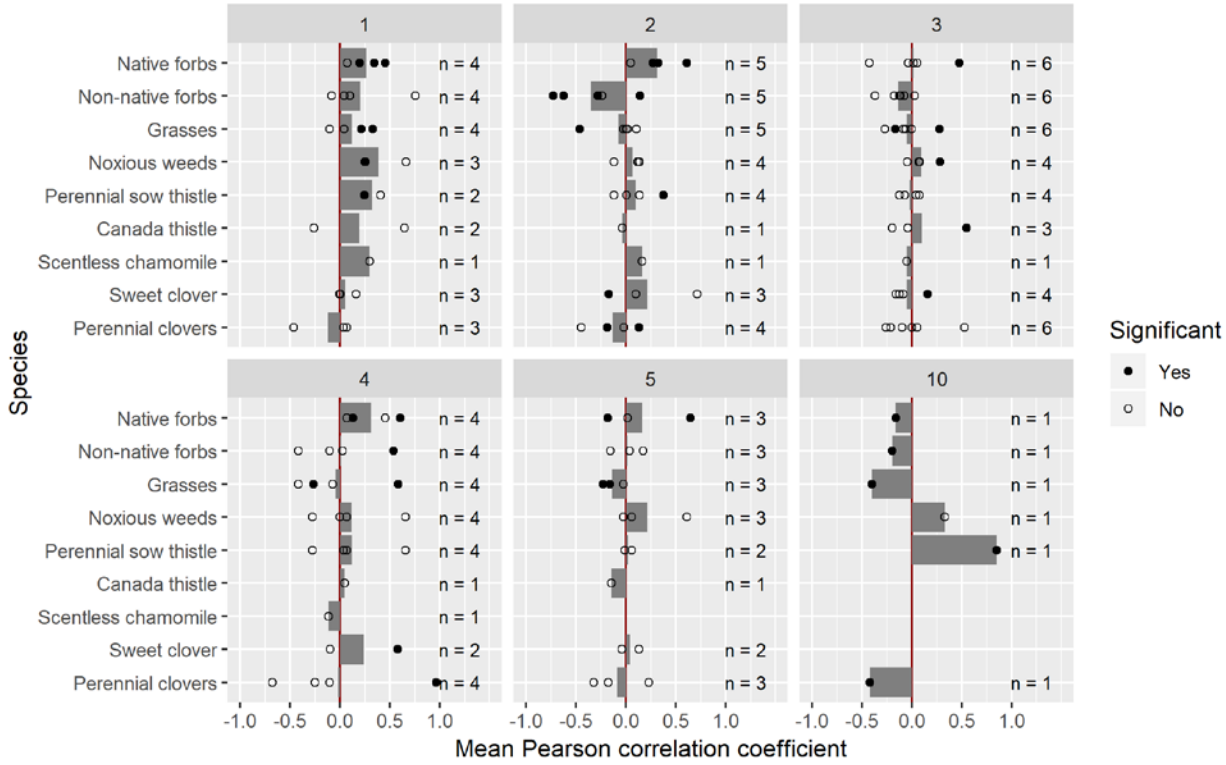

Figure B1. Mean Pearson correlation coefficients woody cover vs. cover types and species by reclamation site. Circles represent individual correlation coefficients (by Site and Year). Filled circles are coefficients that are significant, hollow circles are coefficients that are not significant ($\alpha < 0.05$). If no mean values are present (bars), not enough finite observations were available to perform Pearson's correlation test.

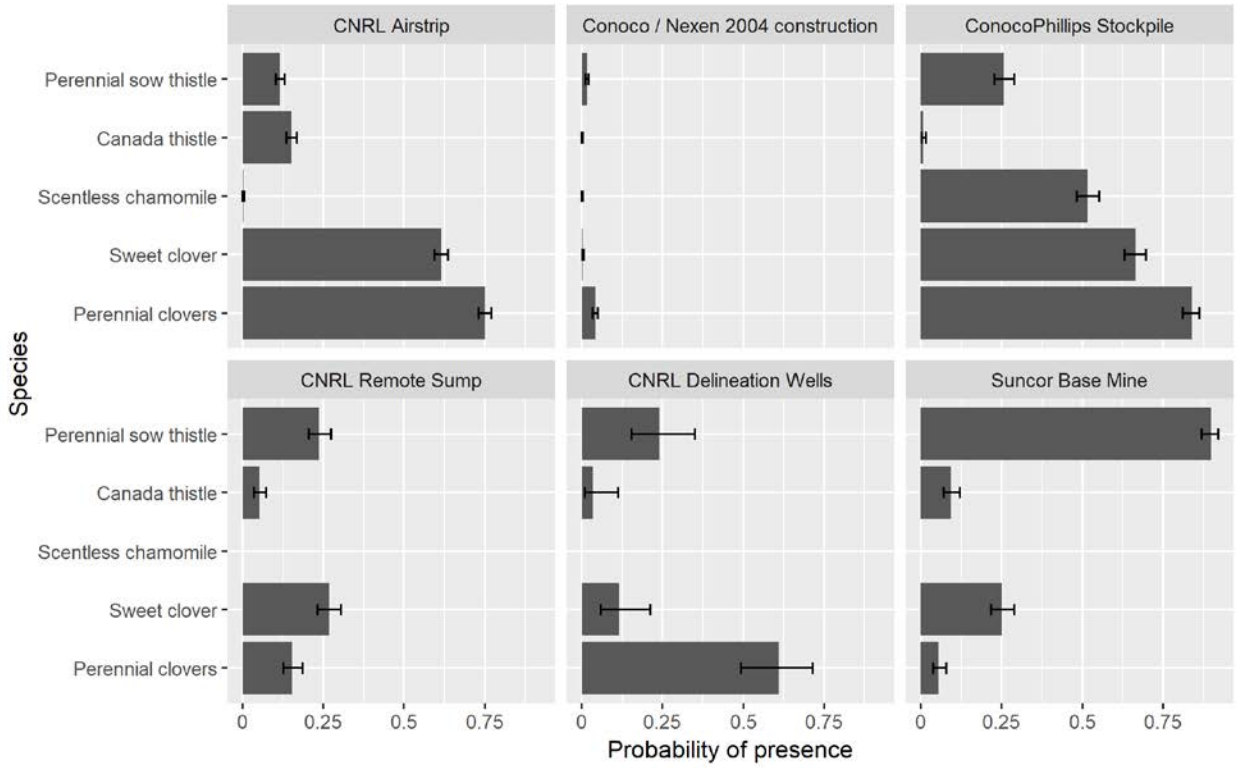

Figure B2. Mean probability of species presence at six reclamation sites (across years). Error bars represent the 95% confidence interval.

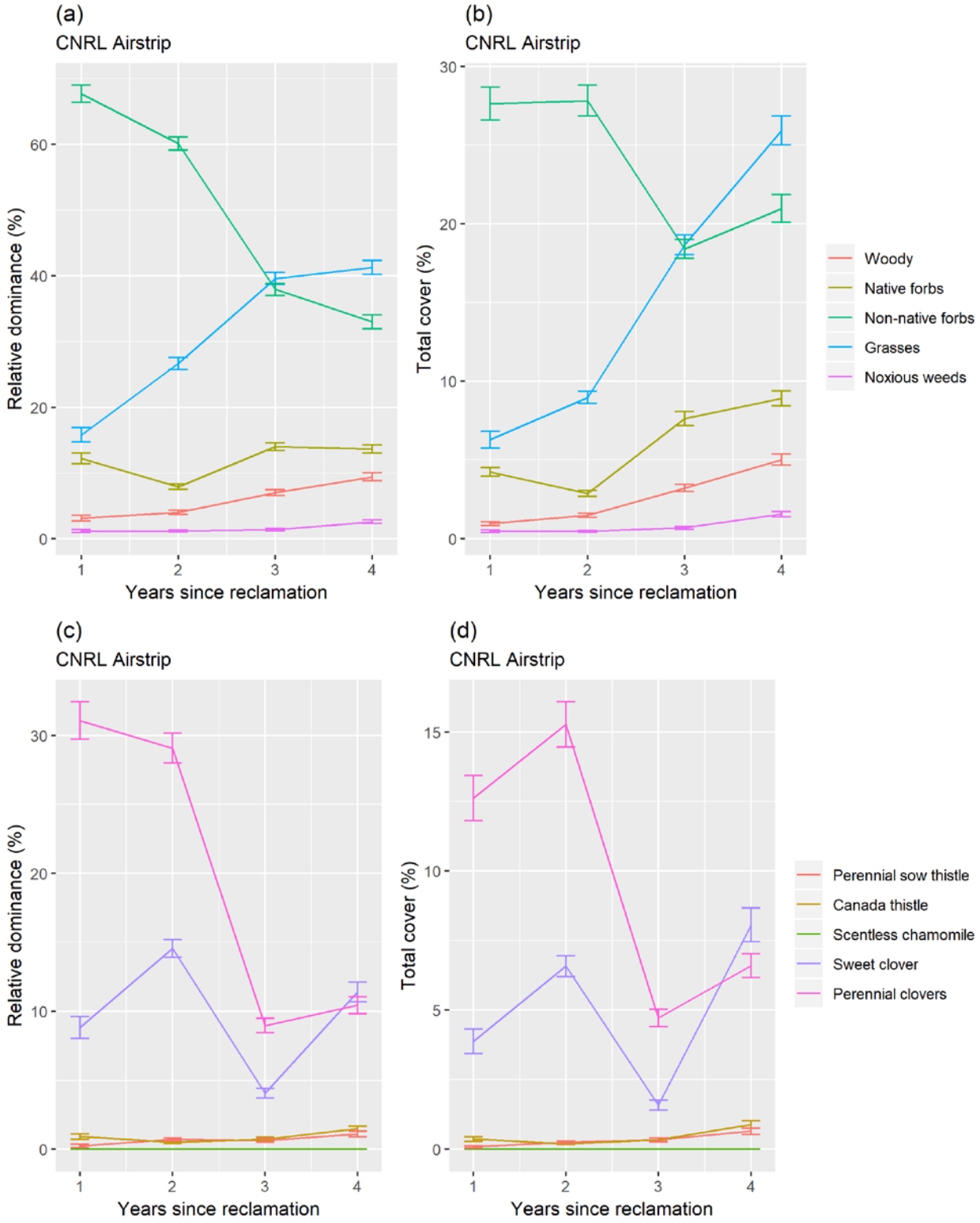

Figure B3. Relative dominance and total cover at the CNRL Airstrip reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

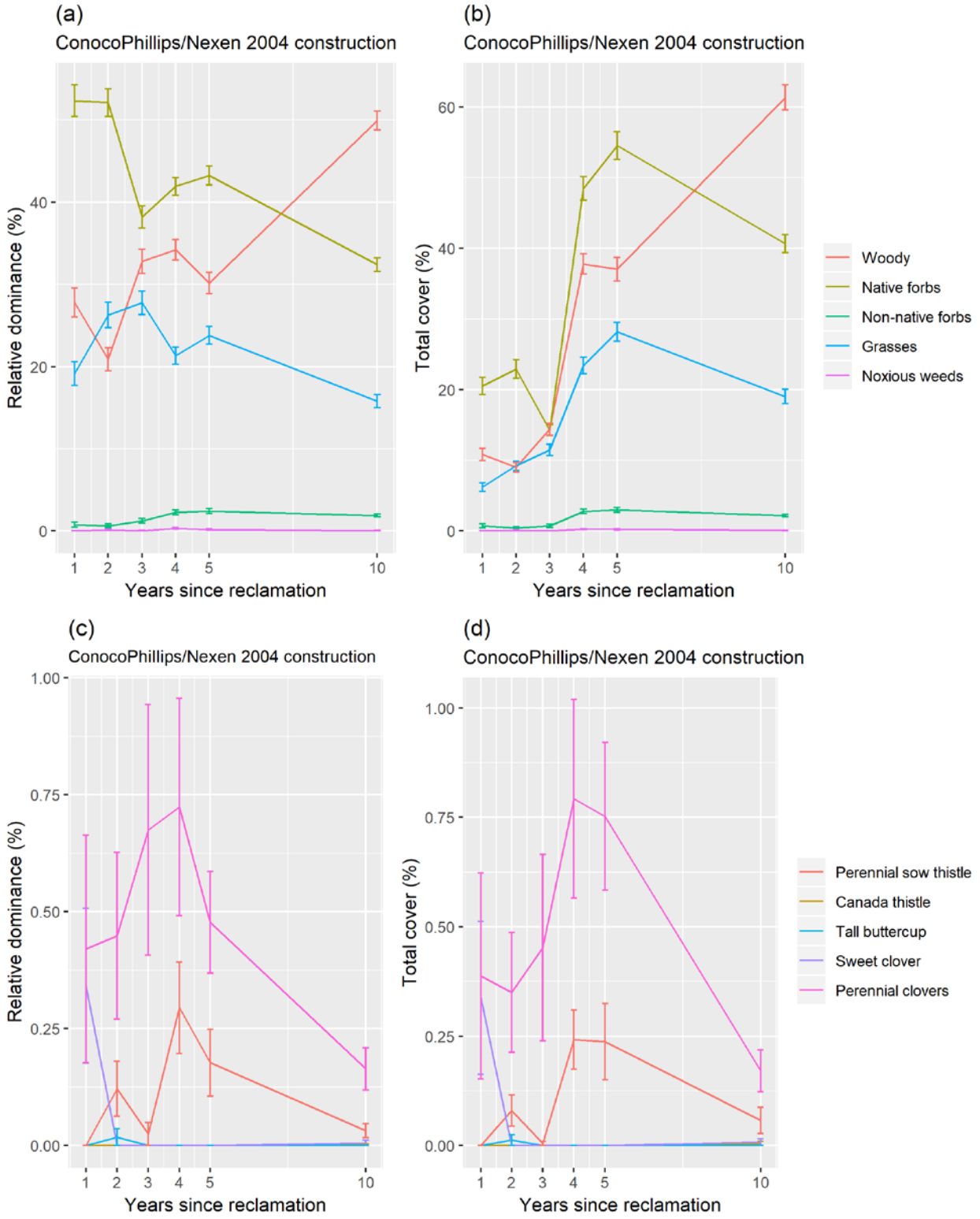

Figure B4. Relative dominance and total cover at the ConocoPhillips/Nexen 2004 construction reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

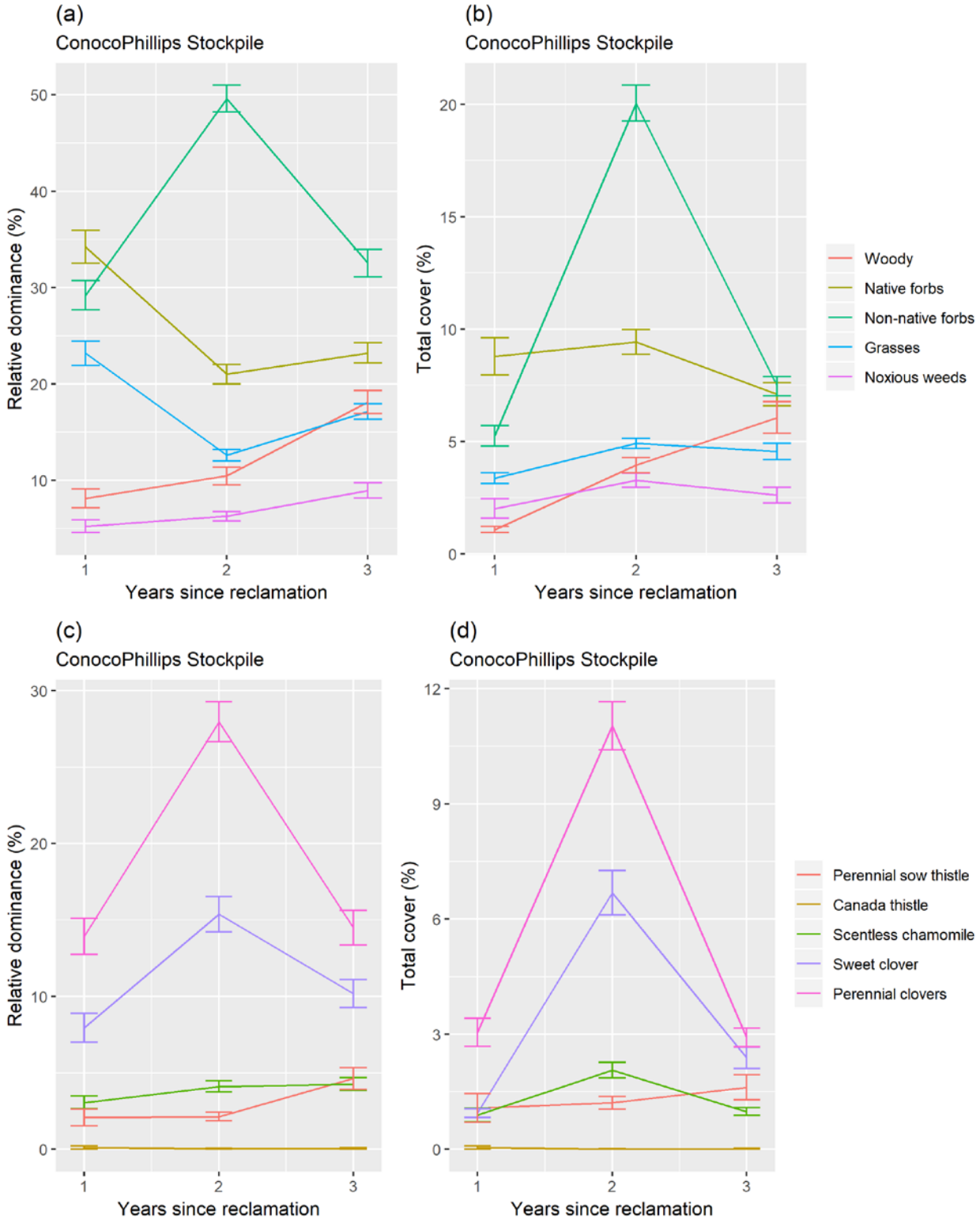

Figure B5. Relative dominance and total cover at the ConocoPhillips Stockpile reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

