Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca (2012-2016)

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Preface

Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca (2012 - 2016)

The following report is comprised of seven chapters related to the Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca, formerly known as the Ecological Monitoring Committee for the Lower Athabasca (EMCLA) Rare Plants Project. This project is the result of a collaborative effort between Dr. Scott E. Nielsen (Applied Conservation Ecology Lab, Department of Renewable Resources, University of Alberta) and Monica Kohler and Dr. Dan Farr at the Alberta Biodiversity Monitoring Institute's Application Center. The project began in 2012 and is ongoing.

This project was initially funded through the Ecological Monitoring Committee for the Lower Athabasca (EMCLA) (2012). Funding underwent several changes in governance, including the Joint Oil Sands Monitoring (JOSM) initiative from 2013-2014, and the Alberta Environmental Monitoring, Evaluation, and Reporting Agency (AEMERA) in 2015. Current funding is received through the Environmental Monitoring and Science Division (ESMD) of Alberta Environment and Parks, a division of the Government of Alberta. Ducks Unlimited provided in-kind support throughout the entirety of the project by making available their Enhanced Wetland Classification for the Lower Athabasca. Further funding was obtained through Natural Sciences Engineering and Research Council (NSERC) Canadian Graduate Scholarships – Masters (CGS-M) and Collaborative Research and Development grants and through the Alberta Conservation Association Grants in Biodiversity.

To cite this report in its entirety please use;

Nielsen, SE., Dennett, J., Denny, C., Kohler, M. & Farr, D. (2017) Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca (2012-2016). 166 pages.

Please cite chapters independently using the following format. Chapter 5 is shown here as an example;

Dennett, J., Gould, SJ., MacDonald, SE. & Nielsen, SE. (2017) Experimental detectability trials using decoy species. Pages 56-68, *in* Nielsen et al., Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca (2012 - 2016).

and in text as;

Dennett *et al.* 2017

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Executive Summary

Preserving biodiversity in human-altered landscapes is a critical conservation issue. Developing science-based recommendations and evaluating tools for land managers are important parts of the conservation process and the means by which biodiversity and ecosystem function can be preserved in close proximity to human disturbance. Vascular plants are rarely afforded the conservation limelight, despite being a critical element of regional diversity and providing an array of ecosystem services. Rare species are also an important aspect of regional flora but patterns in their occurrence, methods to monitor them, and mitigation options to deal with human disturbances are often poorly understood.

The effects of oil and gas exploration and extraction in Alberta's boreal forest are wide ranging and in many cases not well understood, yet land managers require information and data to make decisions at site to lease-scales and where possible mitigate their impacts. Provincial monitoring efforts by the Alberta Biodiversity Monitoring Program do not occur at the scale needed to provide information about regional diversity and rarity within Alberta's oil and gas region.

In 2012 the Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca, known at the time as the Ecological Monitoring Committee for the Lower Athabasca Rare Plants Project, was initiated to inform the status of rare vascular plant species, test protocols to improve sampling and monitoring, and develop models to assist with management of rare plants across the Lower Athabasca Planning Region (LAPR). Prior information on rare plants in the region was either too broad (i.e. ABMI 20-km grid) or too specific to individual parts of leases and developments (i.e. Pre-Disturbance Assessment). In the following report, we provide the findings of the past 5-years of research that addresses these challenges.

In the survey years of 2012 to 2015 a total of 602 Rarity and Diversity plots were completed, generating a comprehensive dataset consisting of 536 vascular plant species across regionally significant habitat types (Chapter 1). These plots were selected in early years using an iteration of a landscape model of rare vascular plant occurrence, which was updated in later years using plot-level data generated by this project. This model has since been used to guide regional conservation and land use planning efforts through the Biodiversity Management Framework, while providing significant additional value as a tool to guide regional and lease-level survey efforts (Chapter 2). A remote sensing-based application of Airborne Laser Scanning (ALS) data was then used to relate and predict vascular plant diversity within the core area of the LAPR and compared to current lease boundaries and caribou ranges (Chapter 3). We suggest that the rare plant and diversity models be used as planning tools to target surveys during environmental assessments and/or be used to avoid sensitive sites during construction and development.

Pre-disturbance assessments are an important element of the environmental assessment phase prior to lease development. These surveys provide locations of rare vascular plant species and allow oil and gas companies to mitigate for known populations of conservation concern. However, imperfect detection is rarely addressed and has the potential to generate false-absences, leading to possible population loss as a result of developments. Failure to detect species when they are present also affects the results of monitoring (attenuates trends) and research (increased Type II errors), yet little guidance is available on how to minimize detection

errors as it relates to survey protocols. For these reasons, we devote several chapters of this report to exploration of imperfect detection as it is critical to the issue of surveying and monitoring cryptic species like rare plants.

First, we conducted an analysis of pseudoturnover (change in species composition at a site between two observers) using a subsample of 67 plots where we had repeat survey data that was collected by well-trained, experienced observers. We consider our estimates to be comparatively low (average pseudoturnover of 15.4%) compared to what is reported in the literature with observed differences among functional groups being apparent with graminoids having the greatest variation in detection. Recognizing and understanding the presence of pseudoturnover in monitoring efforts, particularly in the oil and gas industry where monitoring sites are often visited by different observers, will lead to more reliable estimates of change in biodiversity (trend) over time (Chapter 4).

A second, experimental analysis of imperfect detection used decoy plants and detectability trails to understand how survey variables such as plot size, observer experience, and target species attributes of plant abundance and phenology influence detection. Results demonstrated that cryptic, low abundance vascular plants are detected far more poorly (0-35% success) than is currently recognized in plant surveys. Oil and gas related surveys which target rare species in large plot sizes are likely underestimating the occurrence of rare species demonstrating the need for carefully planned and documented (observer effort) surveys (Chapter 5).

Managing populations of rare species identified on lease areas after they have been successfully detected is a major challenge for industry and government. Translocation is a mitigative strategy used in the region to preserve species under the threat of destruction, but the execution of these projects is subject to limited planning, monitoring, and reporting. We tested the effectiveness of this mitigative tool for two rare peatland species observing high success rates over two monitoring years and a limited influence of recipient site characters, suggesting that monitoring, rather than recipient site location selection, may benefit most from increased resource allocation in future efforts (Chapter 6).

Finally, despite significant effort to locate and mitigate rare vascular plant species on lease areas, populations can be negatively impacted by the direct or indirect effects of development leading to extirpation of rare plant populations. Currently, the rate of extirpation due to oil and gas related factors is unknown. We conducted a remote sensing imagery- and field-based assessment of historic rare plant records from the Alberta Conservation Information Management System (ACIMS), including populations from multiple land-use types. More field sampling is proposed in 2017, but at present we estimate a 30% loss of populations with a trend for increased risk of extirpation when in closer proximity to disturbance. This emphasizes the need for on lease monitoring of plant populations and the communication of findings to ACIMS in the event of population loss (Chapter 7).

Overall, this work contributed to our knowledge and understanding of rare vascular plants in the Lower Athabasca Region of northeast Alberta, while providing tools and protocols that will increase the effectiveness of surveys, monitoring, management, and mitigation actions.

CHAPTER 1.0: Species richness, rare plant status, rare plant distribution, and sampling in the Lower Athabasca Region

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1.1 Summary

Between 2012 and 2015, vegetation surveys were conducted across 602 Rarity and Diversity plots in the Lower Athabasca Region of northeastern Alberta to evaluate vascular plant species richness and the distribution of rare species. A total of 536 species were detected with an average richness of 45.4 species per plot across 12 ecosite categories. Changes to Conservation Status Ranks by the Alberta Conservation Information Management System (ACIMS) affected the number and distribution of rare species (S1-S3) encountered during sampling, which decreased from 101 (18.8%) to 63 (11.8%) species between 2014 and 2015 following the re-evaluation of rankings. Data generated from this project have been used for landscape-level models of species rarity (Chapter 2), evaluation of the effectiveness of remote sensing metrics to predict species diversity (Chapter 3), and estimation of observer error relative to species richness across survey plots (Chapter 4).

1.2 Introduction

Across a four-year period between 2012 and 2015, vegetation surveys were conducted across a series of Rarity and Diversity plots as a component of a Rare Species Monitoring Project for the Lower Athabasca Region with the intent of evaluating plant species richness, distribution of rare species, and status of rare vascular plants in the oil sands region. Rarity status was determined based on the Subnational Conservation Status Rank scheme used by the Alberta Conservation Information Management System (ACIMS), a biodiversity data centre managed by the provincial government, generated using a NatureServe rank calculator (Master *et al.* 2012). Rare species were defined here as those with Conservation Status Ranks (S-Ranks) between S1 and S3 (Table 1.1), corresponding to status ranks for species that are “especially” to “somewhat vulnerable” to extirpation. At the project outset, the Status Ranks of species were based on those applied up through 2014. In 2015, species were re-evaluated by ACIMS with these updates having implications for our findings regarding the presence of rare species in the region.

The primary objectives of the Rarity and Diversity plot sampling project were to (1) collect new observations of rare vascular plants to further refine existing rare plant habitat models, (2) test a new rare plant monitoring protocol that complements those of the Alberta Biodiversity Monitoring Institute (ABMI) (ABMI 2010a; ABMI 2010b) and incorporates Alberta Native Plant Council (ANPC) guidelines (ANPC 2000; ANPC 2012) for rare vascular plant surveys, and (3) assess how changes to Conservation Status Ranks affect our understanding of the distribution of rare vascular plant species.

Table 1.1. Subnational Conservation Status Rank (S-Rank) definitions adapted from those used by the Alberta Conservation Information Management System (ACIMS 2017).

Standard Subnational Conservation Status Ranks	
Rank	Definition
S1	Five or fewer occurrences for a taxon, or especially vulnerable to extirpation due to various factors
S2	Twenty or fewer occurrences for a taxon, or vulnerable to extirpation due to various factors
S2S3	Uncertainty between S2 and S3 status ranks for a taxon
S3	One hundred or fewer occurrences for a taxon, or somewhat vulnerable to extirpation due to various factors such as restricted range or relatively small population sizes
S3S4	Uncertainty between S3 and S4 status ranks for a taxon
S4	Apparently secure; taxon is uncommon but not rare, though potentially some concern due to various factors such as a decline in population sizes
S4S5	Uncertainty between S4 and S5 status ranks for a taxon
S5	Secure; taxon is common, widespread, and abundant
SU	Not ranked due to a lack of information or substantially conflicting information for a taxon, such as with species whose nativeness is unresolved
SNR	Not ranked because the conservation status has not yet been assessed for a taxon
SNA	Rank not applicable because a taxon is not a suitable target for conservation activities, such as with species that are introduced

1.3 Methods

Study area

The study area was defined as the Lower Athabasca Planning Region (LAPR), a 93,212 km^2 area in northeastern Alberta between 54°N and 60°N latitude (Figure 1.1). Elevation ranges from 202 m to 867 m a.s.l., with a mean annual temperature of -0.9°C and mean annual precipitation of about 438 mm (Zhang *et al.* 2014). The area represents one-quarter of the boreal forest region of the province and is characterized by a combination of coniferous, deciduous, and mixedwood upland stands dominated by species including aspen (*Populus tremuloides*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), and jack pine (*Pinus banksiana*). Lowland areas consist of a variety of wetland types including fens, swamps, and bogs along with lakes and streams (Natural Regions Committee 2006; Zhang *et al.* 2014). Much of the area is occupied by undeveloped forests, however, a portion of the landscape is affected by anthropogenic disturbance related to oil sands development, forest harvesting, and agriculture.

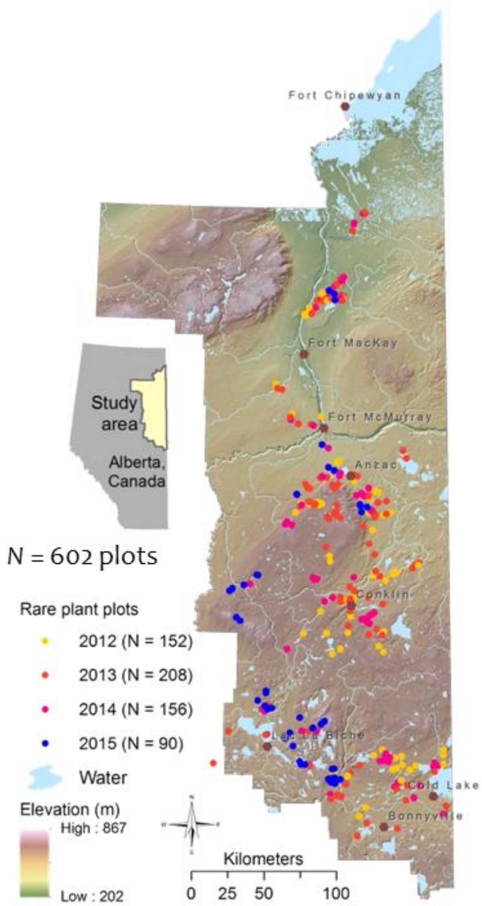

Figure 8.1. Extent of the study area in northeastern Alberta and the location and number of Rarity and Diversity plots (*n* = 602) sampled per year between 2012 and 2015.

Site selection and plot establishment

Vascular plant surveys were conducted in 602 quarter-hectare plots (50 x 50 m) by 18 observers over four summer field seasons. Sites were selected in native terrestrial upland and lowland environments using a stratified random sampling design and model-based predicted locations of targeted rare plant species, compiled from the Ecological Monitoring Committee for the Lower Athabasca (EMCLA) database (see Appendix 1.1 for target species list). Disturbance and accessibility were also considered, as was expert advice regarding landscape features and habitats within the study region with a high probability of rare plant occurrence. No sites were located in open water ecosystems such as marshes or lakes.

Two plots were established per site, each of which was surveyed at least once by a single observer. Plots were separated by a maximum of 200 m, both to reduce travel time and allow for observers to work in close proximity. Where possible, the two plots per site were established in different ecosite types to promote broad representation in the dataset. Efforts were made to situate one of the plots in an area likely to support rare plants (e.g. open sand, rock faces, sites with unique landscape features, ephemeral habitats, transition zones, old growth forest, or jack pine stands).

To enable the examination of observer error within the dataset, 67 plots were surveyed by multiple individuals (Chapter 4.0). An additional eight plots were surveyed in both the spring and late summer of 2014 by the same individual to determine the influence of timing on species detection. See Appendix 1.2 for locations of all survey plots.

Ecosite classification at survey plots

Geographic coordinates of each plot centre were recorded with a handheld GPS unit. Ecosite type was determined based on 12 categories defined by the ABMI (Table 1.2) which reflect dominant vegetation community, structural stage, soil nutrients, and soil moisture level. Additional physical attribute data were collected including plot slope, aspect, dominant canopy species, soil pH, the percentage of the plot that was altered by human or natural disturbance, and percent bare ground or water.

Table 1.2. Definitions and Nutrient/Moisture Codes for the 12 ecosite categories used to classify the Rarity and Diversity plots (n = 602).

Ecosite Categories	
Nutrient/Moisture Code	Definition
NT	Not Treed
PX	Poor/Xeric
PM	Poor/Mesic
PD	Bog (Poor/Hydric)
MX	Medium/Xeric
MM	Medium/Mesic
MG	Medium/Hygric
MD	Poor Fen (Medium/Hydric)
RG	Rich/Hygric
RD	Rich Fen (Rich/Hydric)
SD	Swamp
VD	Marsh (Very Rich/Hydric)

Plant survey methods

Observers performed time-unlimited surveys using belt transects to cover the entirety of each plot, beginning in one corner and walking in a pattern that mimicked parallel 50-m transects while scanning 1-2 m per side (Figure 1.2). Comprehensive species inventories were completed and data were entered in the field on paper datasheets in 2012 and using handheld tablets in subsequent years. Specimens that could not be identified in the field were collected and later reviewed by an expert botanist. Subspecies, varieties, and hybrids were included, and some records were classified at higher taxonomic levels (genus or family) if identification to species-level was not possible. Time of first encounter for each species detected was recorded (which became automatic following the introduction of tablets in 2013), along with the total survey time per plot. Surveys thus collected species presence-absence data, but not information regarding abundance. When rare species were detected, however, Rare Plant Field Data Sheets provided by ACIMS were filled out with detailed descriptions of the location, population, and habitat.

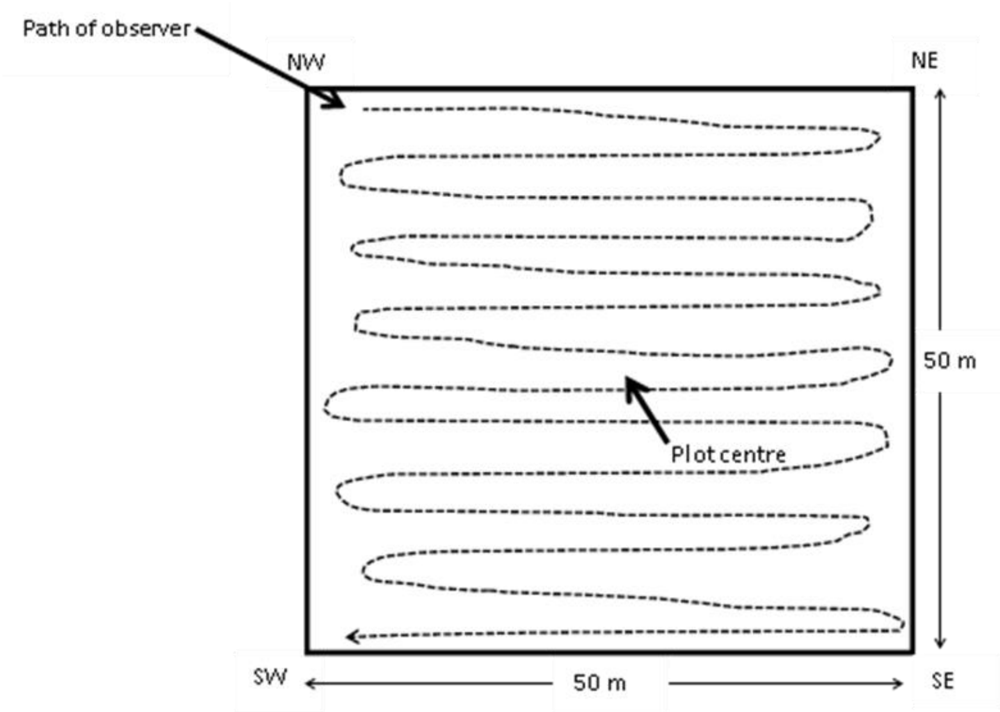

Figure 1.9. Path of parallel belt transects used by observers for time-unlimited vascular plant surveys of the Rarity and Diversity plots (50 x 50 m) (n = 602).

1.4 Results

Vascular plant species richness

Across the 602 Rarity and Diversity plots, a total of 27,320 observations of 536 plant species were recorded (see Appendix 1.3 for full species list). Average survey time per plot was 93 minutes and ranged from 20 to 290 minutes. Average species richness per ecosite category ranged from a minimum of 26.5 species (PD ecosite) to a maximum of 71.9 (SD), with an overall average of 45.4 and associated standard deviation of 21.5 (Table 1.3). Ecosite representation was not balanced due to a lack of availability in the study area, with few plots for some categories (VD) and many for others (RD). Species richness varied moderately among ecosite categories and was generally consistent within ecosite categories (Figure 1.3).

Table 1.3. Number of Rarity and Diversity plots (n = 602) occurring in each of the 12 ecosite categories, mean vascular plant species richness per plot, and variation (standard deviation) per ecosite category.

Ecosite	Number of Plots	Mean Species Richness (α)	Standard Deviation (α)
NT - Not Treed	7	64.4	24.2
PX – Poor Xeric (poor, dry forests)	52	30.6	11.9

PM – Poor Mesic (moist conifer)	97	43.3	21.6
PD – Poor Hydric (bog)	39	26.5	14
MX – Medium Xeric (dry mixedwood)	35	44.1	15.4
MM – Medium Mesic (mesic mixedwood)	93	53.3	12
MG – Medium Hygric (moist mixedwood)	30	67	22.3
MD – Medium Hydric (poor fen)	88	36.5	20.2
RG – Rich Hygric (rich, moist forests)	25	61.2	19.1
RD – Rich Hydric (rich fen)	126	48.8	22.3
SD – "Swamp" Hydric (swamp)	8	71.9	20.5
VD – Very rich Hydric (marsh)	2	30	22.6
Total	602	45.4	21.5

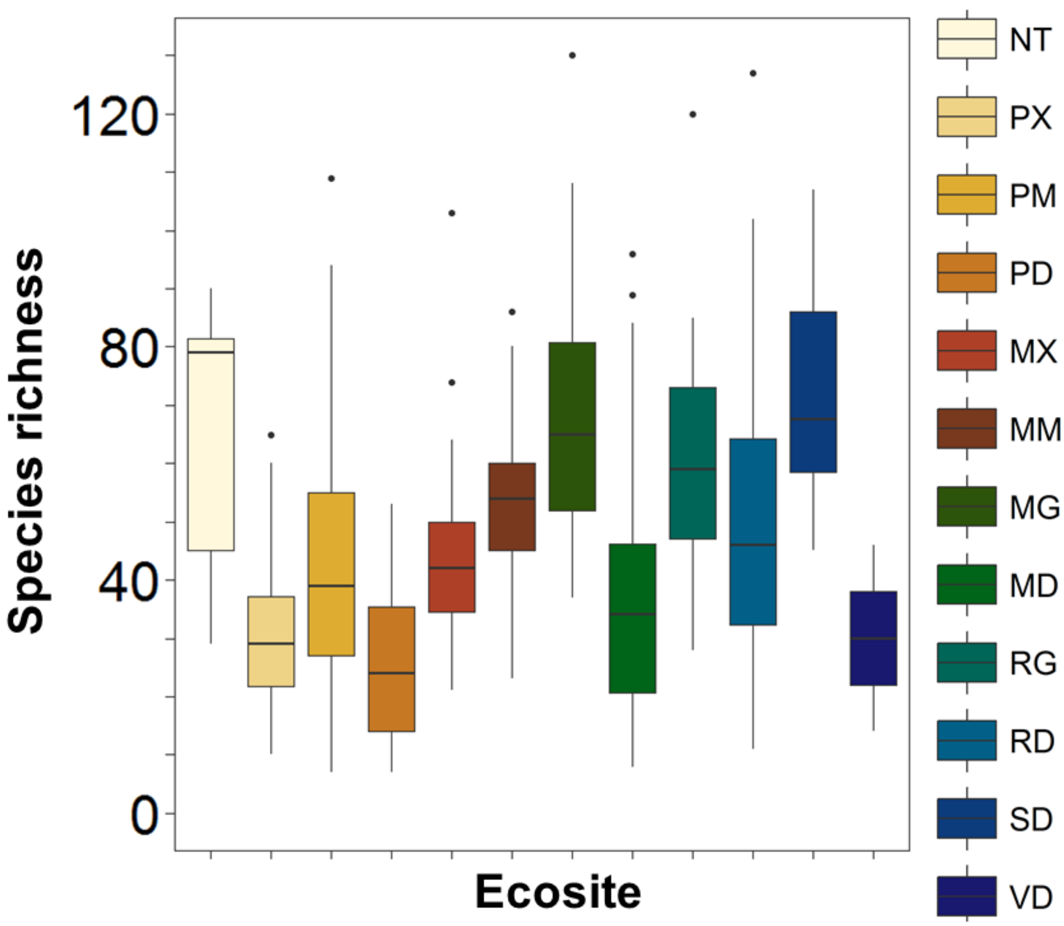

Figure 1.10. Variation in vascular plant species richness for the 12 ecosite categories sampled across the Rarity and Diversity plots (n = 602).