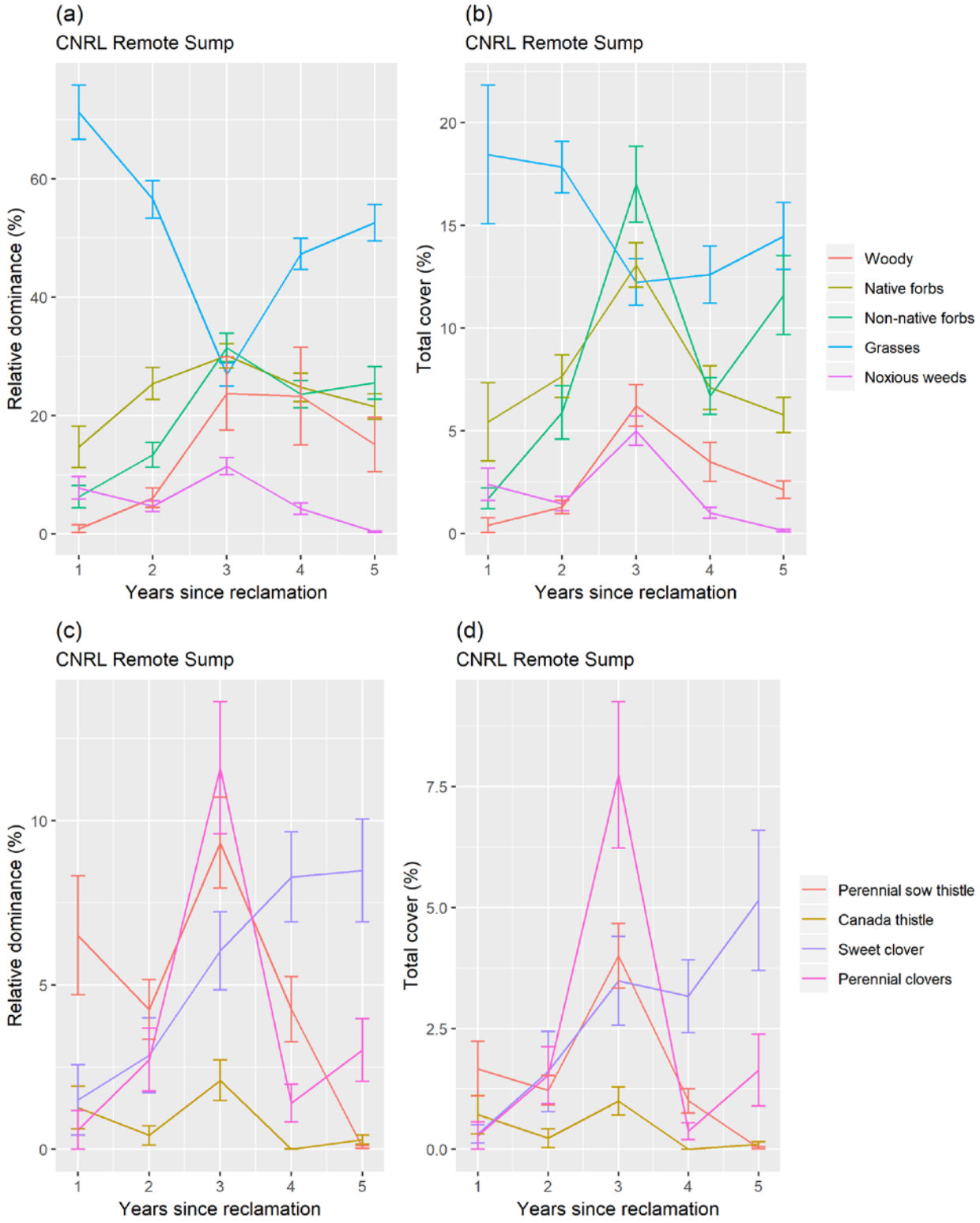

Figure B6. Relative dominance and total cover at the CNRL Remote Sump reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

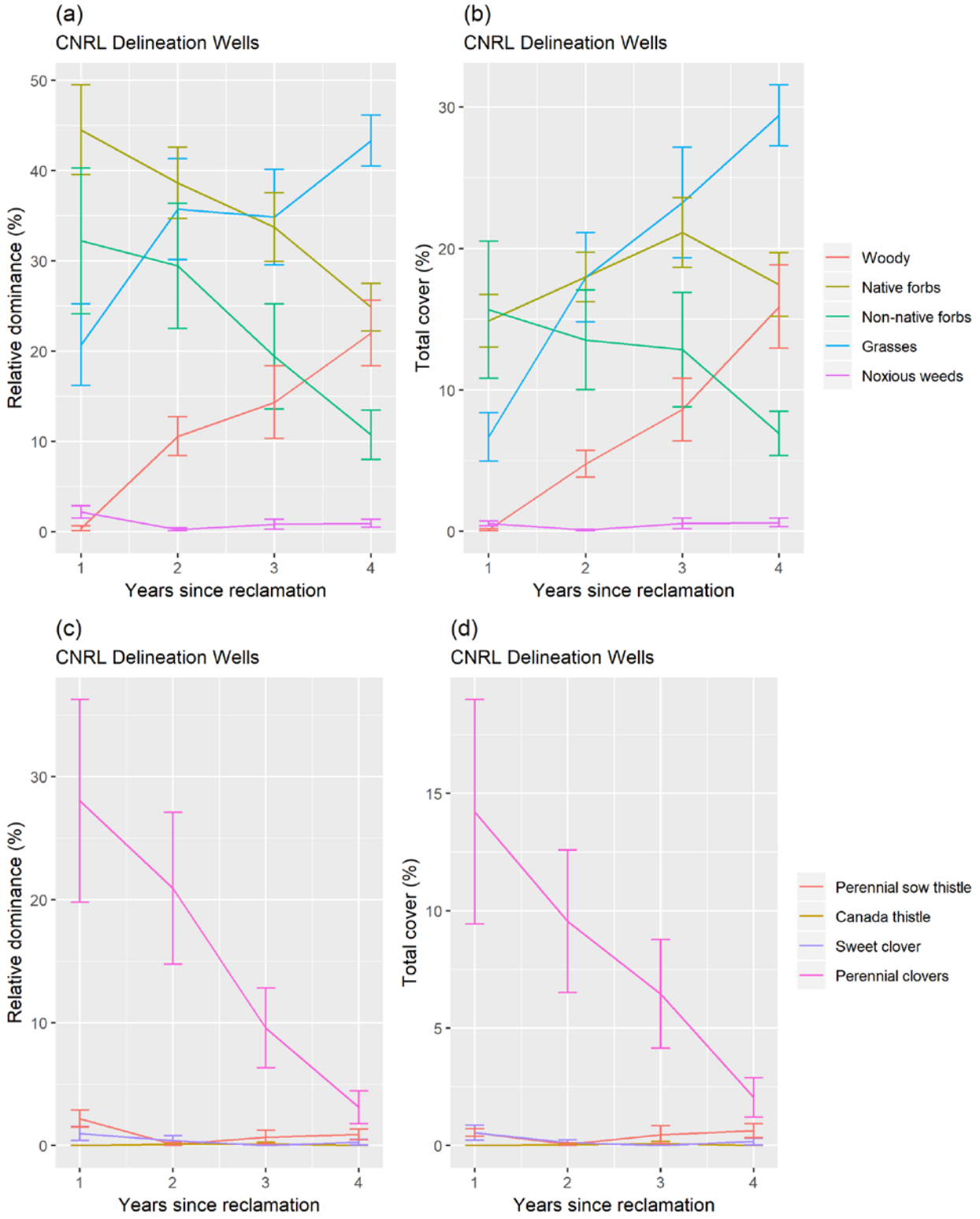

Figure B7. Relative dominance and total cover at the CNRL Delineation Wells reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

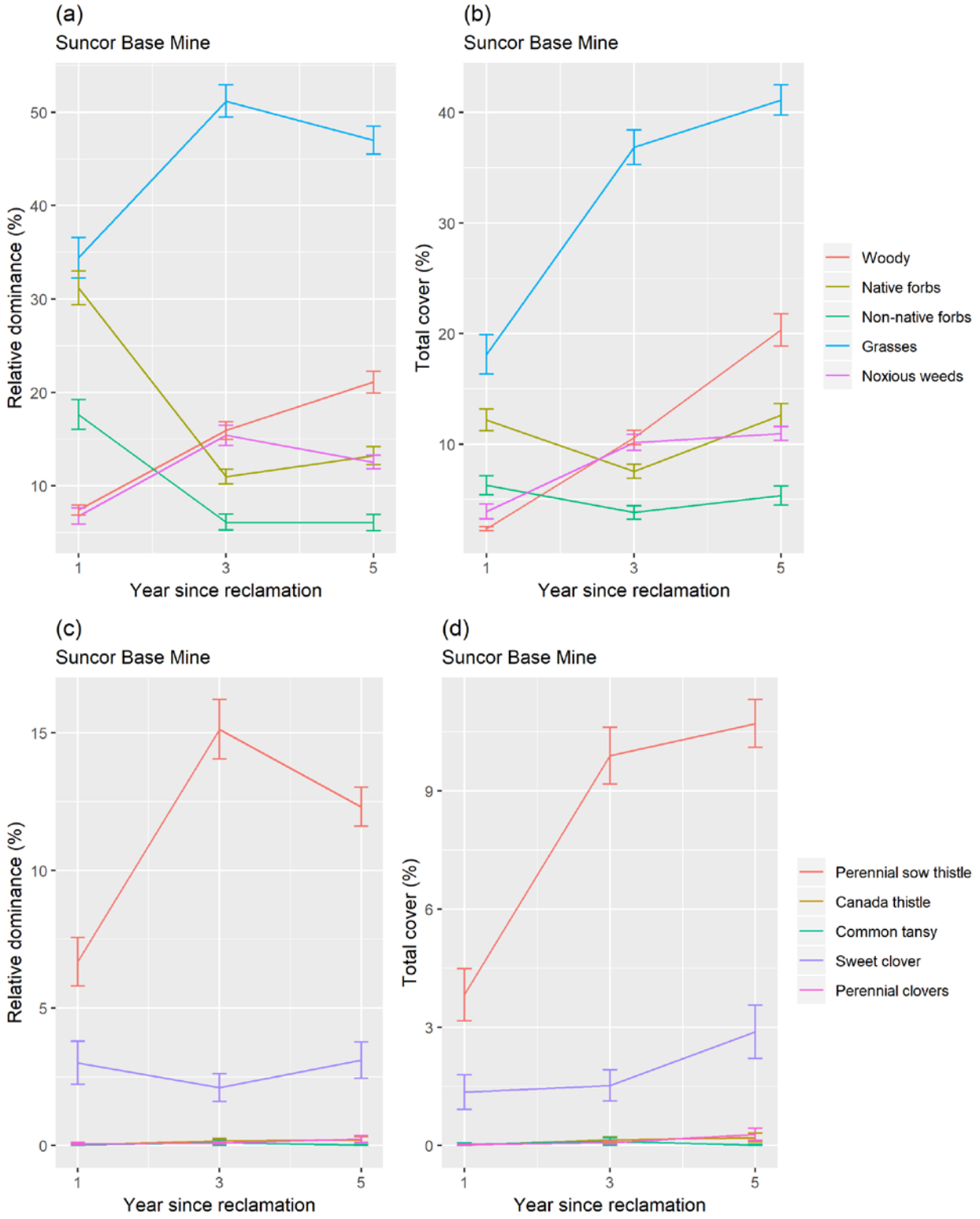

Figure B8. Relative dominance and total cover at the Suncor Base Mine reclamation site for vegetation cover types (a, b) and noxious weed species and non-native nuisance species (c, d). Error bars represent one standard error of the mean. Note: Noxious weed species were excluded from non-native cover values and were treated separately.

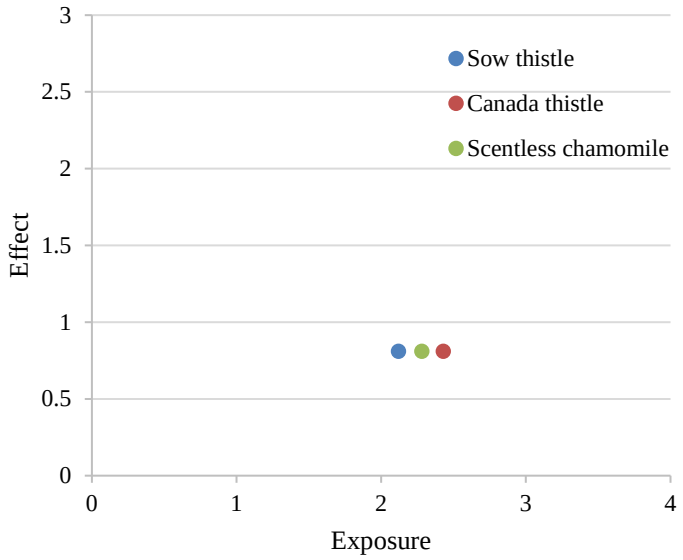

Figure B9. Exposure versus Effect ratings for sow thistle, Canada thistle and scentless chamomile, based on completion of the Alberta Agriculture and Forestry risk assessment tool for invasive species. Answers to the questions were based on the current condition and surrounding area of the ConocoPhillips Reclamation Stockpile.

APPENDIX C: PEARSON CORRELATIONS

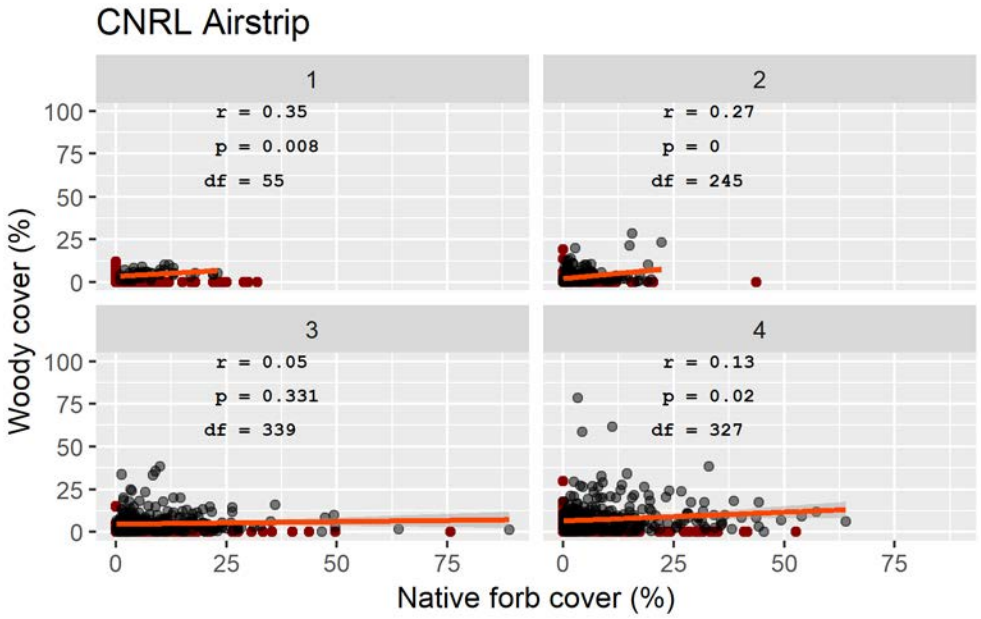

Figure C1. Pearson correlation of woody cover and native forb cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

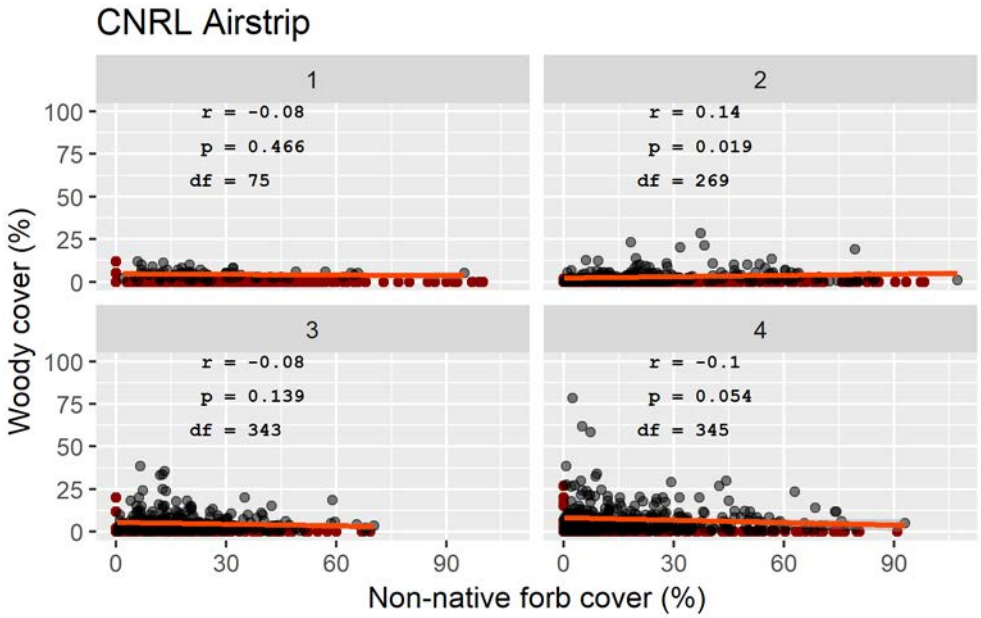

Figure C2. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

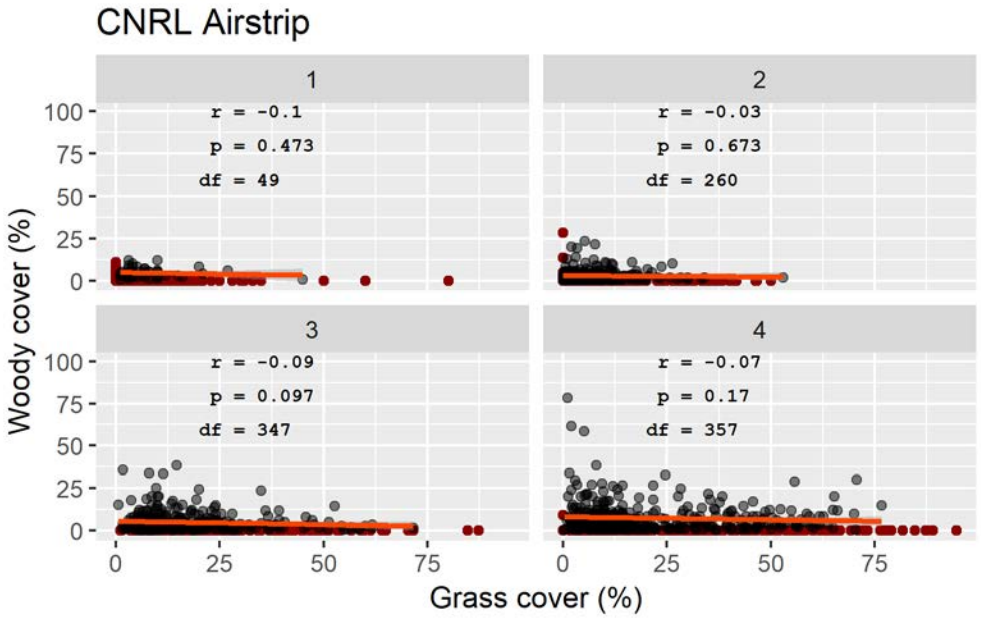

Figure C3. Pearson correlation of woody cover and grass cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