Plant species rarity and changes in Conservation Status Ranks

The re-evaluation of Conservation Status Ranks by ACIMS in 2015 resulted in the rarity status of the 536 species encountered being downgraded (88 species), upgraded (20), or remaining unchanged (416), with some previously unevaluated species receiving a new rank (12) (Table 1.4).

Table 1.4. Number of species for which Conservation Status Ranks were downgraded, upgraded, newly applied, or unchanged between 2014 and 2015 following the re-evaluation of Status Ranks by ACIMS.

Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Species
Downgrade to Status Rank		Total: 88
S1	S2	2
S1	S2S3	1
S1	S3	1
S2	S3	6
S2	S4	2
S3	S4	45
S3	S5	2
S3S4	S4	2
S3S4	S4S5	1
S4	S4S5	3
S4	S5	21
S4S5	S5	2
Upgrade to Status Rank		Total: 20
S5	S4	13
S4	S3	4
S3S4	S3	2
S3	S2	1
Rank Newly Applied		Total: 12
SNR	S3	3
SNR	S4	1
SNR	S5	6
SU	S1	1
SU	S2	1
Rank Unchanged		Total: 416
S1		2
S2		1
S3		38
S3S4		1
S4		60
S5		271
SNA		43

Based on the Status Ranks through 2014, 101 (18.8%) of the species detected were recognized as provincially rare (S1-S3); however, following the re-evaluation of rankings in 2015, this number decreased to 63 (11.7%) (Table 1.5). For the 2014 rankings, 54 plots (9.0%) were found to contain species determined to be especially vulnerable (S1) or vulnerable (S2), but this declined substantially to 33 plots (5.5%) when based on the 2015 rankings (Tables 1.6 & 1.7; Figure 1.4).

The majority of species detected were considered apparently secure (S3) or secure (>S3), which amounted to 380 and 430 species for the 2014 and 2015 rankings, respectively. A further 12 species were not ranked in 2014 (SNR or SU), but received ranks in 2015. Of the 536 species encountered, 493 were native to Alberta and the remaining 43 did not have an associated rank (SNA), as they were either exotic (41 species) or hybrids (2) and ACIMS does not assign ranks to these species.

Table 1.5. Number of vascular plant species (*n* = 536) detected in the Rarity and Diversity plots (*n* = 602) per Conservation Status Rank (S-Rank) for ranks used in 2014 and 2015.

Conservation Status Rank (2014)	Number of Species Detected (%)	Conservation Status Rank (2015)	Number of Species Detected (%)
S1	6 (1)	S1	3 (0.6)
S2	9 (1.7)	S2	5 (0.9)
S2S3	-	S2S3	1 (0.2)
S3	86 (16)	S3	54 (10)
S3S4	6 (1.1)	S3S4	1 (0.2)
S4	88 (16.4)	S4	123 (22.9)
S4S5	2 (0.4)	S4S5	4 (0.7)
S5	284 (53)	S5	302 (56.3)
SNA	43 (8)	SNA	43 (8)
SNR	10 (1.8)	-	-
SU	2 (0.4)	-	-
Total	536		536

Table 1.6. Number of records for vascular plant species recognized as especially vulnerable (S1; *n* = 6) or vulnerable (S2; *n* = 9) based on the 2014 Conservation Status Ranks which were detected in the Rarity and Diversity plots (*n* = 54 of 602 total).

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records
Carex adusta	S1	S3	7
Carex hystericina	S1	S2	1
Lechea intermedia var. depauperata	S1	S1	1
Malaxis paludosa	S1	S2S3	9
Spiranthes lacera	S1	S2	3

Utricularia cornuta	S1	S1	1
Botrychium simplex	S2	S2	1
Carex heleonastes	S2	S3	8
Carex lacustris	S2	S4	2
Carex umbellata	S2	S4	2
Diphasiastrum sitchense	S2	S3	5
Hypericum majus	S2	S3	1
Juncus brevicaudatus	S2	S3	5
Juncus stygius	S2	S3	6
Lactuca biennis	S2	S3	2
Total			54

Table 1.7. Number of records for vascular plant species recognized as especially vulnerable (S1; *n* = 3) or vulnerable (S2; *n* = 5) based on the 2015 Conservation Status Ranks which were detected in the Rarity and Diversity plots (*n* = 33 of 602 total).

Scientific Name	**Conservation Status Rank (2014)**	**Conservation Status Rank (2015)**	**Number of Records**
Carex hystericina	S1	S2	1
Lechea intermedia var. depauperata	S1	S1	1
Spiranthes lacera	S1	S2	3
Utricularia cornuta	S1	S1	1
Botrychium simplex	S2	S2	1
Cardamine dentata	S3	S2	3
Dichanthelium acuminatum	SU	S2	5
Leucophysalis grandiflora	SU	S1	18
Total			33

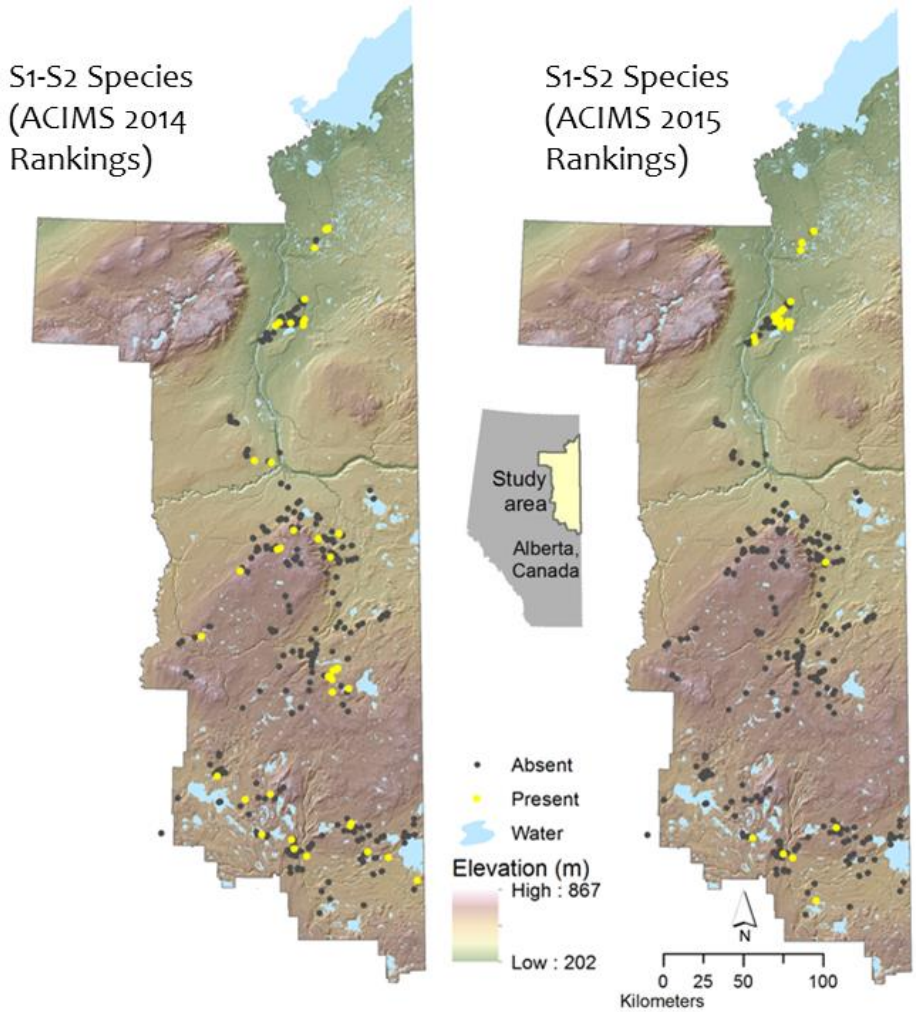

Figure 1.4. Distribution of especially vulnerable (S1) and vulnerable (S2) vascular plant species across the Rarity and Diversity plots within the study area, based on the ranks that applied until 2014 (*n* = 54 of 602 total plots) and those used in 2015 (*n* = 33 plots).

Some ecosite types were found to support more rare species, although the particular categories with the highest average numbers of these changed between the 2014 and 2015 rankings (Tables 1.8 & 1.9; Figures 1.5 & 1.6). For the 2014 rankings, in descending order, the categories RD, SD, and MD had the three highest combined averages of S1-S3 species, but in 2015 these shifted to RD, MD, and PX. Conversely, the three categories with the lowest combined averages of rare species for the 2014 rankings in descending order were VD, PD, and MX, but these changed to PD, MG, and VD in 2015.

Table 1.8. Mean number of species of different Conservation Status Ranks (2014) present across the Rarity and Diversity plots (*n* = 602) per ecosite category.

	Conservation Status Rank (2014)									
	Mean Number of Species Present Across Plots									
Ecosite	S1	S2	S3	S3S4	S4	S4S5	S5	SNA	SNR	SU

NT	1.0	1.0	3.3	1.3	6.3	0.0	45.6	7.6	1.4	0.0
PX	1.0	0.0	2.4	1.0	2.6	1.0	24.6	1.3	1.0	1.1
PM	1.0	1.2	3.0	1.0	3.9	1.0	36.1	2.5	1.1	0.0
PD	0.0	1.0	2.3	1.0	2.9	0.0	21.8	2.5	1.0	0.0
MX	1.0	0.0	2.3	1.0	3.2	1.0	37.5	1.9	1.0	1.0
MM	1.0	0.0	2.4	1.0	4.3	1.0	45.8	2.4	1.0	0.0
MG	0.0	1.0	2.9	1.2	6.6	1.0	55.6	2.9	1.0	0.0
MD	1.0	1.3	3.5	1.0	4.3	1.0	28.2	2.7	1.0	1.0
RG	1.0	1.0	3.1	1.0	5.8	1.0	51.0	2.4	1.0	0.0
RD	1.0	1.1	4.5	1.1	6.0	1.0	37.0	2.2	1.0	1.0
SD	0.0	2.0	4.1	1.0	6.9	0.0	57.8	2.0	1.3	0.0
VD	1.0	0.0	1.0	0.0	4.0	0.0	23.5	2.0	1.0	0.0

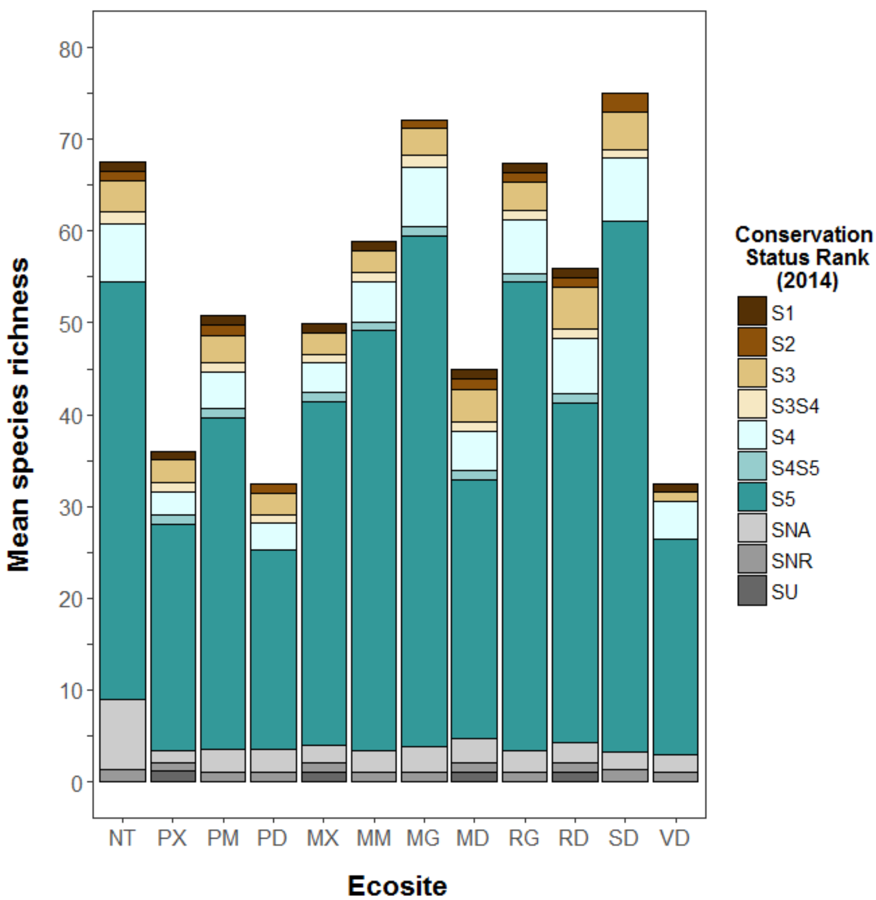

Figure 1.11. Mean vascular plant species richness for the 12 ecosite categories sampled across the Rarity and Diversity plots (*n* = 602) and the number of species per Conservation Status Rank (2014).

Table 1.9. Mean number of species of different Conservation Status Ranks (2015) present across the Rarity and Diversity plots (*n* = 602) per ecosite category.

Conservation Status Rank (2015)

	Mean Number of Species Present Across Plots								
Ecosite	S1	S2	S2S3	S3	S3S4	S4	S4S5	S5	SNA
NT	0.0	1.0	0.0	2.0	1.0	6.9	1.0	47.9	7.6
PX	1.1	1.0	0.0	1.9	0.0	3.1	1.0	24.8	1.3
PM	0.0	0.0	1.0	2.0	0.0	4.3	1.1	37.1	2.5
PD	0.0	0.0	0.0	1.7	0.0	3.1	1.0	22.5	2.5
MX	1.0	0.0	0.0	1.7	0.0	3.6	1.0	38.1	1.9
MM	0.0	1.0	0.0	1.6	0.0	4.0	1.0	47.0	2.4
MG	0.0	0.0	0.0	1.8	1.0	6.7	1.2	57.2	2.9
MD	0.0	1.0	1.0	2.0	0.0	4.8	1.0	29.7	2.7
RG	0.0	0.0	1.0	1.9	1.0	6.5	0.0	52.2	2.4
RD	1.0	1.0	1.0	2.4	1.0	7.1	1.1	38.8	2.2
SD	0.0	1.0	0.0	2.3	0.0	8.6	0.0	59.6	2.0
VD	1.0	0.0	0.0	1.0	0.0	3.0	0.0	25.0	2.0

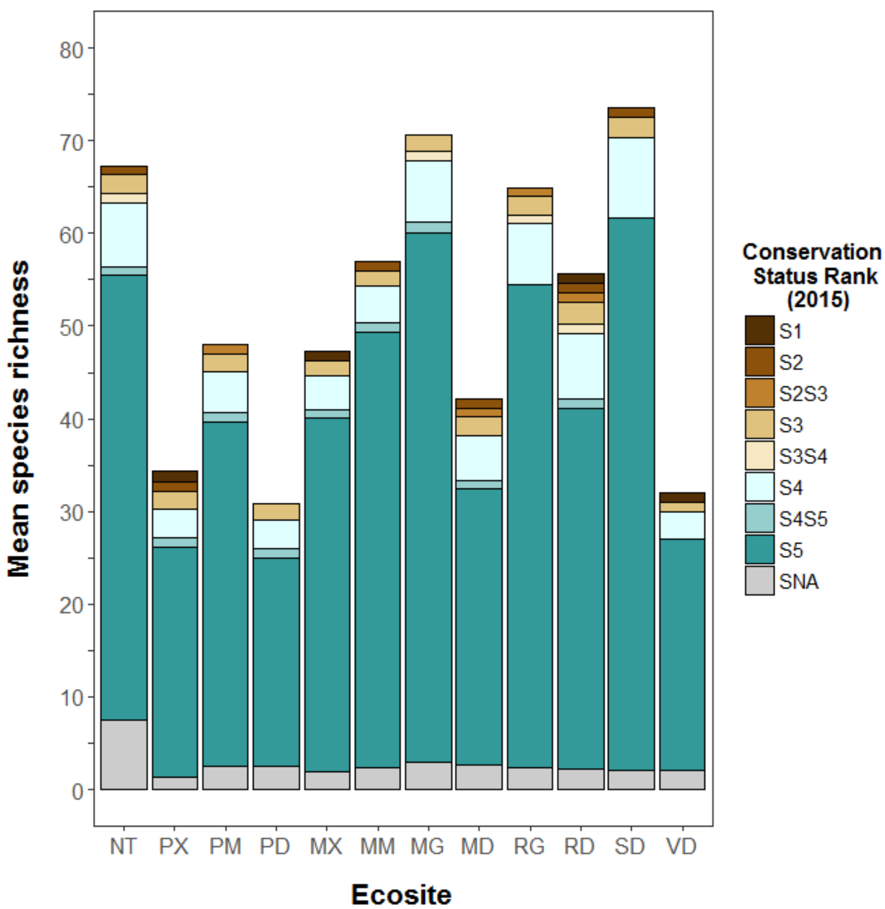

Figure 1.6. Mean vascular plant species richness for the 12 ecosite categories sampled across the Rarity and Diversity plots (n = 602) and the number of species per Conservation Status Rank (2015).

1.5 Discussion

A total of 536 vascular plant species were detected in the 602 quarter-hectare Rarity and Diversity plots surveyed across the study area between 2012 and 2015. Average richness was 45.4 species per plot across all 12 ecosite categories, with SD (swamps) and PD (oligotrophic bogs) supporting the greatest and least diversity, respectively. Swamps, seasonally flooded wetlands with a mineral substrate, most often occur as small habitat patches in Alberta with microsites (hummocky micro-terrain) that promote species diversity. While peatlands include many, often diverse, types, oligotrophic bogs are characterized by exceptionally low nutrients, high acidity, and waterlogged organic substrate, conditions which limits the number of species capable of establishing and surviving in these habitats.

Changes to Conservation Status Ranks affected the number and distribution of rare species (S1-S3) encountered during sampling, which decreased from 101 to 63 species between 2014 and 2015 following the re-evaluation of rankings. We encountered at least one S3 species at nearly all sample plots, demonstrating the efficacy of model-directed adaptive sampled as applied here. Using the 2015 S-ranking we have located eight S1 or S2 species at 33 plots. The downgrading of Status Ranks for a large number of vascular plant species within the study area is likely in part an artefact of increased sampling effort over time by monitoring projects, such as what we have conducted here (all rare species detected in the project were submitted to ACIMS), and a large number of pre-disturbance assessments for oil sands developments that have led to a greater understanding of plant rarity in the region.

CHAPTER 2.0: Landscape patterns of rare vascular plants in the Lower Athabasca region of Alberta, Canada

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2.1 Summary

We used 602 quarter-hectare plots in the Lower Athabasca region to model rare vascular plant (S1 and S2 conservation status) habitat across the area based on landscape predictors of land cover (Ducks Unlimited-Enhanced Wetland Classification), LiDAR-derived vegetation structure, soils (pH), and terrain wetness. The LiDAR-derived and land cover variables were the most important predictors of rarity when considered individually for the 2012-2014 and 2015 conservation ranks respectively. Amount of rare plant habitat in as the region was reduced substantially with changes in the new status rankings and shifted in its location. Generally, patterns of rarity went from fens being among the most important sites for encountering S1 and S2 ranked species to sandy, pine forests (Athabasca Plain) being the most important sites. Maps of rare plant habitat developed from this work are being used as an indicator for the Biodiversity Management Framework regional planning initiative for the Lower Athabasca. It also has value for lease-scale environmental assessments and mitigation planning, informing future monitoring programs and sites, and more generally in helping us understand the factors that promote or limit rare vascular plants within Alberta's boreal forest.

2.2 Introduction

The oil sands region of Alberta represents a major source of environmental concern (Rooney, Bayley & Schindler 2012). Although significant efforts have been made toward reclamation of surface mineable oil sands and determining the responses of individual plant species to reclamation treatments (Renault *et al.* 1998; Purdy, Macdonald & Lieffers 2005; Price, McLaren & Rudolph 2010), much less is known about the effects of in situ oil sands developments where bitumen is extracted through sub-surface wells. In situ oil sands results in a much lower total anthropogenic footprint (~10-20% loss), but remaining native habitats are highly fragmented from the linear nature of disturbances (seismic lines, roads, pipelines, and transmission lines). Together with the permanent footprints, the loss and fragmentation of boreal forests is implicated in the declines of some key boreal species, with the most prominent being woodland caribou. Although much has now been done to understand the factors contributing to caribou decline (e.g. Dyer *et al*. 2002, Boutin *et al.* 2012), much less is known about other taxa, particularly nonvertebrates, including plants. This has resulted in major knowledge gaps within the in-situ oil sands region on taxa such as plants, particularly for sensitive, rare vascular plants.

Sampling of rare vascular plants is difficult due to the fact that they are often cryptic in nature and isolated to specific, uncommon habitats. This has partly contributed to our current knowledge gaps, including information on where rare plants are most likely to occur and how they may respond to disturbances created by in situ oil extraction. Such information is needed for regional conservation assessments, effective land use planning, and for guiding mitigation activities and monitoring programs. Although vascular plant monitoring in Alberta is broadly addressed by the Alberta Biodiversity Monitoring Institute (ABMI) (Stadt *et al*. 2006), sampling intensity of the ABMI monitoring network is too diffuse (grid of 20 km) to be of value for assessments of local responses of species (Nielsen *et al*. 2009). It also suffers from low detection rates of rare species given a time-limited survey protocol and large plot size (1 ha) coupled with high observer errors (Zhang *et al*. 2014). In addition to these systematic monitoring sites, oil sands companies are required to perform Pre-Disturbance Assessment (PDAs) surveys prior to developing individual footprints. These PDAs include rare plant surveys that provide location data and general information for populations encountered on lease areas, but do not lend themselves to monitoring since sites are often later developed, survey effort is largely unknown, and information is not scaled past individual sites on oil sands leases. Complementary methods for rare plant surveys and regional monitoring of rare plants are needed to inform rarity of plants at regional scales, including the development of mapping tools that can be used by government and industry for the conservation and management of rare plant resources and environmental impact assessments at the scale at which projects (leases) occur.