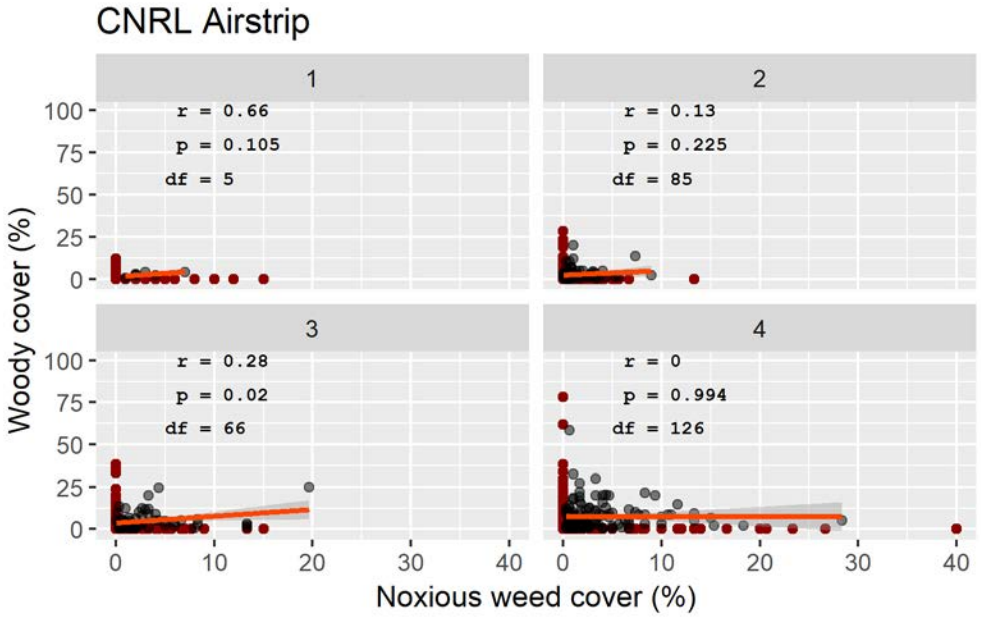

Figure C4. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

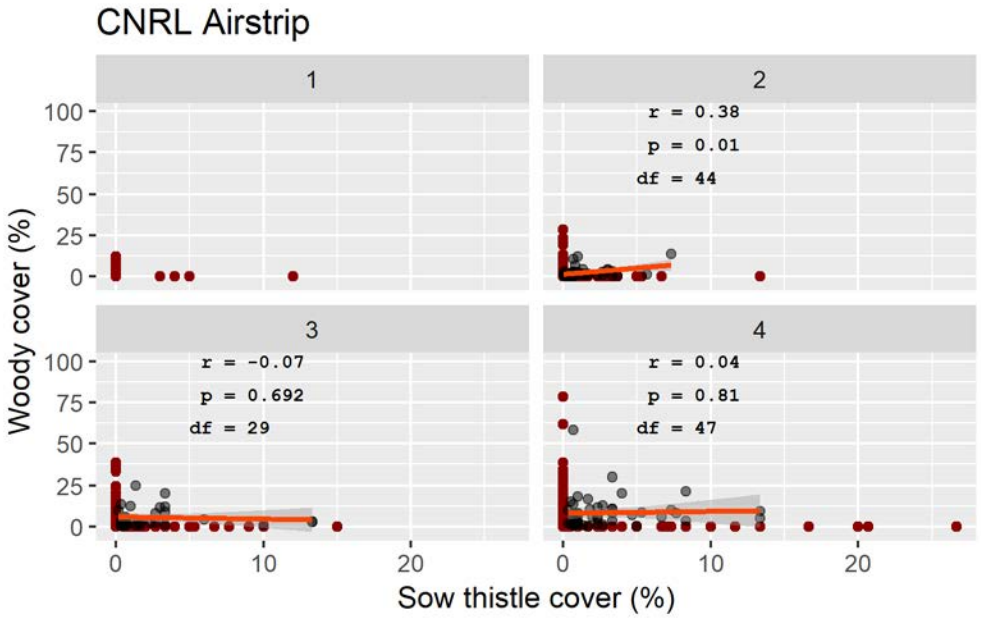

Figure C5. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

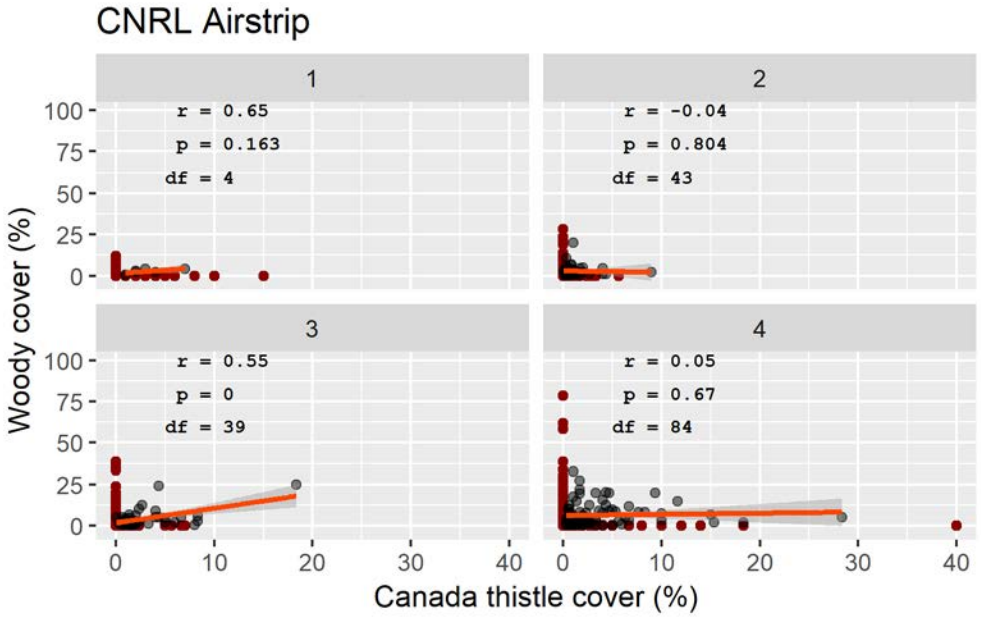

Figure C6. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

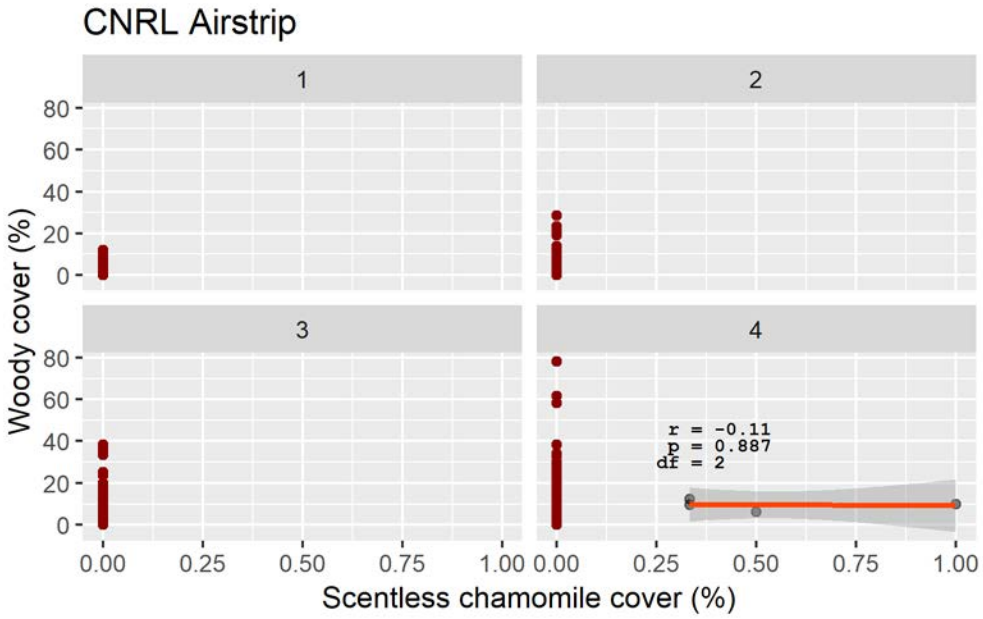

Figure C7. Pearson correlation of woody cover and scentless chamomile cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

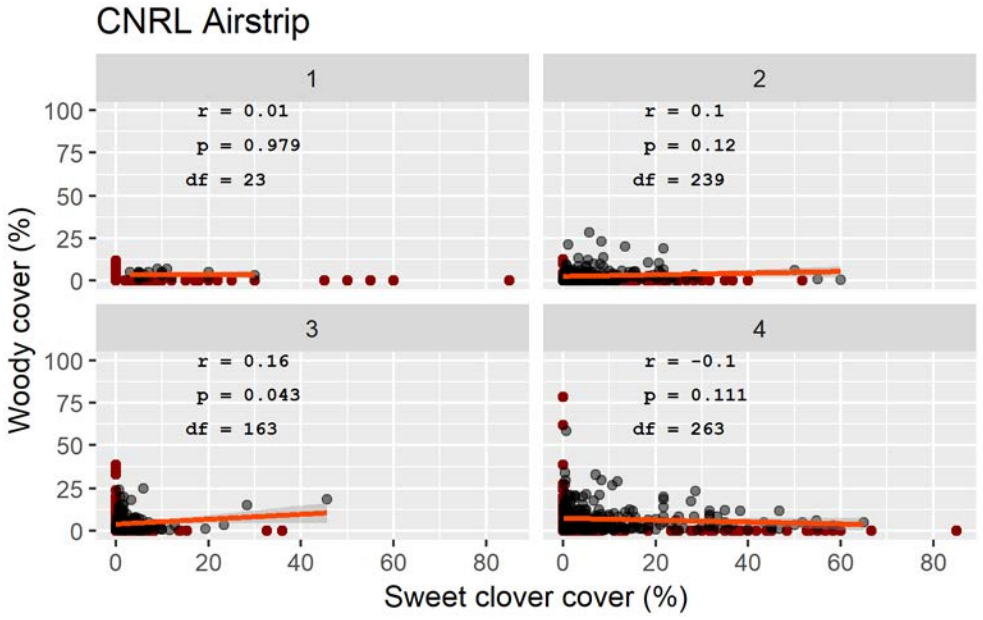

Figure C8. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

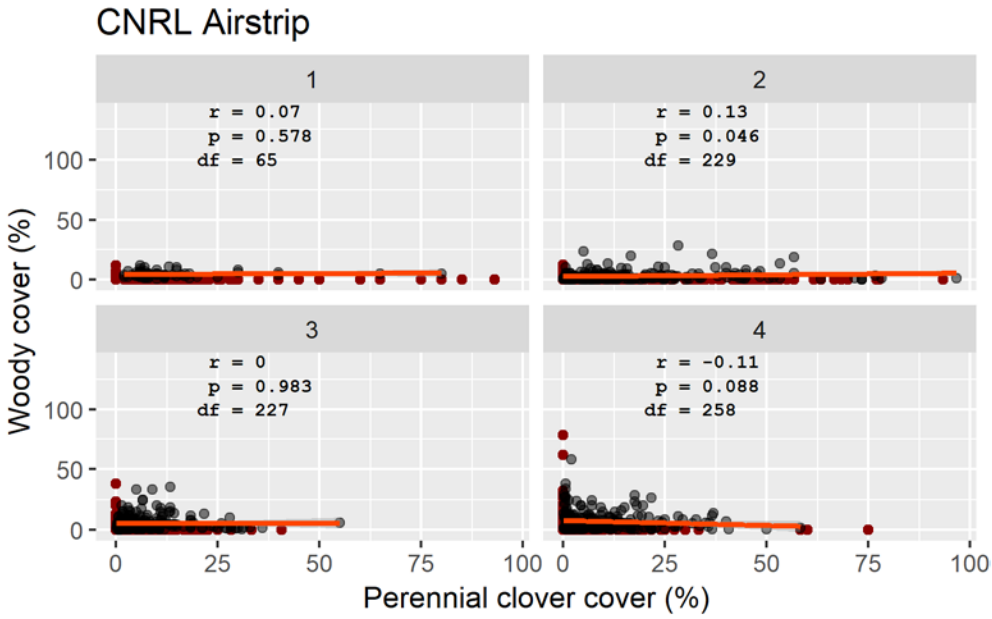

Figure C9. Pearson correlation of woody cover and perennial clovers cover by years since reclamation at the CNRL Airstrip reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

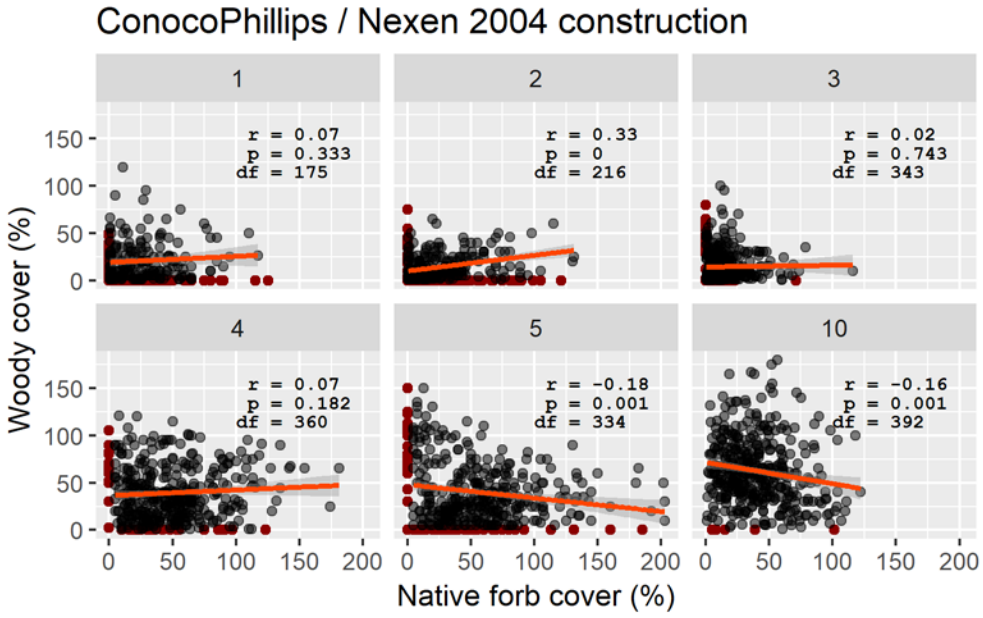

Figure C10. Pearson correlation of woody cover and native forb cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

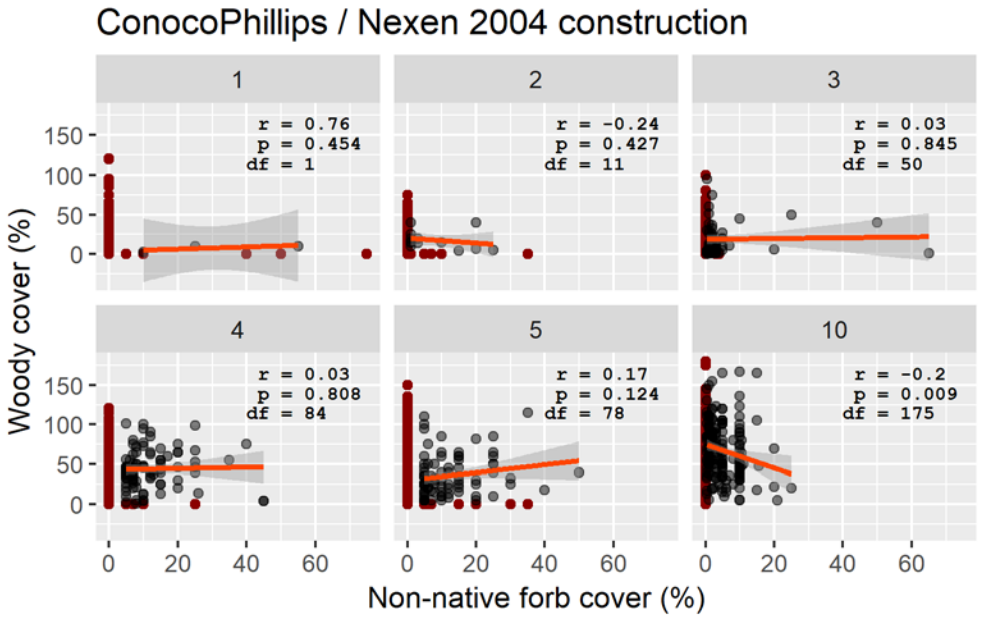

Figure C11. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

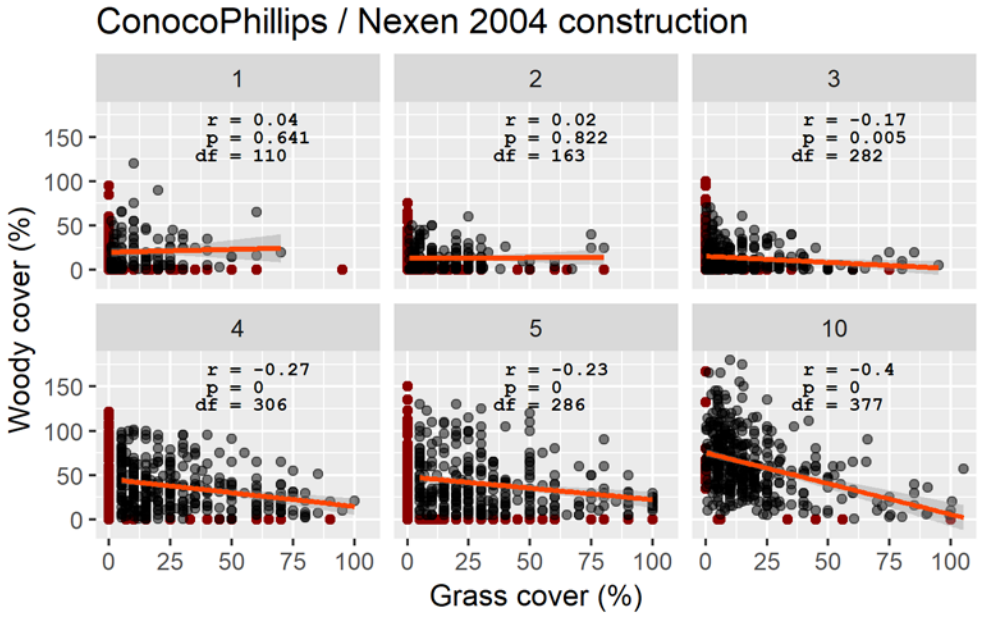

Figure C12. Pearson correlation of woody cover and grass cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

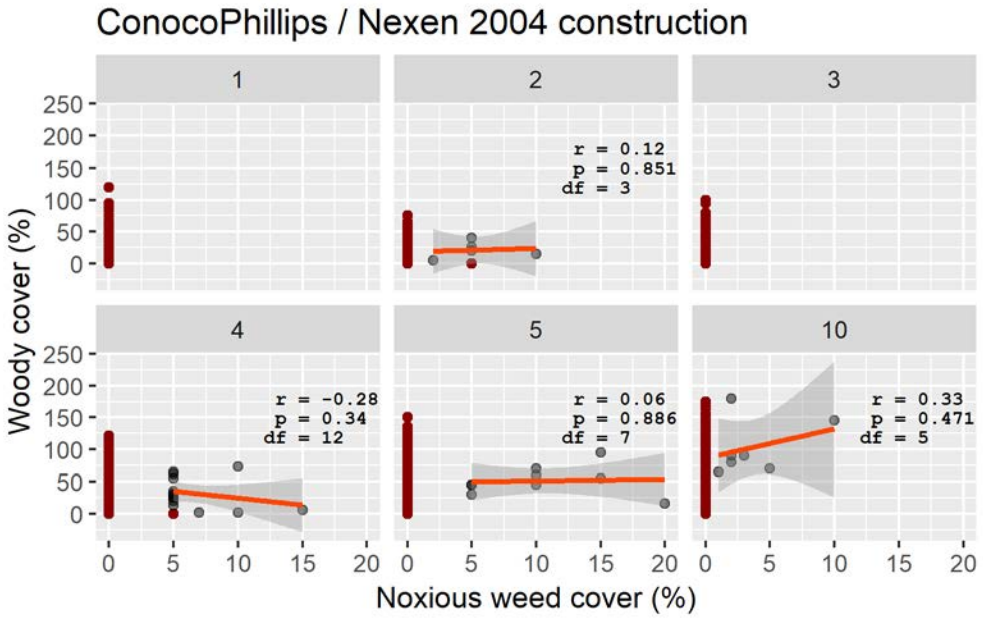

Figure C13. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

Figure C14. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

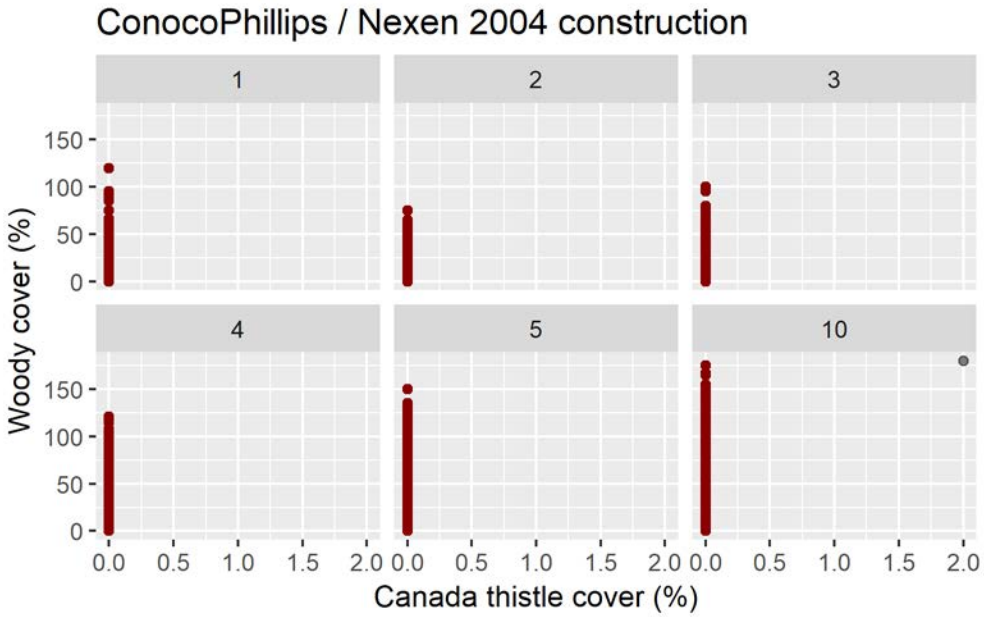

Figure C15. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

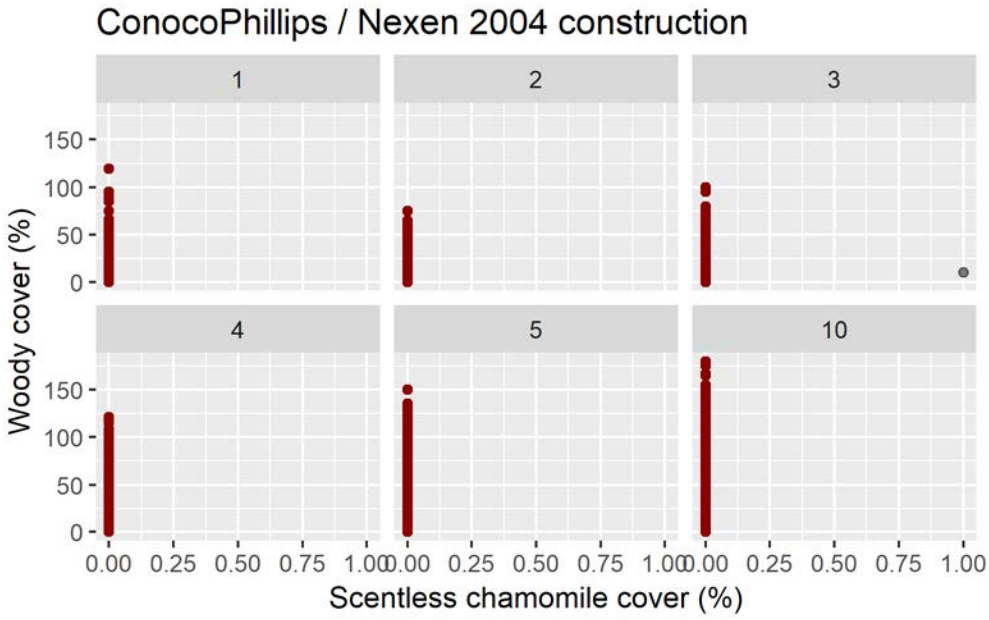

Figure C16. Pearson correlation of woody cover and scentless chamomile cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

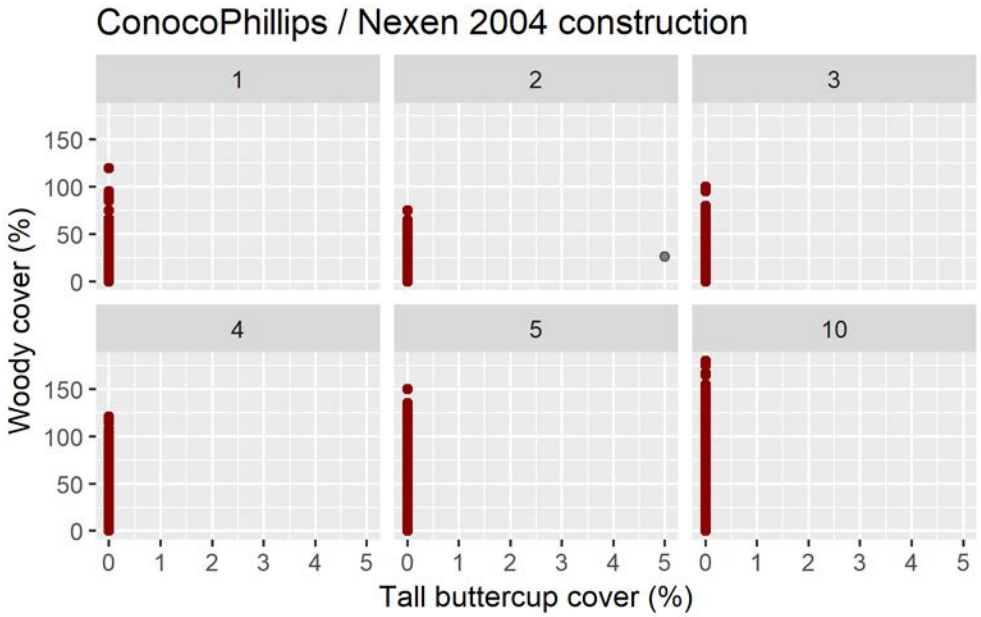

Figure C17. Pearson correlation of woody cover and tall buttercup cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

Figure C18. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

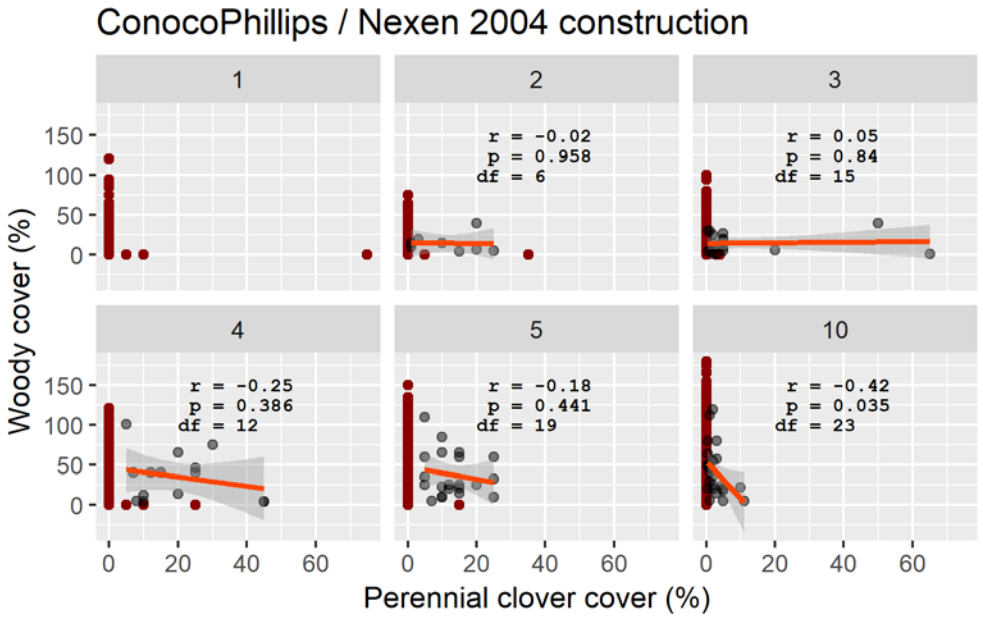

Figure C19. Pearson correlation of woody cover and perennial clover cover by years since reclamation at the ConocoPhillips / Nexen 2004 construction reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

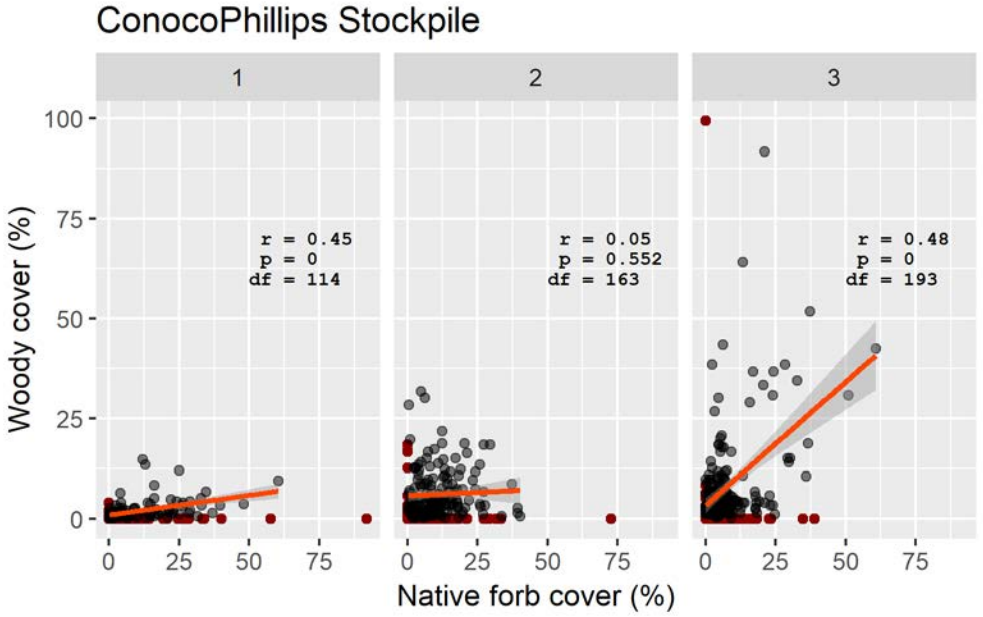

Figure C20. Pearson correlation of woody cover and native forb cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

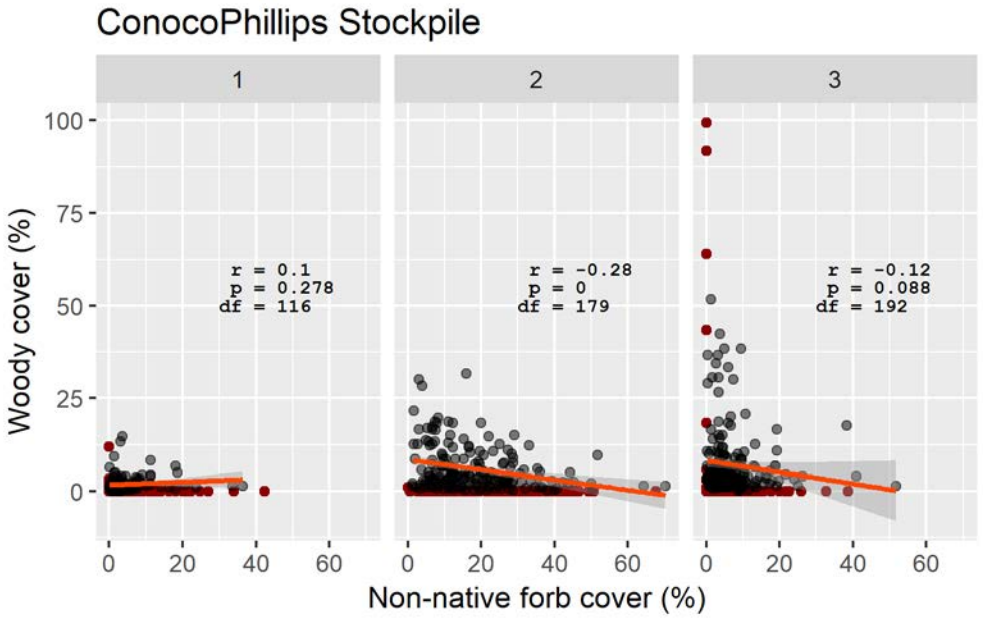

Figure C21. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

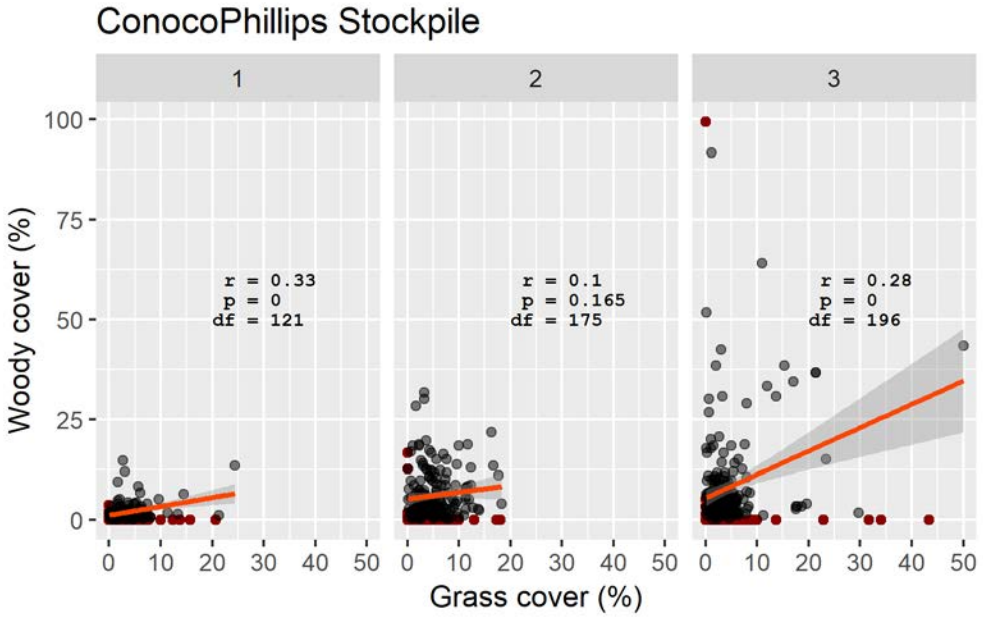

Figure C22. Pearson correlation of woody cover and grass cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