Model-based sampling designs, where information from spatial models are used to guide sampling effort (locations), have been proposed as an alternative to the commonly employed random or systematic designs that dominate current monitoring and survey efforts (Guisan *et al*. 2006). In addition to creating efficiencies (up to 70% cost savings), model-based, adaptive designs provide up-to-date products that can be used to not only guide future sampling effort, but also provide critical information for making relevant management decisions related to the original monitoring objectives.

The purpose of this chapter is to develop, test, and apply an adaptive, model-based sampling design that defines rare plant habitat in the Lower Athabasca region of northeast Alberta. Specific to that goal, our objectives were two-fold: (1) identify the landscape factors that most affect presence of rare vascular plants in the Lower Athabasca; and (2) predict (map) rare plant habitat in the Lower Athabasca region. It is this region of Alberta that has the most extensive in situ oil sands operations thus requiring spatial tools to assist with land use decision-making, regional monitoring, and stewardship.

2.3 Methods

Study area, field plots, and definitions of rarity

We sampled rare vascular plants within the Lower Athabasca region in northeast Alberta, Canada over four years through the Rarity and Diversity plots for the Lower Athabasca project. Field methods are described in Zhang *et al*. (2014) and Chapter 1 of this report. Below we summarize those methods and describe in more detail the allocation of sampling effort. Specifically, we used a stratified sampling approach to allocating field efforts based on the Ducks Unlimited Enhanced Wetland Classification (DU-EWC) and preliminary landscape models predicting rare plant locations that were periodically updated based on historic locations of rare plants (Alberta Conservation Information Management Systems [ACIMS] and industry Pre-disturbance assessments) and locations collected from the prior year's surveys (Nielsen 2011). Stratification was thus adaptive to new information collected from field surveys (i.e., model-based iterative sampling). Model-based sampling designs are an alternative to static traditional fully random or stratified designs. With proper information guiding the adaptive sampling process, major cost savings (up to 70% over random) can be gained (Guisan *et al*. 2006).

Initially, S1, S2, and S3 plant population (sub-national rarity status ranks for Alberta assigned by ACIMS) locations were used to model potential landscape locations of rare plants within land cover types (Nielsen 2011). This was used to guide stratification from all known rare plant records. Later, landscape models used plot data from this research project on locations of where S1 and S2 plants were present. We excluded S3 ranked species as encounter rates of any S3 plant in a plot approached 100%, thus making their inclusion as a group in models meaningless. Landscape predictors included the DU-EWC land cover types and terrain and edaphic variables. The DU-EWC land cover classification scheme includes a number of detailed wetland classes (Table 2.1), such as graminoid rich fen. Separation of wetland types was desirable given the prevalence and importance of lowland land cover types in the Lower Athabasca. Initial model predictions of rarity were separated for each DU-EWC land cover type and sample sites within each 'native' land cover type was selected through randomization.

Table 2.1. List of Ducks Unlimited Enhanced Wetland Classification land cover types considered for models of rare plant occurrence in the Lower Athabasca region of northeast Alberta (source: Ducks Unlimited). Note that some classes (aquatic and anthropogenic were not listed or used in models).

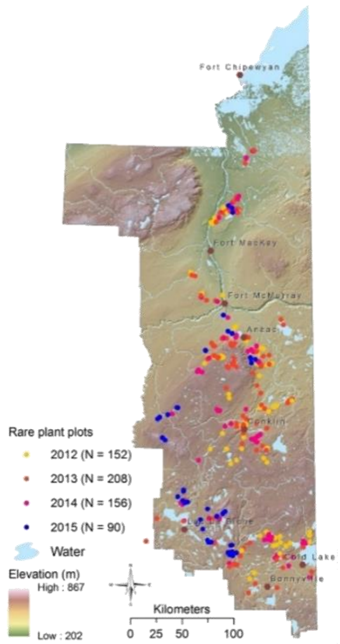
Class Name	Type of community	Soil Moisture	Hydro-dynamics	Nutrient Regime
Emergent Marsh	Mineral Wetland	Very Hydric	Very Dynamic	Very Rich
Meadow Marsh	Mineral Wetland	Hydric	Very Dynamic	Very Rich
Graminoid Rich Fen	Peat Wetland	Hydric	Moving	Rich
Graminoid Poor Fen	Peat Wetland	Hydric	Slow Moving	Poor
Shrubby Rich Fen	Peat Wetland	Sub Hydric	Moving	Rich
Shrubby Poor Fen	Peat Wetland	Sub Hydric	Slow Moving	Poor
Treed Rich Fen	Peat Wetland	Sub Hydric	Moving	Rich
Treed Poor Fen	Peat Wetland	Hygric	Slow Moving	Poor
Open Bog	Peat Wetland	Sub Hygric	Stagnant	Very Poor
Shrubby Bog	Peat Wetland	Sub Hygric	Stagnant	Very Poor
Treed Bog	Peat Wetland	Sub Hygric	Stagnant	Very Poor
Shrub Swamp	Mineral Wetland	Hydric	Dynamic	Rich
Hardwood Swamp	Mineral Wetland	Hygric	Dynamic	Rich
Mixedwood Swamp	Mineral Wetland	Hygric	Dynamic	Rich
Tamarack Swamp	Mineral Wetland	Hygric	Slow Moving	Medium
Conifer Swamp	Mineral Wetland	Sub Hygric	Stagnant	Medium
Upland Conifer	Upland	Mesic to Xeric	Upland	Upland

Upland Deciduous	Upland	Mesic to Xeric	Upland	Upland
Upland Mixedwood	Upland	Mesic to Xeric	Upland	Upland
Upland Pine	Upland	Xeric	Upland	Upland
Burn	Other	Other	Other	Other

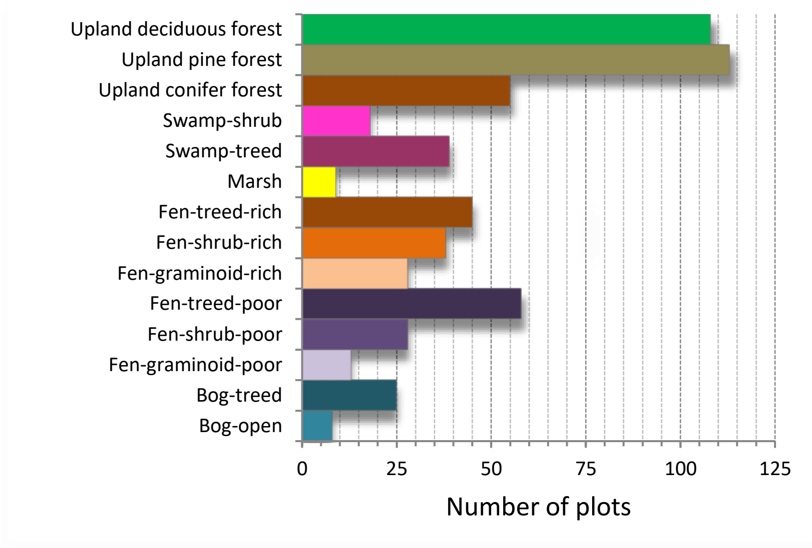
Sample sites were constrained to within a 2.5 km radius of roads with areas predicted to have greater chance of a rare plant being present emphasized. Anthropogenic habitats (clearcuts, agriculture, industry developments) and aquatic habitats dominated by open water were not considered in this study. Site randomization was done in ArcGIS using the *Create Spatially Balanced Points tool* where locations were spread across the available region and scaled so that more random locations were allocated within areas having higher probabilities rare plants (input inclusion probability raster). Random sites included oil sands leases, areas not currently leased, and provincial parks such as Lakeland and Sir Winston Churchill, but did not include the Cold Lake Air Weapons Range, remote areas such as the Birch Mountains, and the entire Canadian Shield north of Lake Athabasca which does not contain hydrocarbons and thus is not threatened from energy developments. In a few instances helicopter support was available and used to access a limited number of remote sites near Fort McMurray including plot locations on Stony Mountain and areas surrounding Gypsy Lake Wildland.

Because rare plants were more likely to occur in particular land cover types, such as fens, we sampled more locations of these land cover types, as well as some land cover types that dominated the region such as deciduous forest, but may have had some microsite or meso-terrain condition that would increase the likelihood of rare plants being present (Figure 2.1b). Emphasis on particular land cover types was determined based on initial queries describing known rare plant records by land cover type. Chapter 1 describes the number of plot locations by ecosites which relate to land cover types from the DU-EWC. All rare plant surveys were completed during the summer months (mid-June to mid-August). Plot size was 0.25 ha (50 x 50 m) with observers allowed to complete the plot without time constraints. Although the emphasis of this project was rare plants, we recorded the presence of all vascular plants within plots in order to fully describe assemblages and to provide more information on general plant biodiversity. Given the large plot size, no effort was made to estimate cover or abundance of common species.

All observers had previous experience with plant surveys with additional training provided in the herbarium (emphasis on S1-S3 plants in the region) and in the field. Unknown plants within plots were collected for later identification. Observers working in teams of two navigated to stratified plots using handheld GPS units. One observer established and surveyed the target plot based on the stratified random location, while the second observer established a paired plot within 200 m of the target plot and in a different land cover type to ensure independence among observations. The paired plot design among observers was used to satisfy safety protocols that limited observers from working no further than 200 m apart. The perimeter of each plot was delineated using 50 and 100 m transect tapes. Observers then surveyed their plot without assistance by walking the plot in ~2 m belt transects and stopping to record all new vascular plant species encountered and the time of observation. Rare plants (S1-S3) were flagged and after the completion of the survey returned to in order to fill in an ACIMS field data sheet describing the habitat, microhabitat, GPS coordinates, population size, and other attributes. Rare plant records were submitted annually to the Government of Alberta's ACIMS program. In total, 602 unique sites were sampled over a 4-year period (2012-2015; Figure 2.1a) with 67 sites re-surveyed multiple times within the same day by a separate observer in order to evaluate observer error (see Chapter 4). For the purpose of this chapter, we use the first survey session at a site for those cases where the site was surveyed more than once.



a.

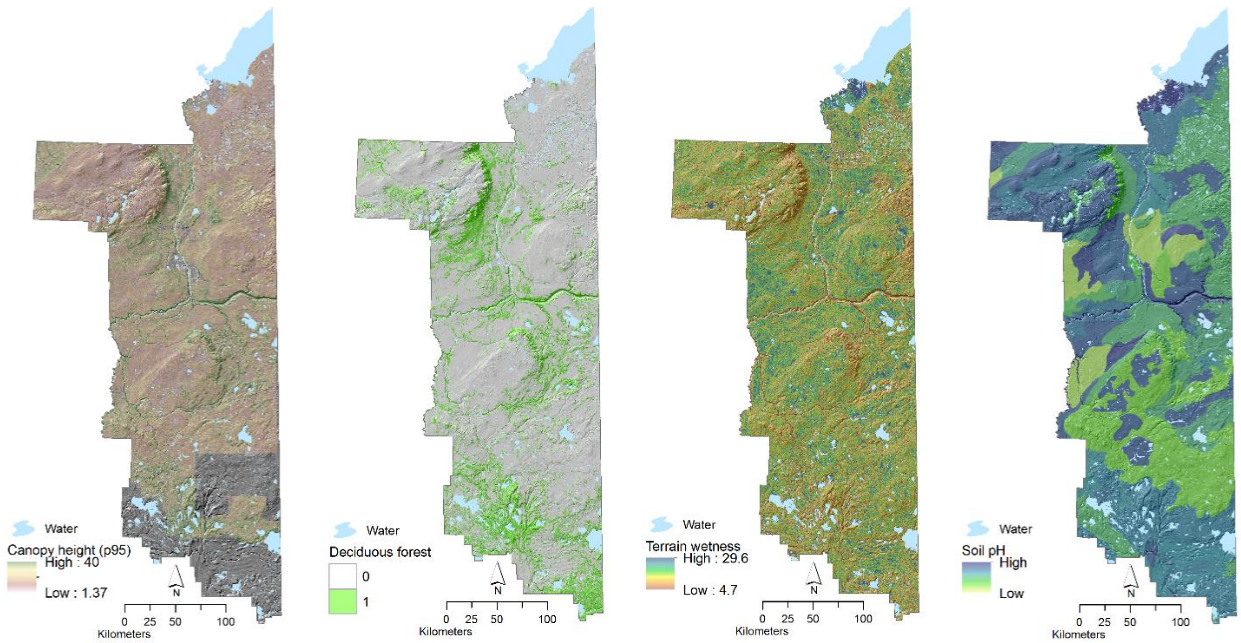


b.

Figure 2.1. (a.) Location of field plots and (b.) number of plots sampled per land cover type (dominant type within plot).

Landscape predictors of rare plant habitats

Environmental predictors of rarity included spatially-explicit variables representing soil conditions (soil pH) (Figure 2.2d), land cover from Ducks Unlimited Enhanced Wetland Classification (DU-EWC) (Figure 2.2b), terrain-derived moisture index (2.2c), and vegetation structure from airborne LiDAR sensors that measures variation in height and structure (Figure 2.2a). LiDAR-derived vegetation structure variables were available for most, but not all, parts of the study area (see Figure 2.2a) effectively representing crown lands outside of the Cold Lakes Air Weapons Range. Models using LiDAR data therefore also represent a subset of plots with a total of 469 plots available within areas having LiDAR data. LiDAR point cloud metrics were summarized for the region at the scale of the plot (50 m raster) using FUSION software (McGaughey 2016). LiDAR-derived variables used for models included canopy relief ratio (CRR), maximum canopy height (95^{th} centile), and standard deviation in canopy height. An example land cover type for the region is shown in Figure 2.2b. The terrain-derived moisture index was estimated from a 50-m digital elevation model (DEM) using the Compound Topographic Index (CTI) method (Moore *et al*. 1993, Gessler *et al*. 1995). Although a smaller area was available for depth-to-water (DTW) from the Wet Area Mapping program, comparisons within that zone suggested that the CTI model from a lower resolution DEM performed as good or better than the more detailed DTW predictions and thus CTI was subsequently used in all models. Soil conditions were measured by soil pH based on Soil Landscapes of Canada version 3.2 (Soil Landscapes of Canada Working Group 2010). Although other soil variables were available, they were either highly correlated with soil pH or did not correlate with rare plant locations. Climate variables were not used in models since the region is quite small relative to differences in climate and because the coldest parts of the study area (i.e. the Birch Mountains) were not sampled. All final predictor variables were scaled to a 50-m raster cell size to ensure that they matched the scale of plots and other rasters. Highly correlated variables ($r > |0.7|$) were removed from analyses by choosing only one of the correlated variables, thus avoiding problems of multicollinearity.



a. b. c. d.

Figure 2.2. Example landscape variables used to predict locations of rare vascular plants (S1 or S2 conservation status): (a.) LiDAR-derived canopy height (95th centile; note that gray areas represent locations without LiDAR data); (b.) land cover (deciduous forest example; Ducks Unlimited); (c.) terrain wetness from 50 m DEM; and (d.) soil pH.

Models of rare plant habitats

We used logistic regression to model the probability of a S1 or S2 rare plant being present at a site based on landscape characteristics (predictors) in order to estimate rare plant habitats across the region. Models used the presence of any S1 or S2 plant within our 602 plots as the response variable (historic ACIMS locations were not used) and landscape variables as predictors. During the course of this study ACIMS reclassified the status of vascular plants in Alberta resulting in major changes to what we defined as rare plants (see Chapter 1 for a detailed review of changes). As a result, we developed two sets of models of plant rarity based on the two different periods of defined rarity. The first model represented 2012-2014 rankings and the second rankings for the 2015-current period. In both cases, all field plots (years of data) were used and differences only reflect the change in ranking of species.

Model selection was based on Akaike's Information Criteria (AIC, Akaike 1974) where different sets of landscape predictors were used to compare support among candidate models (sets of variables). Given the large number of parameters and possible candidate models, parameters of the most supported model were inspected and where obvious weak responses were evident, variables were removed to be more parsimonious as confirmed by AIC scores. Final model parameters were then reported, including traditional statistics of model and parameter significance. Parameters were then used to predict rare plant habitat across the region using ArcGIS map calculator. Model performance and predictive accuracy of final selected models were based on percent deviance explained (pseudo-R^2) and Area-Under-the-Curve Receiver Operating Characteristic (AUC-ROC). Although ecological models often have poor explanatory power (2-5% r^2, Møller & Jennions 2002), we considered models with pseudo-$R^2 > 0.2$ as being reasonably explanatory. To confirm predictive accuracy of models, AUC-ROC values were ranked based on model training data with values < 0.7 are considered to represent poor model accuracy, values between 0.7–0.9 good model accuracy, and values > 0.9 high model accuracy (Swets 1988, Manel *et al*. 2001).

As airborne LiDAR data describing vegetation structure within the region were not available across the entire study area (Figure 2.2a), models were first developed for the area with LiDAR data and secondly for the remaining areas using more general landscape predictors. Final map predictions of rare plant habitat were then fused with the LiDAR-based predictions used wherever available and the more general model used where LiDAR data were not available. This fusion was done using the *Conditional tool* in ArcGIS.

2.4 Results

Rare plant habitat (S1 & S2 ranking, 2012-2014)

Of the 602 plots sampled, 47 had at least one S1 or S2 ranked vascular plant (39 plots when limited to the extent of available LiDAR data) using the 2012 to 2014 ACIMS rankings (Figure 2.4a). Occurrence of rare plants by land cover type (proportion) varied from 0 in marsh and open bog to 0.23 (more than 1 out of 5 plots) in graminoid-poor-fen (Figure 2.3). Other land cover types frequently occupied by S1 and S2 plants included tree-poor-fen, treed-rich-fen, shrub swamp, graminoid-rich-fen, and upland pine forests (Figure 2.3).

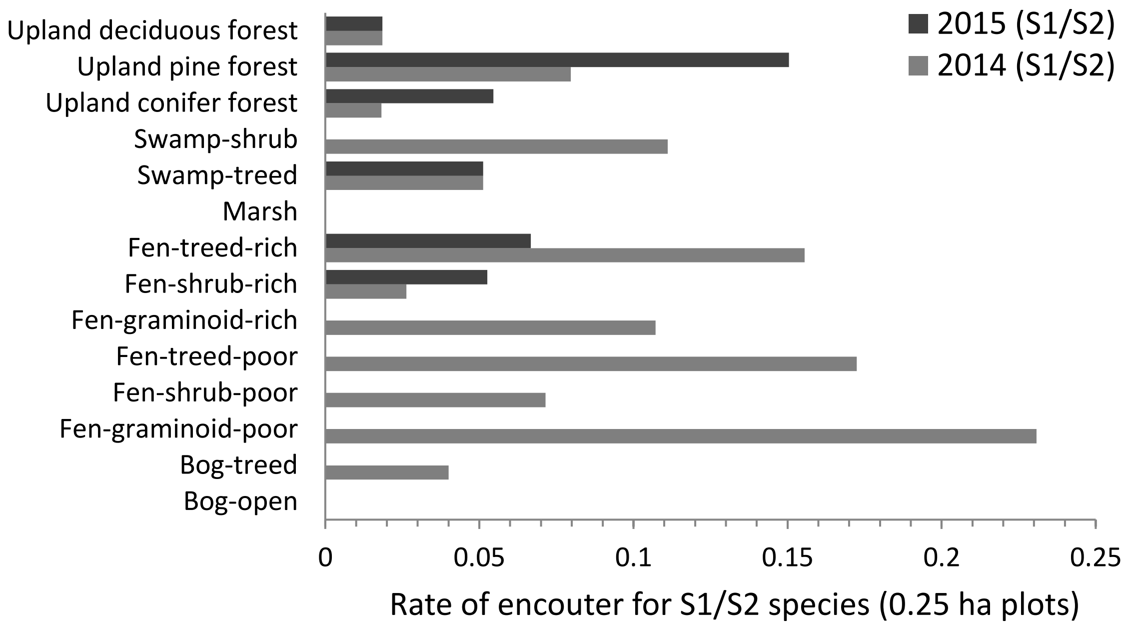
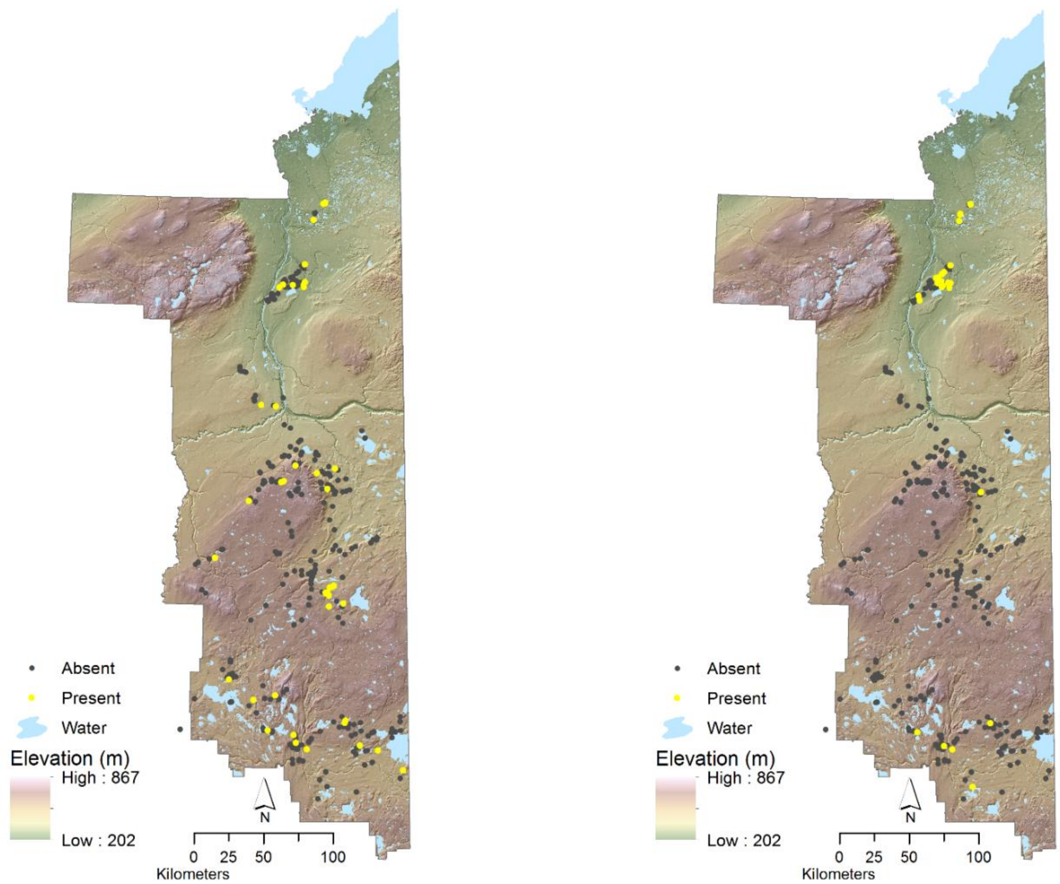


Figure 2.3. Encounter rate patterns of rare vascular plants (S1 or S2) within study plots based on dominant land cover type within the plot. Two rates are reported based on 2012-2014 ranking '2014 S1/S2' light gray) and the most recent ranking ('2015 S1/S2' dark gray). See Chapter 1 for summary data by ecosite.



a. b.