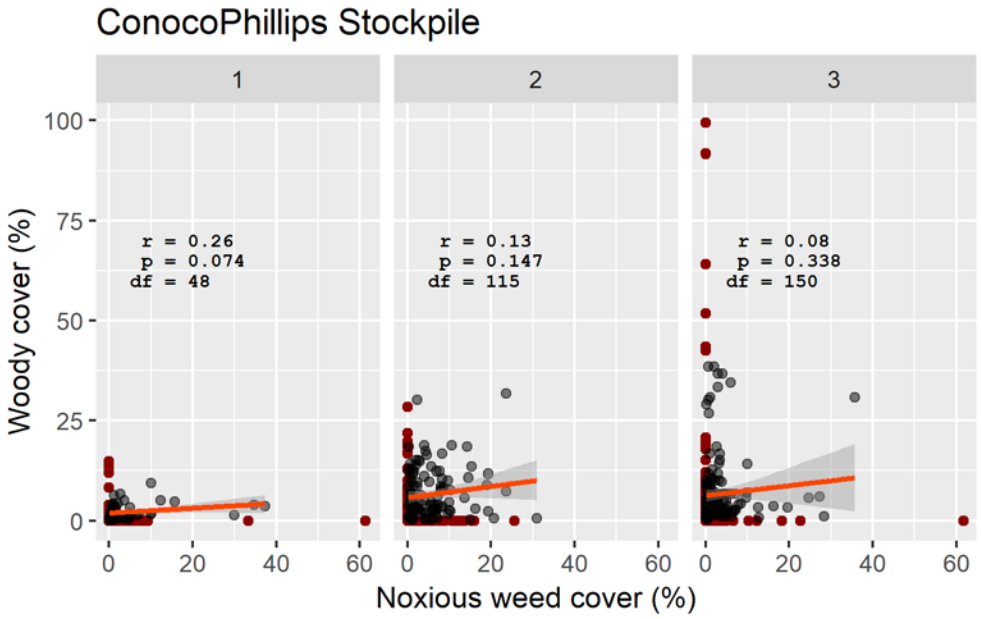

Figure C23. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

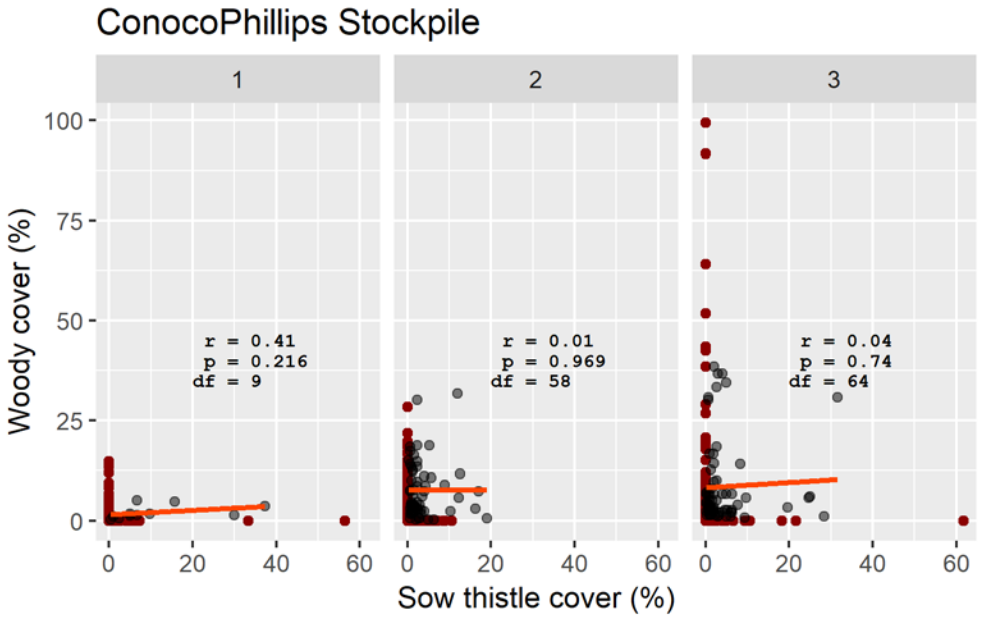

Figure C24. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

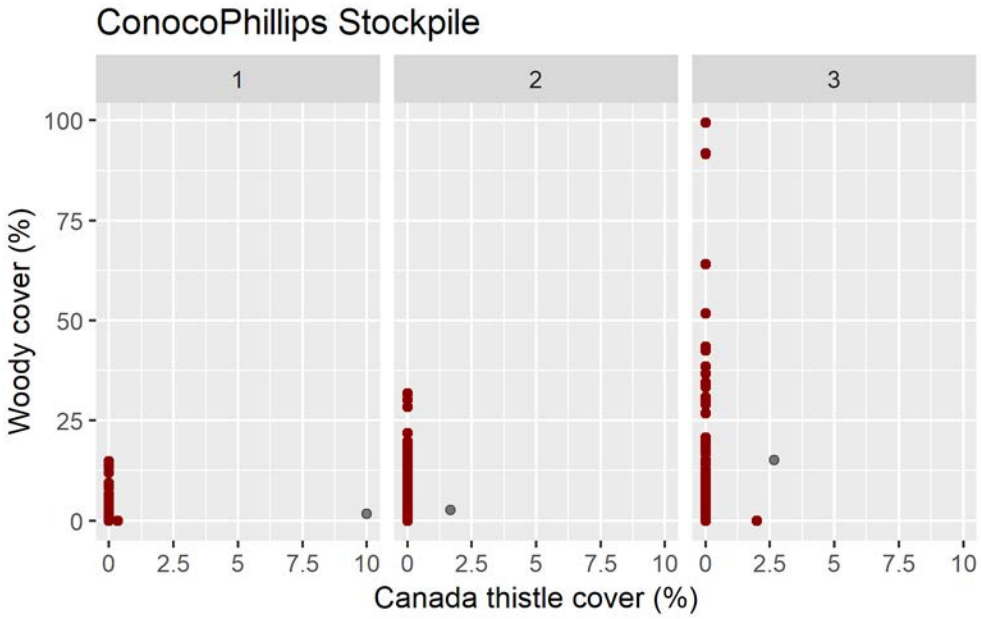

Figure C25. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

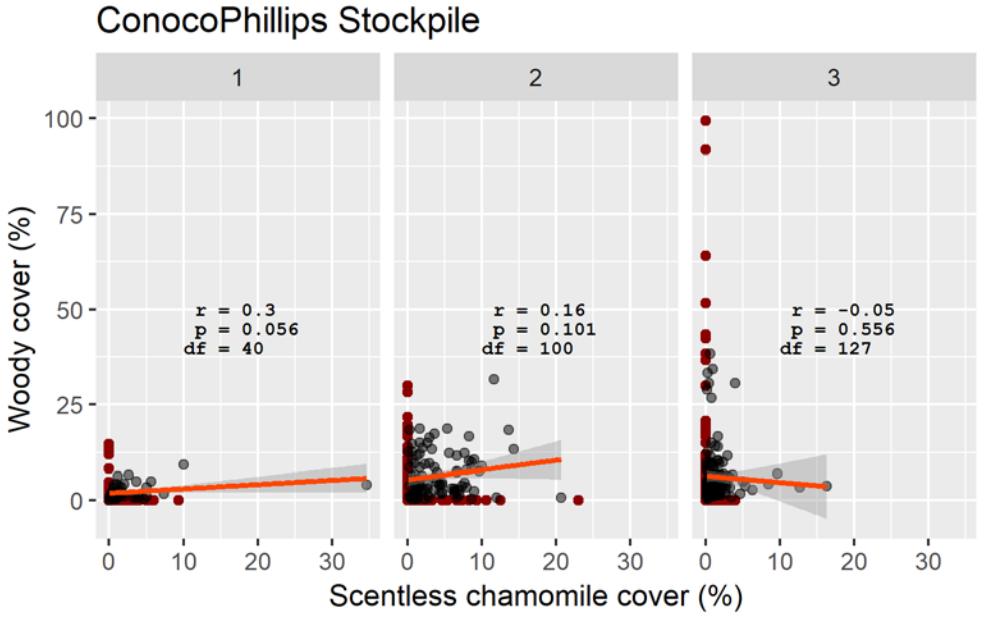

Figure C26. Pearson correlation of woody cover and scentless chamomile cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

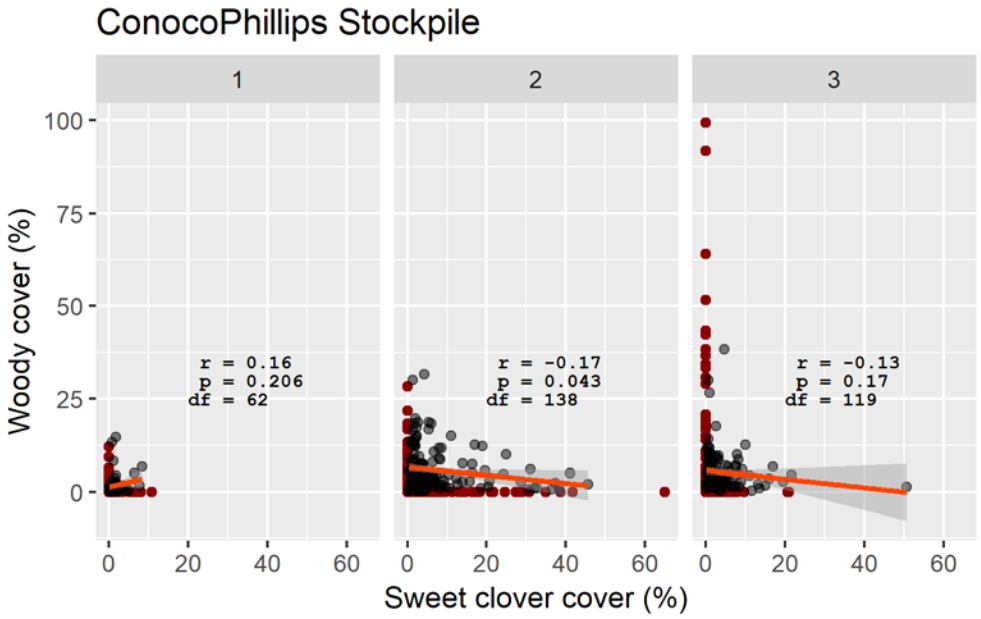

Figure C27. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

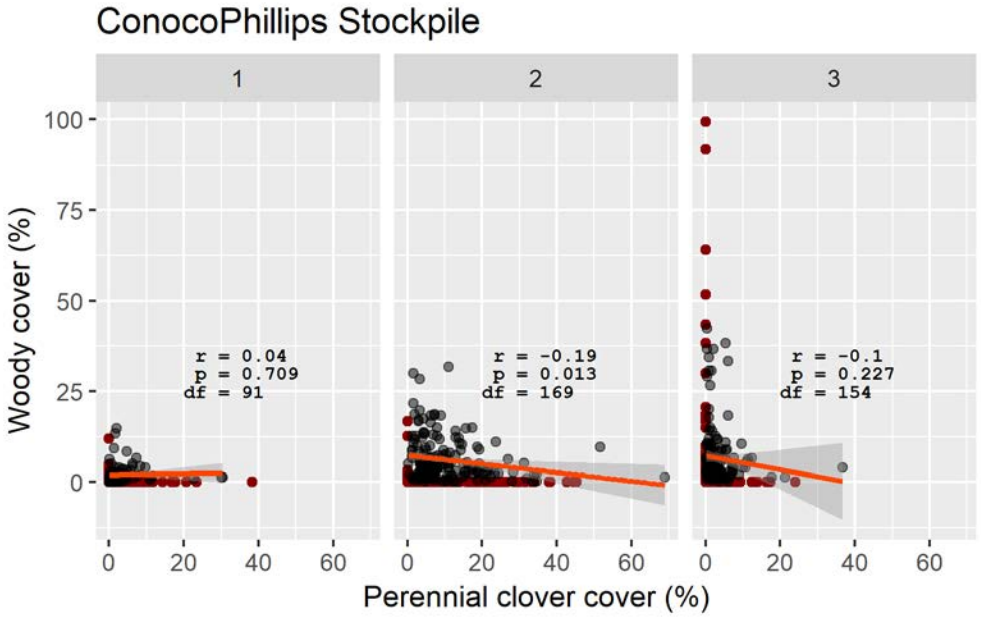

Figure C28. Pearson correlation of woody cover and perennial clover cover by years since reclamation at the ConocoPhillips Stockpile reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

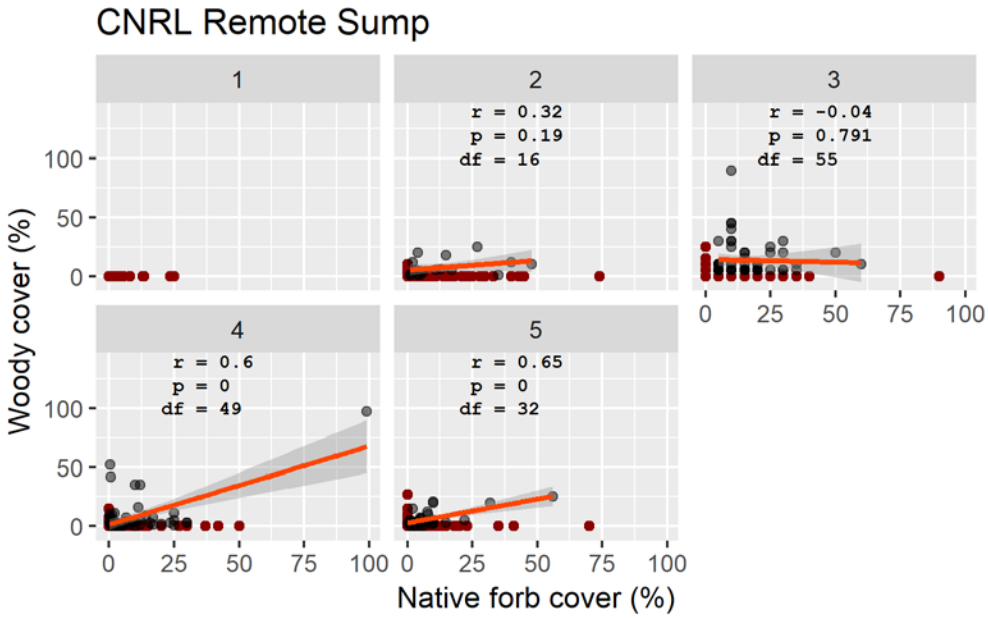

Figure C29. Pearson correlation of woody cover and native forb cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

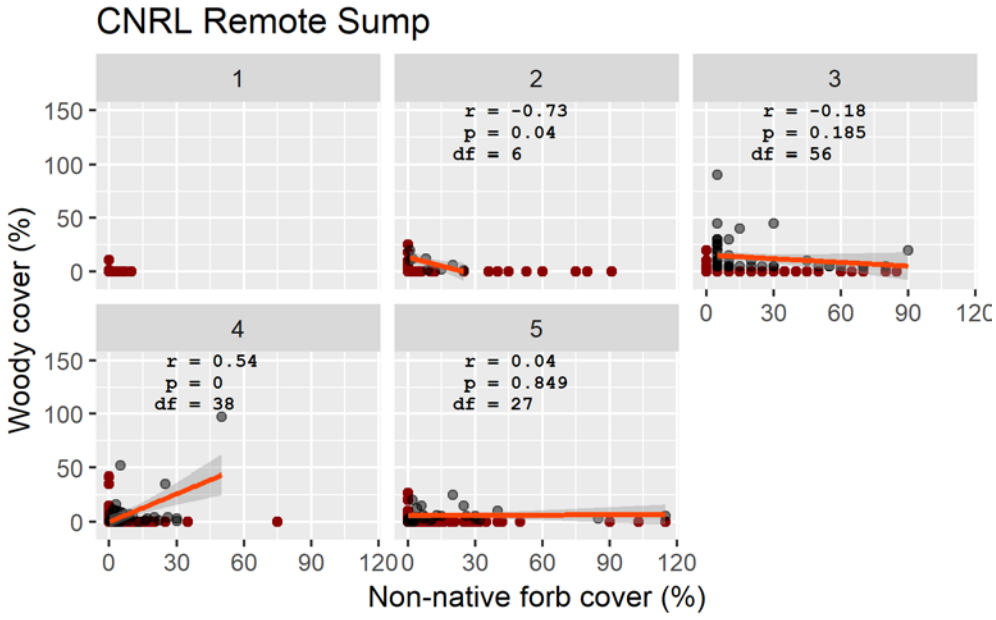

Figure C30. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

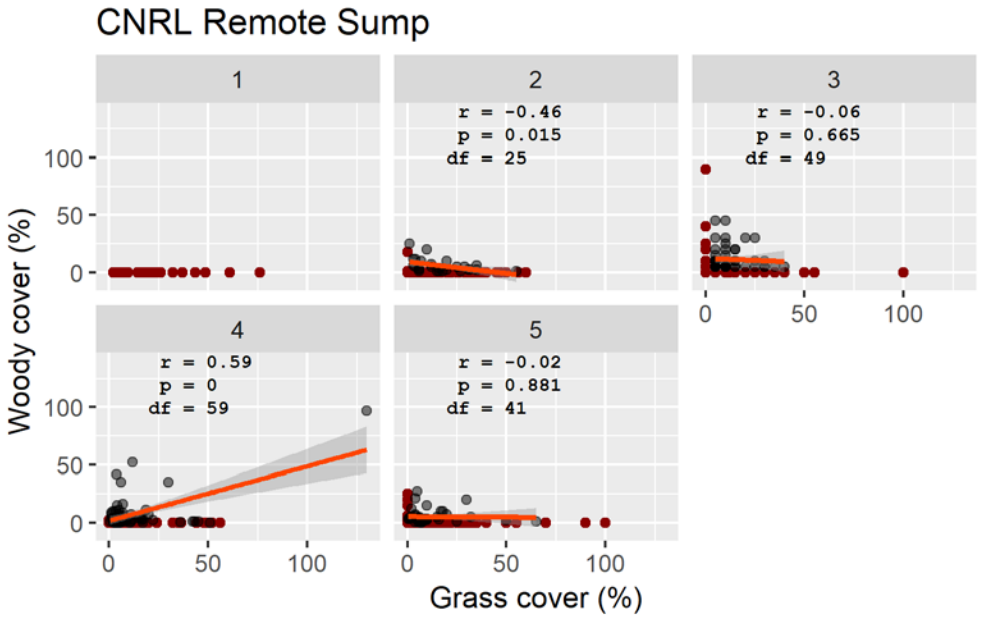

Figure C31. Pearson correlation of woody cover and grass cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

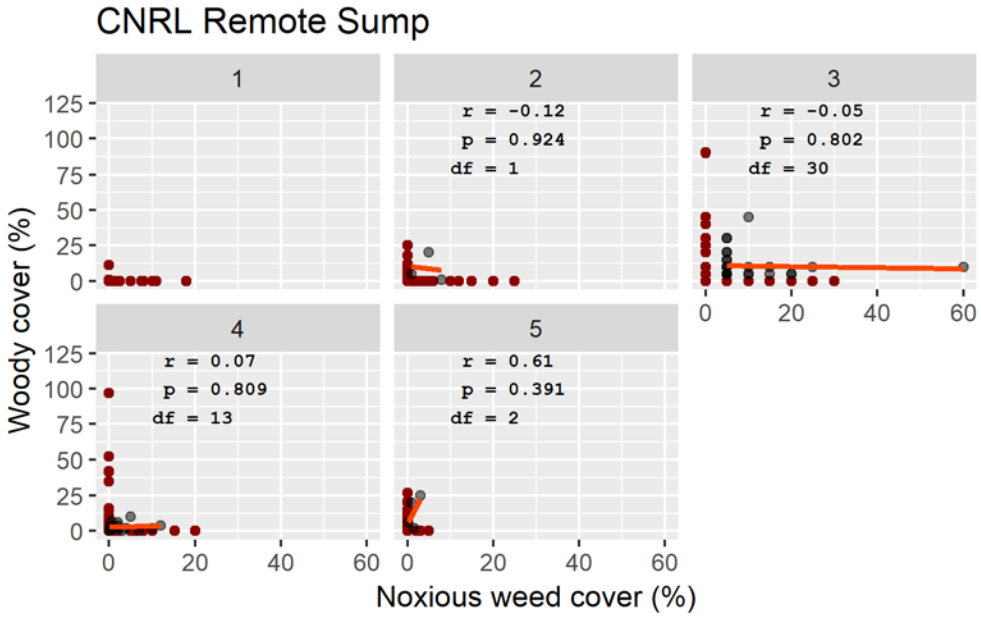

Figure C32. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

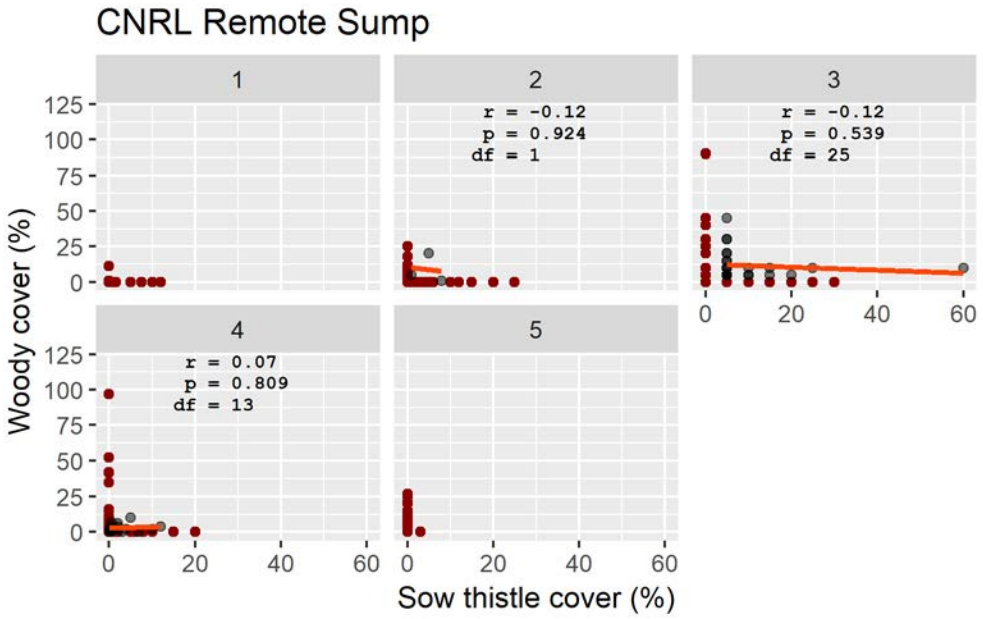

Figure C33. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

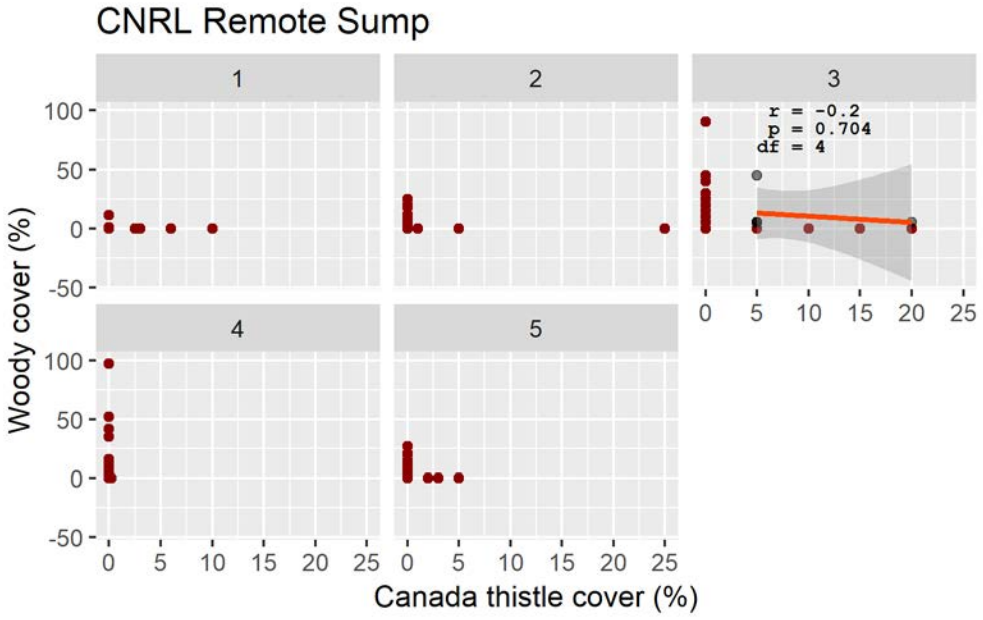

Figure C34. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

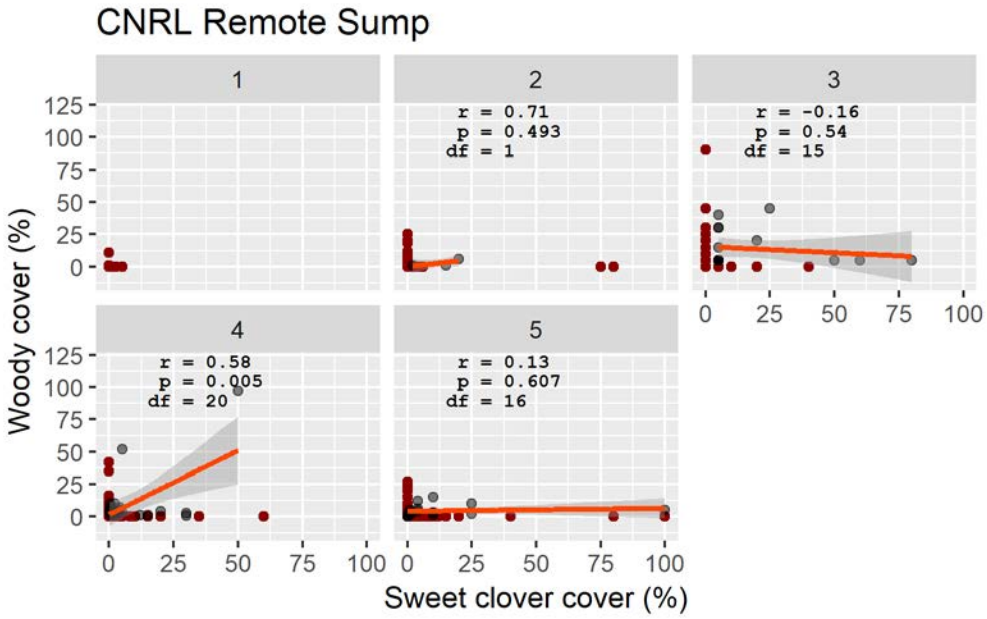

Figure C35. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

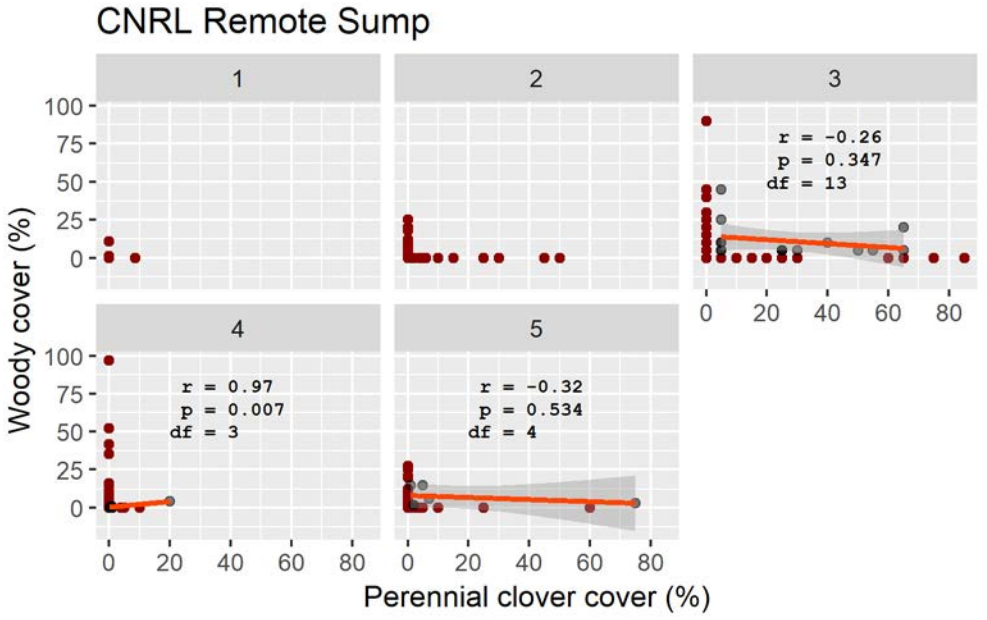

Figure C36. Pearson correlation of woody cover and perennial clover cover by years since reclamation at the CNRL Remote Sump reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

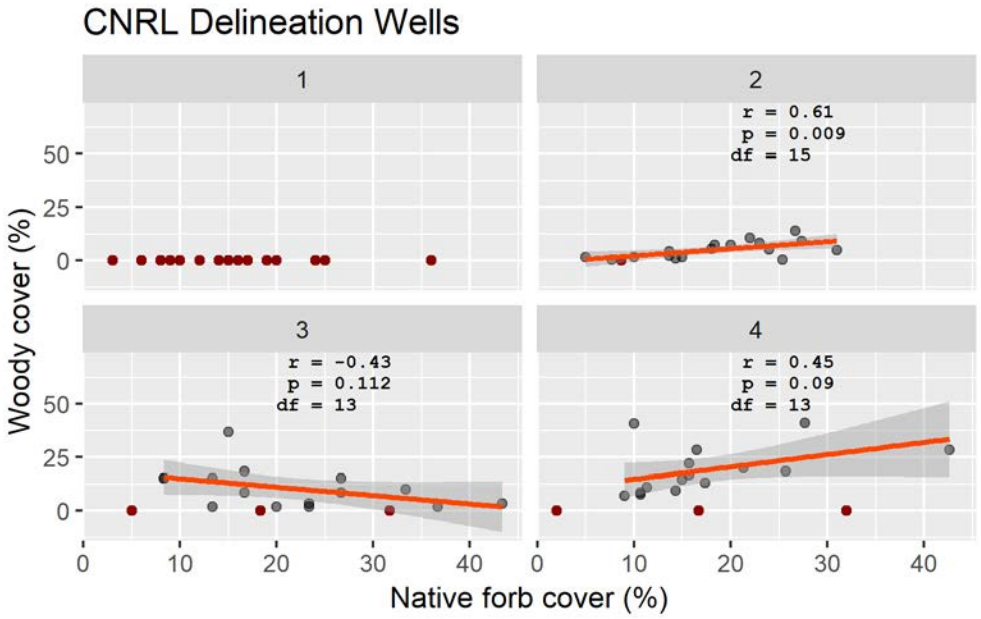

Figure C37. Pearson correlation of woody cover and native forb cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

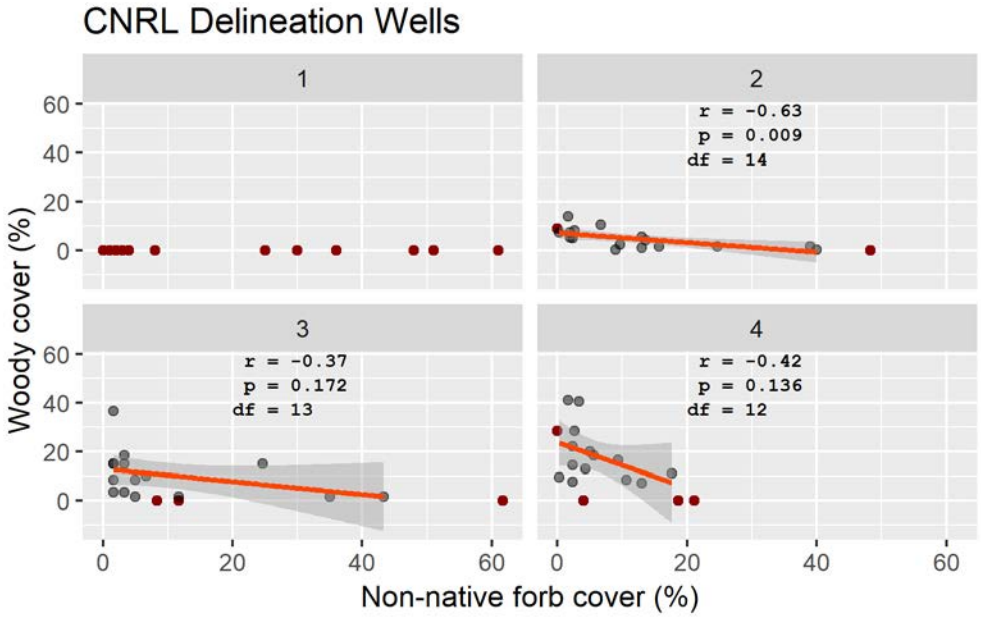

Figure C38. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

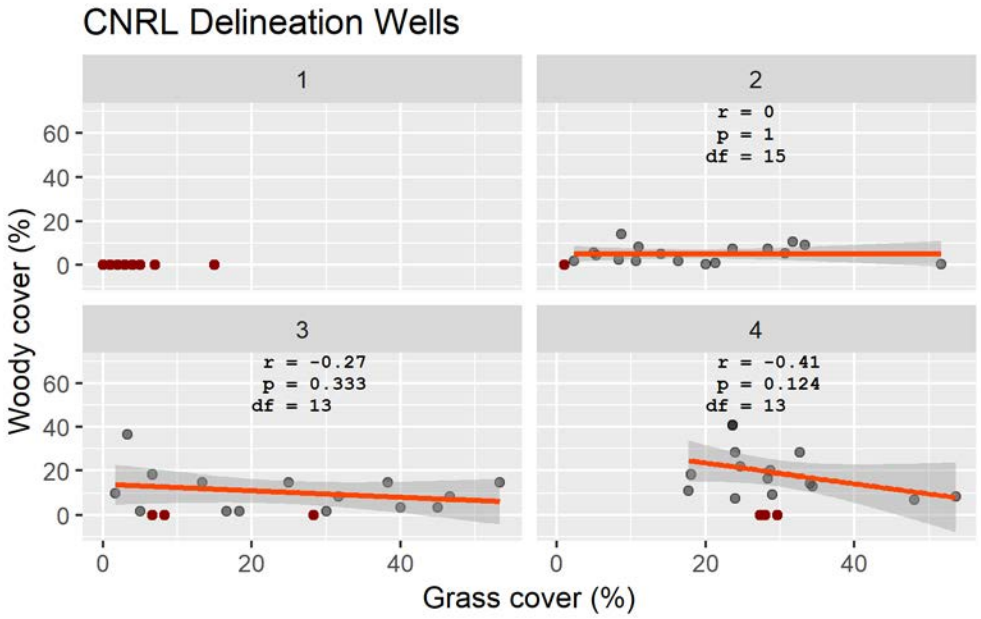

Figure C39. Pearson correlation of woody cover and grass cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

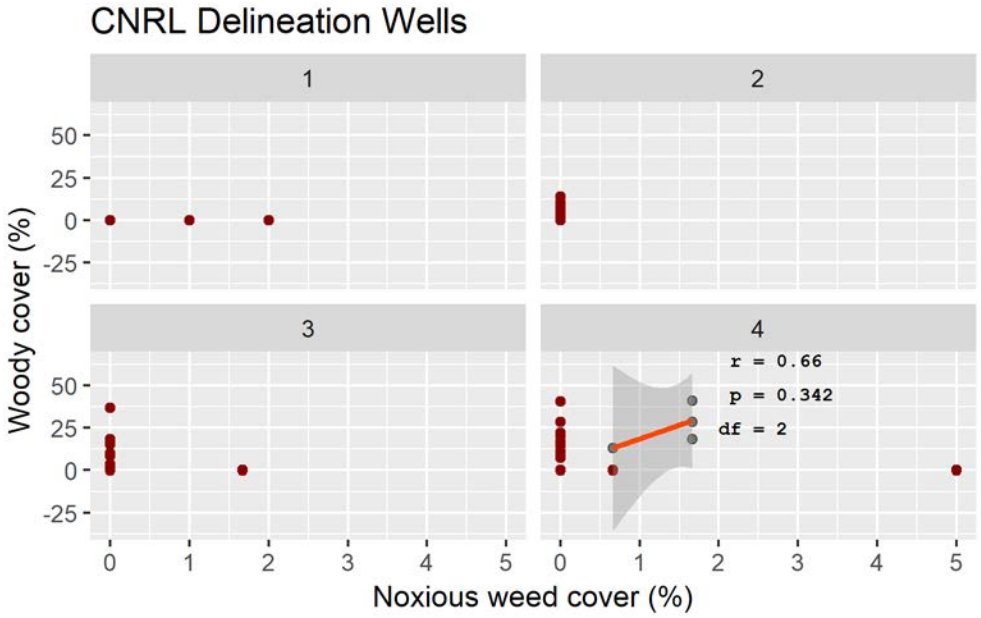

Figure C40. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

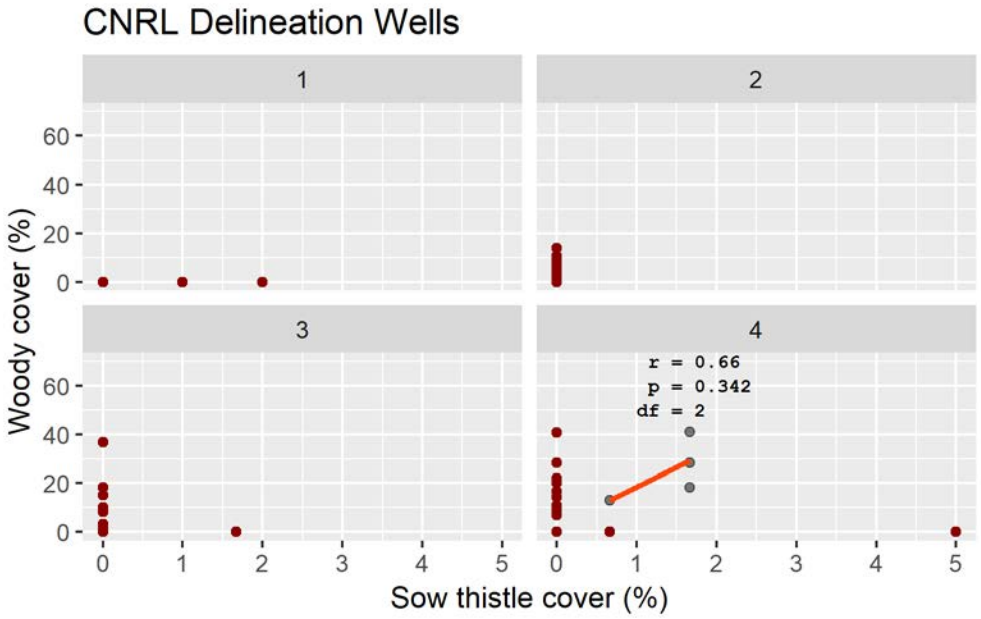

Figure C41. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

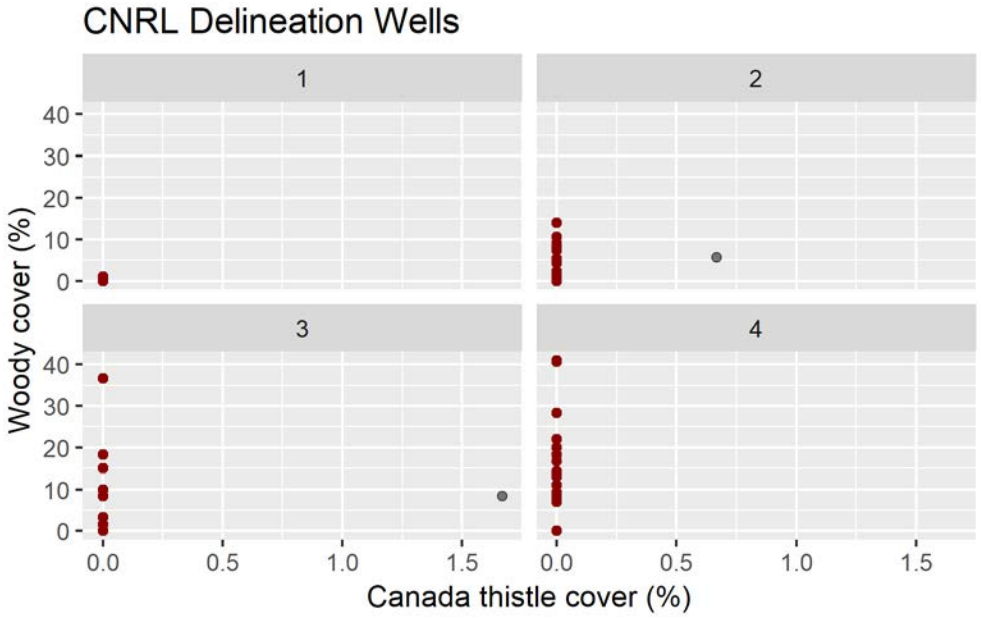

Figure C42. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

Figure C43. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

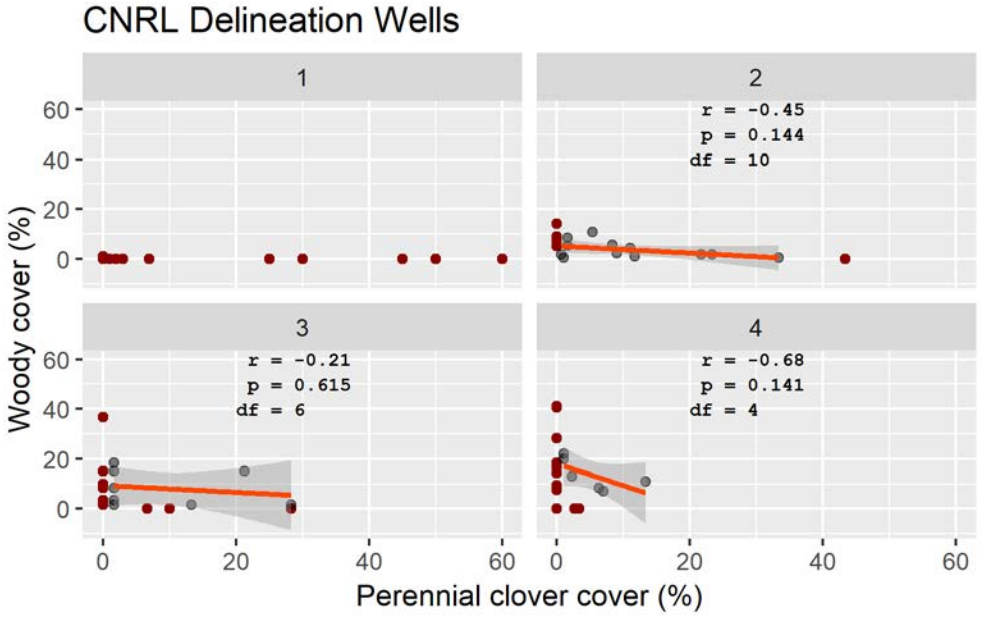

Figure C44. Pearson correlation of woody cover and perennial clover cover by years since reclamation at the CNRL Delineation Wells reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