Figure 2.4. Distribution of field plots with the presence of at least one vascular plant species ranked as a conservation status of S1 or S2 within the Lower Athabasca region based on (a.) 2012-2014 rankings or (b.) 2015 rankings.

The most supported model predicting rare plant presence for the 2012-14 ranked S1 and S2 species included all individual landscape factors related to soils, terrain (wetness), land cover, and vegetation structure (Table 2.2). When considering individual (single) factors, vegetation structure from LiDAR was more supported (ΔAIC > 4) than any other factors, followed by land cover and terrain wetness. Soil pH was similar to the null model suggesting no support for that factor when considered individually. The most supported two-factor model included vegetation structure (LiDAR) and land cover. Interestingly, when considering 3 combined landscape factors, soil pH was added despite initially being neutral. The final adjusted global model that contained all 4 landscape factors had good model fit (pseudo-R^2 of 0.228) and model accuracy (ROC = 0.841; Table 2.2). Ranking of the importance of land cover types were similar to those described above (Figure 2.3). Overall, graminoid-poor-fens had the highest rate of rare plants (Table 2.2). Both soil pH and terrain wetness (CTI) had non-linear responses along their gradients with peak occurrence of rare plants at moderate levels of soil pH and wetness. Finally, for vegetation structure metrics the canopy relief ratio (CRR) was found to be positively related to rare plant occurrences, while vegetation height (95^{th} centile) was negatively related to rare plant occurrences (Table 2.3). Parameters included in the model without LiDAR metrics were similar to those with LiDAR variables (Table 2.3), while still maintaining reasonably good model fit (pseudo-R^2 = 0.182) and similar overall model accuracy (ROC = 0.812).

Table 2.2. Comparison of candidate models describing the presence of S1 or S2 rare plant within the Lower Athabasca region based on soils (S), terrain (T), land cover (L), and vegetation structure derived from airborne LiDAR data (V). AIC values in bold font represented the most-supported model (lower AIC is better) within the set of models tested (by single, two, three, and four-factor sets). Model complexity represented by number of parameters (*K*). ROC represents model predictive accuracy, while model fit (R^2) was measured by percent deviance explained. The adjusted global model was the final model used for explanation and model prediction.

	2012-14 ranking (S1 or S2)				2015 ranking (S1 or S2)			
Model	AIC	*K*	ROC	R^2	AIC	*K*	ROC	R^2
Single factor models:								
S-Soils	270.48	3	0.600	0.016	199.04	3	0.682	0.066
T-Terrain wetness	266.79	3	0.594	0.029	206.43	3	0.637	0.030
L- Land cover	254.54	11	0.769	0.134	**168.89**	6	0.866	0.241
V- Vegetation structure	**250.60**	4	0.765	0.097	185.34	4	0.795	0.142
Null (constant)	270.65	1	0.500	0.000	208.57	1	0.500	0.000
Two-factor models:								
S+T	267.55	5	0.638	0.041	197.95	5	0.779	0.090
S+L	251.07	13	0.804	0.162	162.00	8	0.884	0.293
S+V	249.60	6	0.778	0.116	181.78	6	0.816	0.178
T+L	252.33	13	0.788	0.158	168.26	8	0.881	0.263
T+V	248.63	6	0.777	0.119	183.99	6	0.817	0.167
L+V	**247.09**	14	0.829	0.185	**160.16**	9	0.889	0.312
Three-factor models:								
S+T+L	249.89	15	0.812	0.182	163.32	10	0.890	0.306
S+T+V	248.69	8	0.792	0.134	181.60	8	0.832	0.198
S+L+V	**243.70**	16	0.837	0.212	**154.07**	11	0.897	0.361
T+L+V	244.56	16	0.838	0.209	156.01	11	0.898	0.351
Four-factor models:								
Global (S+T+L+V)	242.62	18	0.845	0.231	156.44	13	0.899	0.369
Final model	**241.45**	**17**	**0.841**	**0.228**	**152.84**	**9**	**0.891**	**0.347**

Table 2.3. Logistic regression parameters for the most-supported (AIC) model (with and without LiDAR data) describing probability of a S1 or S2 vascular plant being present in the Lower Athabasca region of Alberta using 2012-2014 conservation status ranking. Land cover variables are in comparison to the reference category of deciduous forest.

	Model w/ LiDAR variables			Model w/o LiDAR variables		
Variable	Coef.	SE	*P*	Coef.	SE	*P*
Soil pH	5.706	2.788	0.041	6.183	2.686	0.021
Soil pH^2	-0.581	0.298	0.051	-0.641	0.287	0.026
T-CTI (wetness)	41.53	21.53	0.054	39.00	20.64	0.059

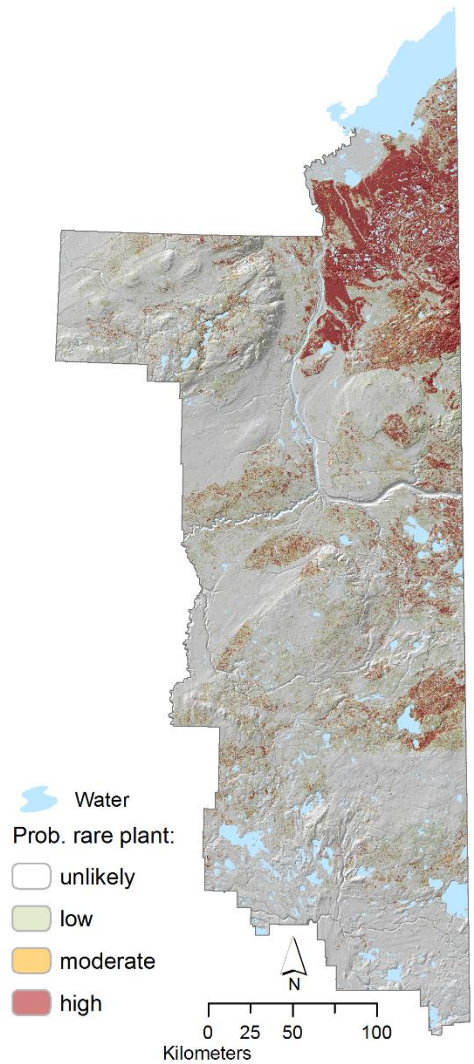
T-CTI^2 (wetness)	-8.679	4.490	0.053	-8.194	4.310	0.057
L-Treed-bog	3.161	1.453	0.030	2.556	1.381	0.064
L-Graminoid-poor-fen	5.324	1.458	<0.001	5.616	1.353	<0.001
L-Shrub-poor-fen	3.851	1.369	0.005	4.168	1.255	0.001
L-Treed-poor-fen	3.928	1.212	0.001	3.940	1.142	0.001
L-Graminoid-rich-fen	3.357	1.551	0.030	3.827	1.528	0.012
L-Shrub-rich-fen	2.426	1.401	0.083	2.681	1.329	0.044
L-Treed-rich-fen	4.263	1.197	<0.001	4.098	1.126	<0.001
L-Conifer swamp	3.174	1.474	0.031	3.031	1.466	0.039
L-Upland burn	4.893	1.708	0.004	4.544	1.678	0.007
L-Upland pine	2.520	1.005	0.012	2.808	1.024	0.006
V-Canopy height (CRR)	5.872	1.799	0.001			
V-Canopy height (p95)	-0.116	0.053	0.028			
Constant (intercept)	-69.29	26.19	0.008	-65.77	25.00	0.009

Map predictions of the 2012-2014 S1 and S2 ranked vascular plant habitat showed patchy patterns of rare plant habitat throughout the region reflecting the value of a number of land cover types and other landscape factors (Figure 2.5a). Some notable sites included the southern parts of the Birch Mountains, the area around Winfred Lake east of Conklin, and Marguerite River Wildland along the Saskatchewan border east of Fort McKay.

Rare plant habitat (S1 & S2 ranking, 2015-current)

Of the 602 plots sampled, 31 had at least one S1 or S2 ranked vascular plant (27 plots when limited to the extent of available LiDAR data) as ranked by conservation status using 2015 rankings (Figure 2.4a). Noticeable changes in frequency of rare plant encounters were observed with the recent change in conservation status of plants. Proportion of occurrence by land cover varied from 0 for most land cover types to 0.16 in upland pine forests which nearly doubled in encounter rate of rare plants between 2014 and 2015 (Figure 2.3). This was largely due to previously unclassified species that were specialists to dry sandy plains (Athabasca Sand Plain) being ranked to S1 or S2 status with many sites on the sand plain now classified as having a conservation-ranked species. Other land cover types frequently occupied by S1 and S2 plants included tree-rich-fen, shrub-rich-fen, treed swamp, and upland conifer forests (Figure 2.3).

a.



b.

Figure 2.5. Predicted distribution of rare vascular plants (S1 or S2 conservation rank) within the Lower Athabasca of northeast Alberta, Canada based on landscape predictors and either (a.) 2012-2014 conservation status or (b.) 2015 conservation status. Prediction classes are based on model sensitivity, specificity, and optimal threshold classification probability (unlikely = sensitivity $\geq$ 0.9; low = sensitivity < 0.9, while being lower than the optimal threshold probability; moderate = sensitivity < 0.9, while being higher than the optimal threshold probability; high = specificity > 0.9 and higher than the optimal threshold probability).

The most supported model predicting rare plant presence for the 2015-ranked S1 and S2 species included all of individual landscape factors related to soils, terrain (wetness), land cover, and vegetation structure (Table 2.2). When considering individual (single) factors, land cover was much more supported than the other factors, followed by vegetation structure from LiDAR, soils, and terrain wetness. All single factors models were more supported than the null model. The most supported two- and three-factor models included vegetation structure (LiDAR) and land cover for the two-factor model with soil pH added for the three-factor model (similar to 2012-14 conservation status model). The final adjusted global model that contained these same 3 landscape factors with further simplification and overall good model fit (pseudo-R^2 of 0.347) and model accuracy (ROC = 0.891; Table 2.1). Soil pH had a non-linear response with peak occurrence of rare plants at moderate pH levels. Finally, for LiDAR-derived vegetation structure metrics the canopy relief ratio (CRR) was positively related to rare plant occurrences, while the standard deviation in canopy height was negatively related to rare plant occurrences (Table 2.3). Parameters included in the model without LiDAR metrics were similar to those with LiDAR variables, but with the upland conifer land cover type removed as there was less evidence for its inclusion once vegetation structure variables were removed (Table 2.4).

Table 2.4. Logistic regression parameters for the most-supported (AIC) model (with and without LiDAR data) describing probability of a S1 or S2 vascular plant being present in the Lower Athabasca region of Alberta using 2015 conservation status ranking. Land cover variables are in comparison to the reference category of deciduous forest and other unlisted native habitats.