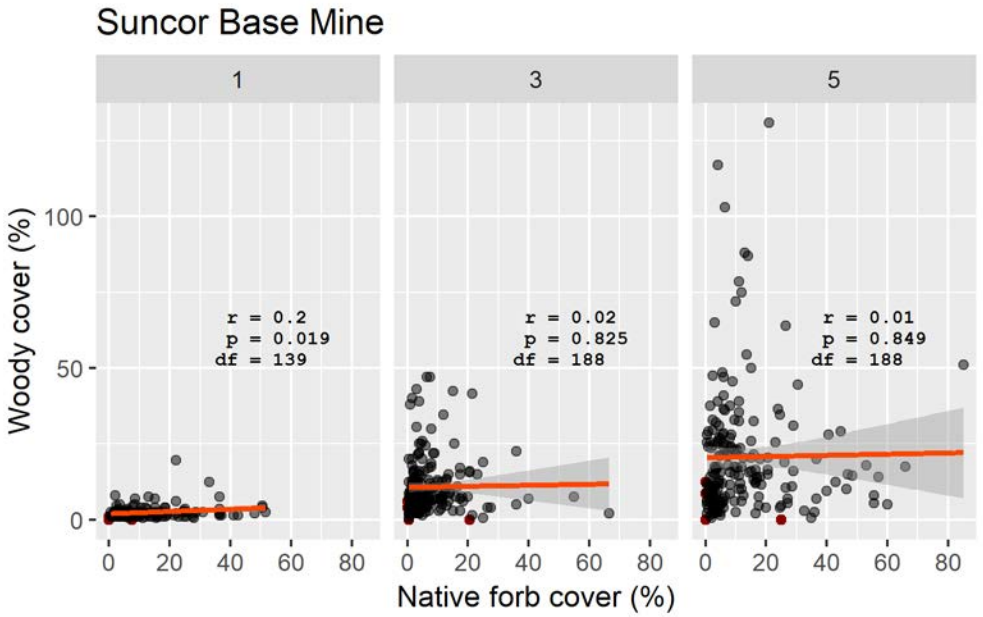

Figure C45. Pearson correlation of woody cover and native forb cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

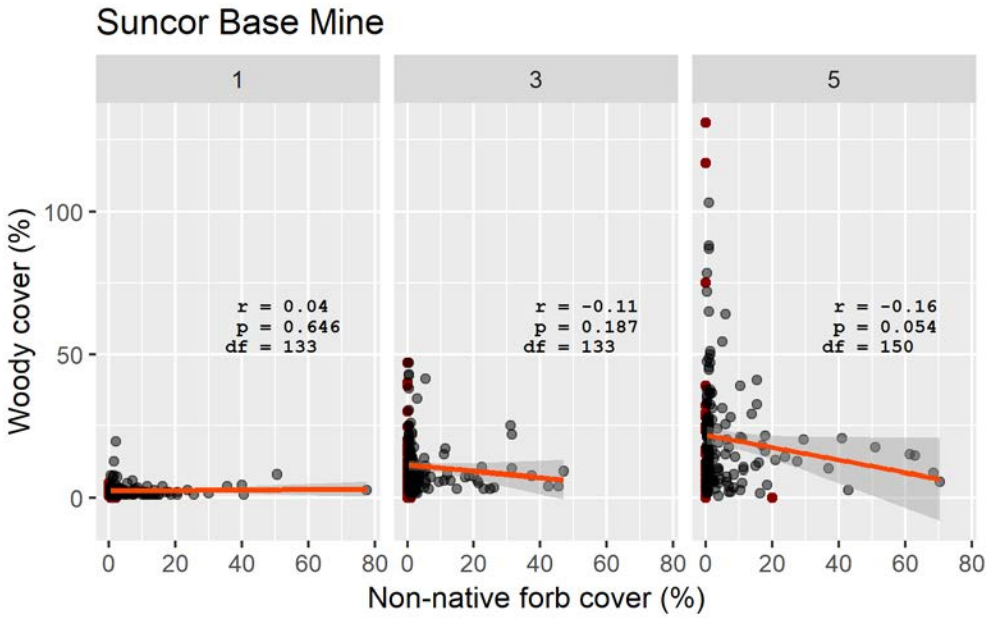

Figure C46. Pearson correlation of woody cover and non-native forb cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

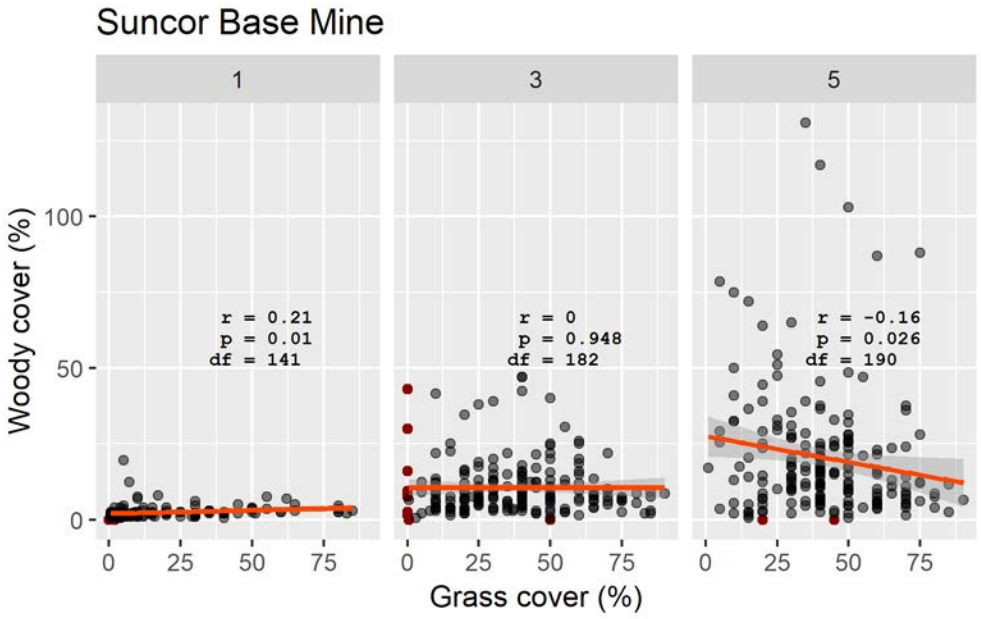

Figure C47. Pearson correlation of woody cover and grass cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

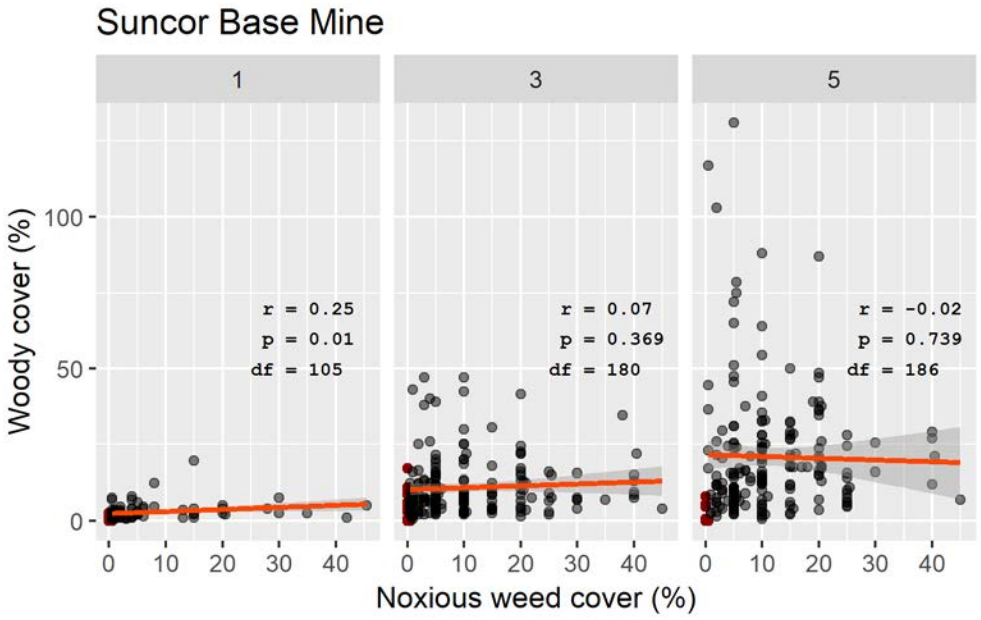

Figure C48. Pearson correlation of woody cover and noxious weed cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

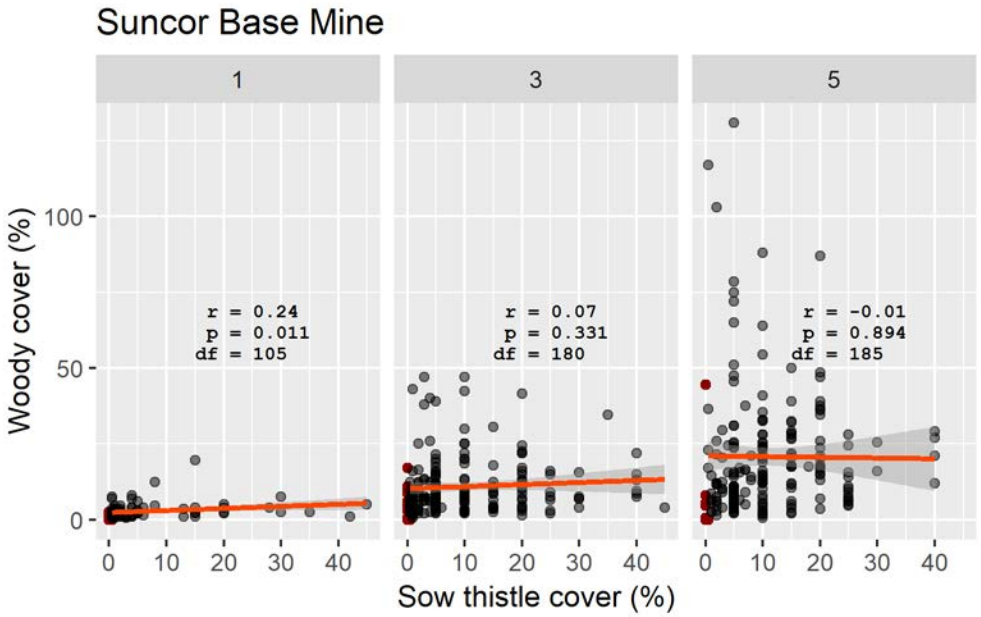

Figure C49. Pearson correlation of woody cover and perennial sow thistle cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

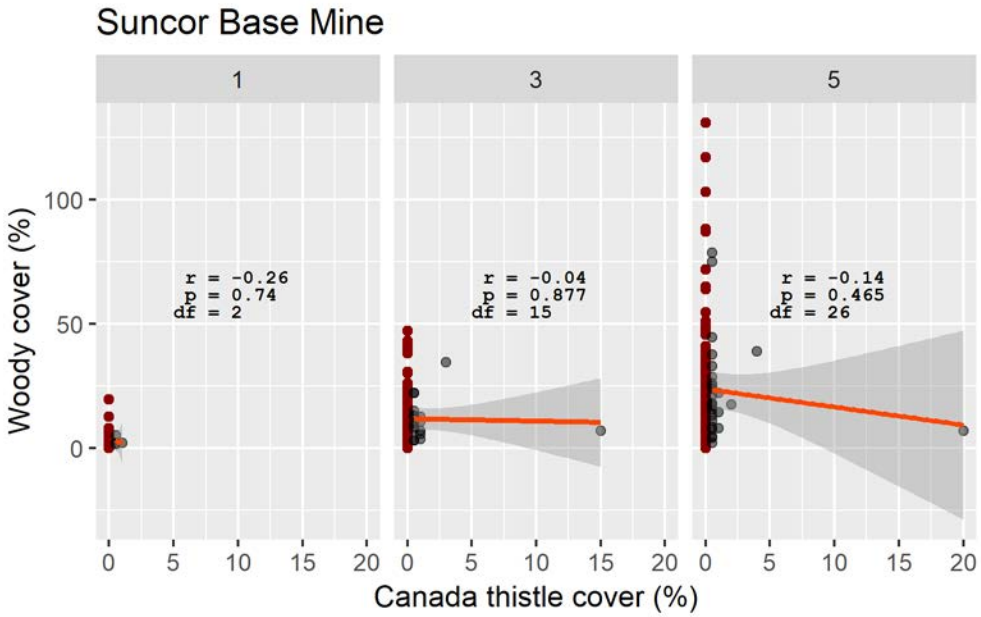

Figure C50. Pearson correlation of woody cover and Canada thistle cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

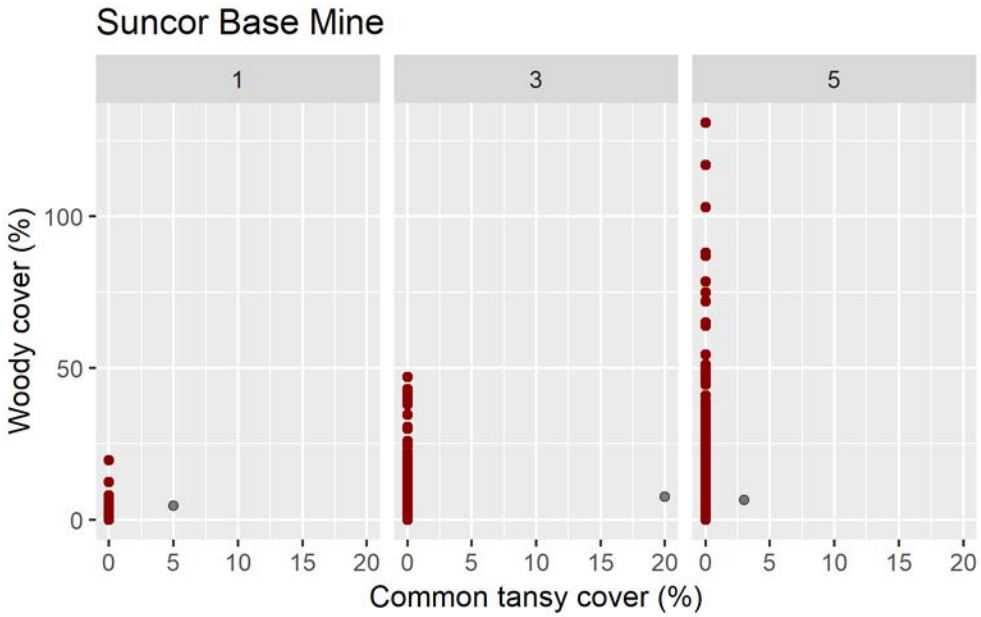

Figure C51. Pearson correlation of woody cover and common tansy cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis.

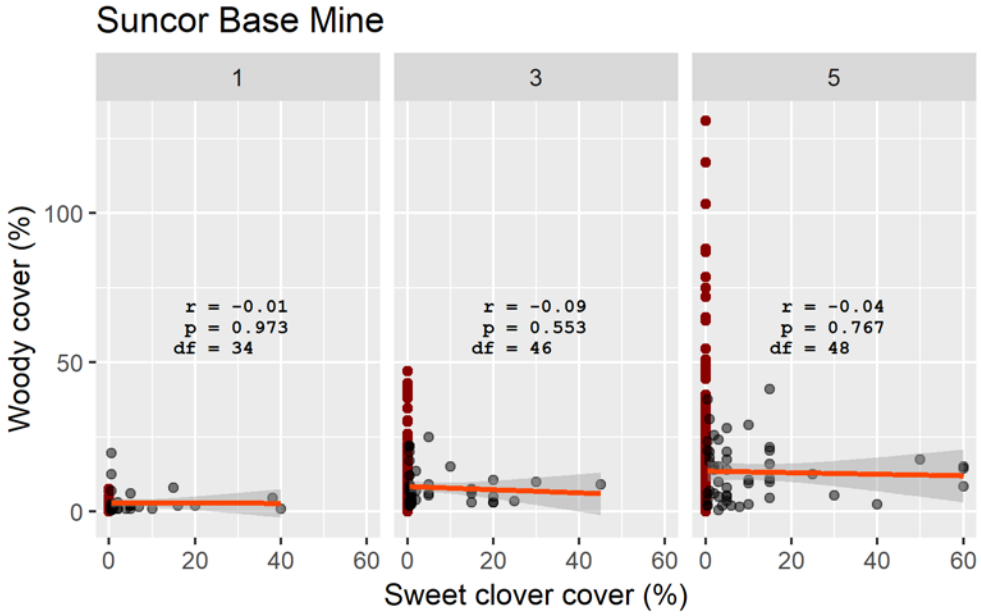

Figure C52. Pearson correlation of woody cover and sweet clover cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

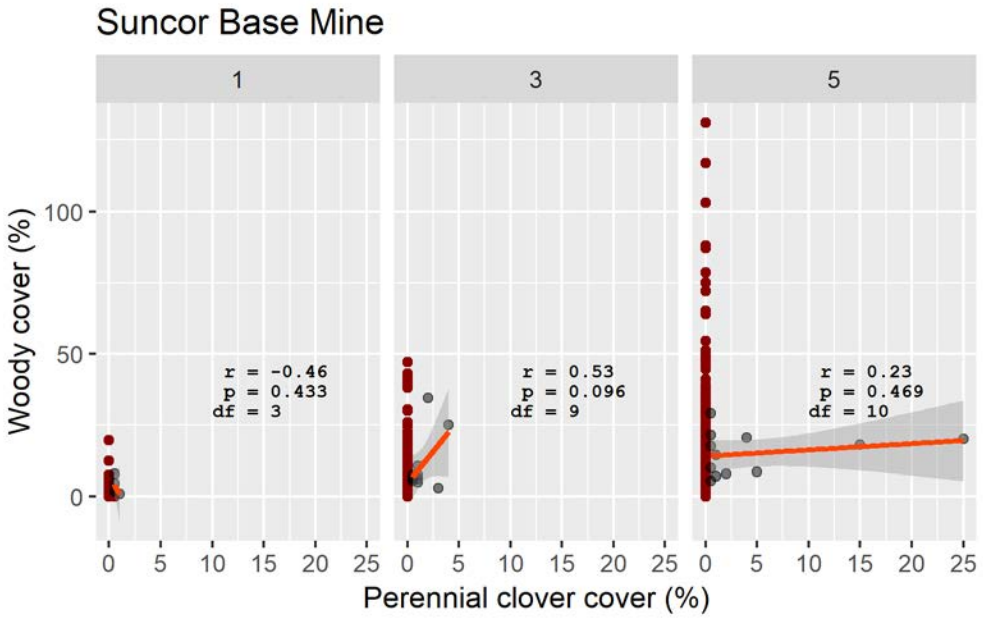

Figure C53. Pearson correlation of woody cover and perennial clover cover by years since reclamation at the Suncor Base Mine reclamation site. Red dots indicate zero cover which was excluded from the Pearson correlation analysis. The orange line represents a linear model fit to the data. r = Pearson correlation coefficient; p = probability; df = degrees of freedom.

APPENDIX D: MASTER SPECIES TABLE

List of all species found at each reclamation site grouped in the following classes: woody, native forbs, non-native forbs and grasses.

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
Woody	***Woody***	***Woody***	***Woody***	***Woody***	***Woody***
Alnus viridis	*Abies balsamea*	*Alnus incana*	*Alnus viridis*	*Alnus rugosa*	*Alnus crispa*
Cornus sericea	*Alnus crispa*	*Alnus viridis*	*Betula papyrifera*	*Betula papyrifera*	*Amelanchier alnifolia*
Picea glauca	*Alnus rugosa*	*Cornus sericea*	*Cornus sericia*	*Cornus canadensis*	*Arctostaphylos uva-ursi*
Pinus banksiana	*Amelanchier alnifolia*	*Picea glauca*	*Picea glauca*	*Cornus sericea*	*Artemisia campestris*
Populus balsamifera	*Arctostaphylos uva-ursi*	*Populus balsamifera*	*Pinus banksiana*	*Picea glauca*	*Astragalus alpinus*
Populus tremuloides	*Betula glandulosa*	*Populus tremuloides*	*Populus balsamifera*	*Populus balsamifera*	*Betula glandulosa*
Ribes triste	*Betula papyrifera*	*Ribes lacustre*	*Populus tremuloides*	*Ribes lacustre*	*Betula papyrifera*
Rosa acicularis	*Betula pumila*	*Ribes oxyacanthoides*	*Prunus pensylvanica*	*Ribes oxycanthoides*	*Betula pumila*
Rubus idaeus	*Cornus stolonifera*	*Rosa acicularis*	*Rosa acicularis*	*Ribes triste*	*Chenopodium album*
Salix spp.	*Corylus cornuta*	*Rubus idaeus*	*Rubus idaeus*	*Rosa acicularis*	*Cornus sericia*
Sheperdia canadensis	*Ledum groenlandicum*	*Salix* spp.	*Salix* spp.	*Rubus idaeus*	*Dasiphora fruticosa*
Symphoricarpos albus	*Lonicera dioica*	*Sheperdia canadensis*	*Vaccinium myrtilloides*	*Rubus pubescens*	*Larix laricina*
	Lonicera involucrata	*Vaccinium myrtilloides*		*Salix* spp.	*Myrica gale*
Native forbs	*Lonicera villosa*		***Native forbs***	*Sheperdia canadensis*	*Picea glauca*
Achillea millefolium	*Picea glauca*	***Native forbs***	*Achillea millefolium*	*Symphoricarpos albus*	*Pinus banksiana*
Achillea sibirica	*Pinus banksiana*	*Achillea millefolium*	*Achillia sibirica*	*Viburnum edule*	*Pinus contorta*
Arnica chamissonis	*Populus balsamifera*	*Achillea sibirica*	*Arenaria lateriflora*		*Populus balsamifera*
Aster ciliolatus	*Populus tremuloides*	*Aster ciliolatus*	*Aster ciliolatus*	***Native forbs***	*Populus tremuloides*
Aster conspicuus	*Prunus pensylvanica*	*Aster conspicuus*	*Aster conspicuus*	*Achillea millefolium*	*Prunus pensylvanica*
Aster hesperius	*Ribes glandulosum*	*Aster puniceus*	*Aster puniceus*	*Achillea sibirica*	*Ribes americanum*
Aster puniceus	*Ribes hudsonianum*	*Castilleja miniata*	*Chamerion angustifolium*	*Aralia nudicaulis*	*Ribes glandulosum*
Castilleja miniata	*Ribes lacustre*	*Cerastium nutans*	*Chenopodium album*	*Aster ciliolatus*	*Ribes hudsonianum*
Castilleja raupii	*Ribes oxyacanthoides*	*Chenopodium capitatum*	*Collomia linearis*	*Aster conspicuus*	*Ribes lacustre*
Chamerion angustifolium	*Ribes* spp.	*Collomia linearis*	*Corydalis aurea*	*Aster* spp.	*Ribes oxyacanthoides*

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
Collomia linearis	*Ribes triste*	*Cornus canadensis*	*Epilobium glandulosum*	*Astralagus* spp.	*Rosa acicularis*
Corydalis aurea	*Rosa acicularis*	*Corydalis aurea*	*Epilobium latifolium*	*Epilobium angustifolium*	*Rubus idaeus*
Epilobium glandulosum	*Rubus idaeus*	*Epilobium angustifolium*	*Equisetum* spp.	*Epilobium glandulosum*	*Rumex occidentalis*
Equisetum spp.	*Salix* spp.	*Epilobium glandulosum*	*Fragaria virginiana*	*Equisetum* spp.	*Salix exigua*
Fragaria virginiana	*Shepherdia canadensis*	*Equisetum* spp.	*Galium boreale*	*Fragaria virginiana*	*Salix* spp.
Galium boreale	*Symphoricarpos albus*	*Erigeron glabellus*	*Galium triflorum*	*Galium boreale*	*Shepherdia canadensis*
Galium triflorum	*Symphoricarpos* spp.	*Fragaria vesca*	*Geranium becknellii*	*Galium triflorum*	*Viburnum edule*
Gentiana amarella	*Vaccinium angustifolium*	*Fragaria virginiana*	*Geum aleppicum*	*Geranium bicknellii*	*Viburnum opulus*
Geranium bicknellii	*Vaccinium caespitosum*	*Galium triflorum*	*Geum macrophyllum*	*Geum aleppicum*	
Geum allepicum	*Vaccinium myrtillus*	*Gentianella amarella*	*Hieracium umbellatum*	*Geum rivale*	***Native forbs***
Geum macrophyllum	*Vaccinium vitis-idaea*	*Geranium bicknellii*	*Koeleria cristata*	*Hierarcium umbellatum*	*Achillea millefolium*
Hieracium umbellatum	*Viburnum edule*	*Geum macrophyllum*	*Lathyrus ochroleucus*	*Lathyrus ochroleucus*	*Achillea sibirica*
Lactuca tatarica		*Hieracium umbellatum*	*Lathyrus venosus*	*Mertensia paniculata*	*Anemone canadensis*
Lathyrus ochroleucus	***Native forbs***	*Lathyrus ochroleucus*	*Mentha arvensis*	*Mitella nuda*	*Aquilegia brevistyla*
Lathyrus venosus	*Achillea millefolium*	*Lathyrus venosus*	*Mertensia paniculata*	*Petasites palmatus*	*Arnica chamissonis*
Lepidium densiflorum	*Achillea sibrica*	*Mentha arvensis*	*Potentilla norvegica*	*Plantago major*	*Artemisia campestris*
Matricaria maritima	*Actaea rubra*	*Mertensia paniculata*	*Rhinanthus borealis*	*Potentilla norvegica*	*Artemisia cana*
Mertensia paniculata	*Anemone riparia*	*Petasites palmatus*	*Rumex occidentalis*	*Rhinathus borealis*	*Artemisia frigida*
Mitella nuda	*Arabidopsis lyrata*	*Potentilla norvegica*	*Solidago canadensis*	*Veronica scutellata*	*Aster borealis*
Petasites palmatus	*Aralia nudicaulis*	*Ranunculus macounii*	*Stellaria longifolia*	*Vicia americana*	*Aster ciliolatus*
Potentilla norvegica	*Arenaria lateriflora*	*Rhinanthus borealis*	*Stellaria longipes*	*Viola renifolia*	*Aster conspicuus*
Ranunculus sceleratus	*Aster ciliolatus*	*Rubus pubescens*	*Thalictrum venulosum*	*Zizia aptera*	*Aster puniceus*
Rhinanthus borealis	*Aster conspicuus*	*Solidago canadensis*	*Urtica dioica*		*Aster* spp.
Rorippa islandica	*Aster laevis*	*Utrica dioica*	*Vicia americana*	***Non-native forbs***	*Astragalus agrestis*
Rumex maritimus	*Aster puniceus*	*Vicia americana*		*Cirsium arvense*	*Astragalus alpinus*
Rumex occidentalis	*Astragalus tenellus*		***Non-native forbs***	*Galeopis tetrahit*	*Astragalus americanus*
Rumex salicifolius	*Athyrium filix-femina*	***Non-native forbs***	*Capsella bursa pastoris*	*Medicago falcata*	*Astragalus canadensis*
Solidago canadensis	*Bidens cernua*	*Cirsium arvense*	*Cerastium vulgatum*	*Medicago sativa*	*Astragalus* spp.
Stellaria longifolia	*Cardamine pensylvanica*	*Medicago lupilina*	*Chenopodium album*	*Medicago* spp.	*Astragalus alpinus*

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
Stellaria media	*Circaea alpina*	*Medicago sativa*	*Chenopodium capitatum*	*Melilotus officinalis*	*Barbarea orthoceras*
Thalictrum sparsiflorum	*Collomia linearis*	*Melilotus spp.*	*Cirsium arvense*	*Meliotus* spp.	*Caltha palustris*
Typha latifolia	*Cornus canadensis*	*Plantago major*	*Crepis tectorum*	*Sonchus arvense*	*Campanula rotundifolia*
Vicia americana	*Disporum trachycarpum*	*Polygonum aviculare*	*Descurania sophia*	*Taraxacum officinale*	*Chamerion angustifolium*
	Dracocephalum parviflorum	*Sonchus arvensis*	*Galeopsis tetrahit*	*Trifolium hybridum*	*Chenopodium capitatum*
Non-native forbs	*Dryopteris austiaca*	*Taraxacum officinale*	*Lepidium densiflorum*		*Collomia linearis*
Capsella bursa-pastoris	*Epilobium angustifolium*	*Trifolium hybridum*	*Matricaria martima*	***Grasses***	*Comandra umbellata*
Cirsium arvense	*Epilobium glaberrimum*		*Matricaria matricarioides*	*Agropyron dascytalum*	*Corydalis aurea*
Galeopsis tetrahit	*Epilobium palustre*	***Grasses***	*Medicago lupulina*	*Agropyron trachycaulum* var. *trachycaulum*	*Dasiphora fruticosa*
Maianthemum canadense	*Equisetum arvense*	*Agropyron dasystachyum*	*Medicago sativa*	*Agropyron trachycaulum* var. *unilaterale*	*Dracocephalum parviflorum*
Matricaria matricaroides	*Equisetum fluviatile*	*Agropyron intermedium*	*Meliolotus*spp.	*Agrostis scabra*	*Epilobium angustifolium*
Medicago lupulina	*Equisetum hyemale*	*Agropyron repens*	*Plantago major*	*Beckmannia syzigachne*	*Epilobium glaberrimum*
Medicago sativa	*Equisetum pratense*	*Agropyron trachycaulum var. trachycaulum*	*Polygonum arenastrum*	*Bromus ciliatus*	*Epilobium palustre*
Melilotus spp.	*Equisetum scirpoides*	*Agropyron trachycaulum var. unilaterale*	*Polygonum aviculare*	*Calamagrostis canadensis*	*Equisetum arvense*
Plantago major	*Equisetum sylvaticum*	*Agrostis scabra*	*Polygonum erectum*	*Carex* spp.	*Equisetum hyemale*
Polygonum arenastrum	*Erigeron acris*	*Alopecurus aequalis*	*Sonchus arvensis*	*Deschampsia caespitosa*	*Equisetum pratense*
Sonchus arvensis	*Erigeron glacialis*	*Beckmannia syzigachne*	*Taraxacum officinale*	*Elymus innovatus*	*Equisetum scirpoides*
Sonchus asper	*Erigeron philadelphicus*	*Bromus ciliatus*	*Trifolium hybridum*	*Koeleria macrantha*	*Equisetum sylvaticum*
Sonchus oleacurus	*Erysimum cheiranthoides*	*Calamagrostis canadensis*	*Trifolium pratense*	*Phleum pratense*	*Erigeron acris*
Sonchus uliginosus	*Fragaria vesca*	*Carex* spp.	*Trifolium repens*	*Poa* spp.	*Erigeron canadensis*
Taraxacum officinale	*Fragaria virginiana*	*Deschampsia caespitosa*			*Eriophorum angustifolium*
Thlaspi arvense	*Galium boreale*	*Elymus innovatus*	***Grasses***		*Euphorbia serpyllifolia*
Trifolium hybridum	*Galium labradoricum*	*Hordeum jubatum*	*Agropyron dasyanthum*		*Fragaria vesca*
Trifolium pratense	*Galium trifidum*	*Lolium perenne*	*Agropyron Intermedium*		*Fragaria vesca*
Trifolium repens	*Geocaulon lividum*	*Phleum pratense*	*Agropyron trachycaulum* var. *trachycaulum*		*Fragaria virginiana*
	Geranium bicknellii	*Poa* spp.	*Agropyron trachycaulum* var. *unilaterale*		*Galium triflorum*
Grasses	*Geum aleppicum*		*Agrostis scabra*		*Galium boreale* *Gentianella amarella*

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
Agropyron trachycaulum var. *trachycaulum*	*Geum macrophyllum*		*Alopecurus aequalis*		*Geranium bicknellii*
Agropyron trachycaulum var. *unilaterale*	*Geum rivale*		*Backmania syzigachne*		*Geum aleppicum*
Agrostis scabra	*Halenia deflexa*		*Bromus biebersteinii*		*Geum macrophyllum*
Alopecurus aequalis	*Hieracium umbellatum*		*Bromus ciliatus*		*Geum* spp.
Beckmannia syzigachne	*Impatiens noli-tangere*		*Bromus inermis*		*Hieracium umbellatum*
Bromus ciliatus	*Lactuca tatarica*		*Calamagrostis canadensis*		*Hippuris vulgaris*
Bromus inermis	*Lathyrus ochroleucus*		*Calamagrostis inexpansa*		*Juncus alpinoarticulatus*
Calamagrostis candensis	*Lathyrus venosus*		*Carex* spp.		*Juncus bufonius*
Carex spp.	*Linnaea borealis*		*Dactylis glomerata*		*Lathyrus ochroleucus*
Deschampsia caespitosa	*Lycopodium obscurum*		*Deschampsia caespitosa*		*Lathyrus venosus*
Elymus innovatus	*Lycopus uniflorus*		*Elymus innovatus*		*Lepidium densiflorum*
Festuca rubra	*Maianthemum canadense*		*Festuca ovina*		*Lysimachia thyrsiflora*
Hordeum jubatum	*Melampyrum lineare*		*Festuca rubra*		*Mentha arvensis*
Phleum pratense	*Mentha arvensis*		*Hordeum jubatum*		*Mertensia paniculata*
Poa spp.	*Mertensia paniculata*		*Phleum pratense*		*Moehringia lateriflora*
Secale cereale	*Mitella nuda*		*Poa* spp.		*Monolepis nuttalliana*
	"Orchid" spp.		*Poa palustris*		*Myrica gale*
	Ozmorhiza depauperata		*Rhynchospora alba*		*Parnassia palustris*
	Pedicularis labradorica		*Secale cereale*		*Petasites frigidus*
	Petasites palmatus				*Petasites palmatus*
	Potentilla norvegica				*Petasites sagittatus*
	Potentilla tridentata				*Polygonum lapathifolium*
	Pyrola asarifolia				*Potentilla norvegica*
	Pyrola secunda				*Potentilla tridentata*
	Pyrola spp.				*Pyrola asarifolia*
	Pyrrocoma uniflora				*Ranunculus macounii*
	Ranunculus abortivus				*Ranunculus sceleratus*
	Rhinanthus borealis				*Rhinanthus borealis*
	Rubus pubescens				*Rorippa islandica*

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
	Scutellaria galericulata				
	Senecio eremophilus				*Rosa acicularis*
	Sium suave				*Rumex occidentalis*
	Solidago canadensis				*Rumex occidentalis*
	Stellaria longipes				*Scirpus lacustris*
	Stellaria spp.				*Scutellaria galericulata*
	Thalictrum venulosum				*Senecio pauciflorus*
	Trientalis borealis				*Sibbaldia tridentata*
	Urtica dioica				*Solidago canadensis*
	Veronica americana				*Solidago graminifolia*
	Veronica scutellata				*Solidago simplex*
	Vicia americana				*Stachys palustris*
	Viola adunca				*Thalictrum venulosum*
	Viola canadensis				*Triglochin maritima*
	Viola nephrophylla				*Typha latifolia*
	Viola palustris				*Urtica dioica*
	Viola renifolia				*Vicia americana*
					Viola adunca
	Non-native forbs				*Viola canadensis*
	Cirsium arvense				
	Galeopsis tetrahit				***Non-native forbs***
	Matricaria maritima				*Artemisia absinthium*
	Melilotus alba				*Capsella bursa-pastoris*
	Melilotus officinalis				*Chenopodium album*
	Plantago major				*Cirsium arvense*
	Ranunculus acris				*Crepis tectorum*
	Sonchus arvensis				*Galeopsis tetrahit*
	Sonchus asper				*Lotus corniculatus*
	Stellaria media				*Matricaria maritima*

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
	Taraxacum officinale				*Medicago lupulina*
	Trifolium hybridum				*Medicago sativa*
	Trifolium pratense				*Medicago* spp.
	Trifolium repens				*Melilotus alba*
					Melilotus officinalis
	Grasses				*Melilotus* spp.
	Agropyron repens				*Neslia paniculata*
	Agropyron smithii				*Plantago major*
	Agropyron trachycaulum				*Polygonum convolvulus*
	Agrostis scabra				*Senecio vulgaris*
	Agrostis stolonifera				*Sonchus arvensis*
	Alopecurus aequalis				*Tanacetum vulgare*
	Beckmannia syzigachne				*Taraxacum officinale*
	Bromus ciliatus				*Tragopogon dubius*
	Bromus inermis				*Trifolium hybridum*
	Calamagrostis canadensis				*Trifolium pratense*
	Calamagrostis inexpansa				*Trifolium pratense*
	Calamagrostis stricta				***Grasses***
	Carex spp.				*Data was not listed by species*
	Cinna latifolia				
	Danthonia intermedia				
	Deschampsia caespitosa				
	Elymus innovatus				
	Elymus junceus				
	Festuca ovina				
	Festuca rubra				
	Hierochloe odorata				
	Hordeum jubatum				
	Koeleria macrantha				

CNRL Airstrip	ConocoPhillips / Nexen construction 2004	CNRL Remote sump	ConocoPhillips Stockpile	CNRL Delineation Wells	Suncor Base Mine
	Oryzopsis asperifolia				
	Phalaris arundinacea				
	Phleum pratense				
	Poa palustris				
	Poa pratensis				
	Typha latifolia				