	Model w/ LiDAR variables			Model w/o LiDAR variables		
Variable	Coef.	SE	*P*	Coef.	SE	*P*
Soil pH	9.932	4.412	0.024	12.33	4.209	0.003
Soil pH^2	-1.069	0.478	0.025	-1.306	0.456	0.004
L-Treed-rich-fen	2.650	1.345	0.049	2.302	1.249	0.065
L-Conifer swamp	4.130	1.244	0.001	3.792	1.117	0.001
L-Upland conifer	2.323	1.374	0.091			
L-Upland pine	4.172	0.869	0.000	3.676	0.698	<0.001
V-Canopy relief ratio	3.853	1.879	0.040			
V-Canopy height (St.Dev.)	-0.796	0.252	0.002			
Constant (intercept)	-27.41	9.957	0.006	-33.18	9.727	0.001

Map predictions of 2015 S1 and S2 ranked vascular plant habitat showed distinct pattern with the Athabasca Sand Plain having the greatest likelihood of encountering rare plants (Figure 2.5b). Areas of treed-rich-fen, upland conifer, and conifer swamp were the other parts of the region showing distinct patterns of higher rare plant occurrences. The extent of these regions was much less than that of the 2012-14 predictions, where much more of the central and southern Lower Athabasca contained rare plant habitat (Figure 2.5a). This demonstrates the effect of the reclassification of the conservation status of plants with the key result being the emphasis the far northern sand plain and the de-emphasis of many of the fens and bogs common to the central parts of the study area.

2.5 Discussion

Rare plant (S1 & S2) habitat in the Lower Athabasca was modeled for the region for both the 2012-2014 conservation status period and the more recent 2015 to current period. Initial 2012-2014 models demonstrated significant areas of rare plant habitat throughout the in situ region, including high rates of encounter in most of the fens. In 2015 this pattern changed with changes in status ranking of species with more importance placed on drier sandy habitats such as the Athabasca Sand Plain in the north (area north of McClelland Lake). We suspect that a number of species ranked as S1 and S2 on the sand plain are more common than current information provides (data and knowledge gaps). In fact, one species, *Leucophysalis grandiflora*, was given an S1-ranked status in 2015, yet found within 18 of 602 sites (see Chapter 1) suggesting that it is much more common than other available information suggests. Conversely, many sites where rarity was downgraded in models (e.g. fens) due to the collection of historic records of species associated with those habitats, may require further assessments and monitoring to ensure records associated with nearby disturbances haven't resulted in their loss (see Chapter 7 on estimates of extirpation rates).

When considering landscape predictors of rarity, we found that not only was the Ducks Unlimited Enhanced Wetland Classification effective in predicting rarity, but so was LiDAR-derived vegetation structure metrics (Coops *et al*. 2007, 2016), particularly vegetation height (95^{th} percentile) and the canopy relief ratio. In fact, when considered individually, the LiDAR-derived vegetation metrics were similar to better than land cover in predicting rare plant habitat. This suggests that remote-sensing based proxies of rare plant habitat may be used to not only predict current habitat, but also potentially used for monitoring change. More work is needed to validate these new relationships and to better understand mechanisms of those relationships. Regardless, some clear patterns and associations between land cover types (e.g. fens, pine forests) and vegetation structure provide a basis for understanding regional patterns in rarity. It should be noted that rare plants can occur in species-poor sites, like pine forests, and thus approaches to conserving the most diverse communities will not satisfy conservation of rare species and thus principles of complementary need to be considered.

Finally, model (map) outputs should be used for regional to local assessments planning. Currently, this product is being used in the Land Use Framework's regional planning for the Lower Athabasca as a Biodiversity Management Framework (BMF) indicator. This suggests that oil sands operators should consider use of the rare plant habitat models developed here when doing lease-scale environmental assessments in order to guide site-level surveys and to identify approaches to plan developments that minimize their impact on important rare plant habitat.

Implications for management and conservation

Rare vascular plants of current conservation concern within northeast Alberta (S1 & S2 sub-national status) were found mostly within fens, especially treed-rich and shrub-rich fens, pine forests, treed swamps, upland conifer forests, and to a lesser degree deciduous forests. Particular care should be given to developments within these habitats and if disturbed, mitigation methods should be used to minimize their impacts. Where possible long-term monitoring of sites with populations of rare species should be considered (~5-year return frequency), particularly those in proximity to development. Map predictions of rare plant habitat should be considered within regional assessments, such as its use as an indicator in the Biodiversity Management Framework (which it currently is), for environmental impact assessments over large areas, such as in situ oil sands leases, and in regional conservation planning.

CHAPTER 3.0: Using airborne laser scanning to predict plant species richness and assess conservation threats in the oil sands region of Alberta's boreal forest

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3.1 Summary

Timely and cost-effective monitoring of biodiversity across large areas is a major challenge, yet an important component of monitoring programs that inform policy and conservation strategies. Recent advances in Airborne Laser Scanning (ALS) provide new opportunities to simultaneously measure vegetation structure and terrain morphology at fine spatial scales. However, there is limited research on whether ALS metrics correlate with biodiversity measures. We used vascular plant data from 283 quarter-hectare (50 m × 50 m) plots from the boreal forest in northeast Alberta, Canada to evaluate the potential for ALS-derived metrics to explain species richness patterns for vascular plants, as well as for four growth forms: herbaceous (including forbs and graminoids) and woody plants. We found canopy height from ALS was the most consistent and important factor positively related to local patterns in vascular plant richness. Multivariate regression models of ALS-derived metrics explained 20% to 35% of the variation in species richness among vascular plant and the four subclasses. When considering the current distribution of in situ oil sands leases in the region, vascular plant richness inside of the leases are higher than those outside of the leases. Areas delineated for woodland caribou conservation had lower average plant richness suggesting that caribou conservation will do little to protect hotspots of plant diversity in Alberta's boreal forest. Our results highlight the value of using fine-scale measures of ALS-derived vegetation structure to explain, predict, and potentially monitor local plant diversity for a high latitude forested ecosystem.

3.2 Introduction

Given recent and projected trends in climate change and human disturbance, biodiversity threats continue to be a major conservation concern (Sala *et al*. 2000; Thuiller 2007). Essential to understanding trends in biodiversity and subsequently prioritizing conservation efforts is the need to better understand environment-biodiversity relationships and to derive efficient methods for monitoring biodiversity change (Araújo & Rahbek 2006; Kreft & Jetz 2007). Taxonomic richness of species (alpha diversity), most often obtained directly from field surveys, is the most typical measure of biodiversity (Thuiller 2007). However, it is not practical to monitor biodiversity in this way across large regions. A major challenge in managing biodiversity conservation is therefore to link biodiversity measures at local scales to cost-effective monitoring across large areas (Mairota *et al*. 2015). Appropriate surrogates for direct assessments of biodiversity are therefore needed. Advances in remote sensing technology have created opportunities for monitoring habitat and vegetation structure at local to global scales, leading to potentially better, more economical, and faster alternatives to field surveys (Pimm *et al*. 2015).

Habitat loss and climate change are currently considered the two most critical factors threatening biodiversity (Brooks *et al*. 2002, 2006; Thomas *et al*. 2004); both can be measured using remote sensing (Turner *et al*. 2003). Although some studies suggest that multispectral passive optical sensors can be used to predict biodiversity at large scales (Coops *et al*. 2008; John *et al*. 2008; Zhang *et al*. 2016), most passive spectrum-derived satellite indices do not consider vertical structure of vegetation, a key driver of biodiversity at local scales (MacArthur & MacArthur 1961; Bergen *et al*. 2009). Moreover, new insights and methods are needed to recognize that vegetation structure and species composition differ even in two adjoining sites sharing a consistent regional species pool (Cook *et al*. 2002). Indeed, the physical structure of vegetation has long been noted by scientists as key to explaining variation in species diversity, particularly for animals, in part because it relates to possible mechanisms of ecological complexity and niche partitioning (MacArthur & MacArthur 1961; Kalko & Handley 2001). However, metrics related to vertical distribution and stratification of vegetation have historically been feasible only through collection of field data (Baker & Wilson 2000), thus limiting their application to local case studies.

Recent advances in Airborne Laser Scanning (ALS) technology now provide opportunities for measuring and monitoring the structure and complexity of vegetation across larger areas. This includes measures of canopy cover, height class distribution of vegetation, and maximum canopy height (Bergen *et al*. 2009). These metrics of vegetation structure have been used to predict the richness of vertebrates, particularly for birds (e.g., Bradbury *et al*. 2005; Clawges *et al*. 2008; Coops *et al.* 2016), with little done to assess whether ALS metrics explain local patterns in plant diversity.

Plant diversity at local scales (i.e., community level) is known to be affected by many different factors, including biome-scale environmental conditions or regional-to-local factors of topography, environmental heterogeneity, vegetation type, and vegetation structure (e.g., Moser *et al*. 2005; Kreft & Jetz 2007; Fine 2015). Exploring the factors affecting plant diversity at the community level therefore requires understanding of both regional climate factors and local environmental variables, including those that can be measured by ALS. Here, we use 283 plant biodiversity plots from the boreal forest in northeast Alberta, Canada, an area undergoing rapid landscape change due to oil sands developments, to examine whether ALS vegetation and terrain measurements, in combination with other environmental variables, relate to patterns of plant species richness. Establishing this relationship will enable landscape-scale predictions of conservation values. The boreal forest is the largest terrestrial biome on the earth, playing a major role in global biodiversity conservation and ecosystem function (Melillo *et al*. 1993; Näsholm *et al.* 1998). The biome is, however, sensitive to global climate change and human disturbance (Sala *et al*. 2000; Larsson & Danell 2001). Understanding biodiversity patterns (e.g. biodiversity hotspots) in the boreal forest, as well as their relationships with local to regional factors, is one key step for managing biological conservation and monitoring change due to exogenous (e.g. climate change) and endogenous (e.g. habitat fragmentation) threats. This includes a better understanding the implications of exploration and extraction of oil in Alberta’s oil sands (Rooney *et al*. 2012), the world's largest oil reserve (Sherrington 2005), on plant biodiversity hotspots. And to explore whether the locations of plant biodiversity hotspots overlap with those of other major conservation objectives, in particular areas of woodland caribou (*Rangifer tarandus*) habitat, which represent the current focus of conservation initiatives in Canada's boreal forest (Schneider *et al*. 2010).

3.3 Methods

Study area

The study area was located in the boreal forest of northeast Alberta, Canada ranging in latitude from 55.3° N to 57° N (Figure 3.1). This area is part of the Boreal Forest Natural Region, which includes the lower portion of the Athabasca River and Lake Athabasca (Natural Regions Committee 2006). Elevations in the area range from 231 m to 863 m a.s.l., with annual precipitation and mean annual temperatures ranging from 430 mm to 492 mm and from -1.2 °C to 0.3 °C, respectively. On the uplands, soils are typically Brunisols, while wetland areas are Mesisols, Organics, Gleysols, and Grey Luvisols. Forests in the area are comprised of a mosaic of deciduous, mixed wood, and coniferous stands, with upland stands dominated by *Populus*, *Picea*, and *Pinus* spp., while lowland areas are represented by fens, swamps, and bogs (Natural Regions Committee 2006; Zhang *et al*. 2014).

Plot data

Plot data were collected under the Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca, formerly known as the Ecological Monitoring Committee for the Lower Athabasca (EMCLA) Rare Plants Project. Field surveys occurred in the summers of 2012 to 2015 with a plot size of 50 m × 50 m (0.25 ha). Vascular plants were identified to species in each plot and recorded as presence/absence data. Unknown specimens were collected and identified later in the lab to species. See Chapter 1 for detailed field methods. In total, 602 plots were completed, but only 283 plots overlapped with ALS data on both vegetation structure and topography-derived variables and thus were used in this study. Since the underlying drivers and assembly mechanisms of plant diversity may differ across growth forms (Mao *et al.* 2013), all plants were classified into five growth forms (subdivisions) based on records from Floras (http://www.efloras.org/). These subdivisions included (1) all vascular plants, (2) herbaceous plants (further separated to (3) forbs and (4) graminoids), and (5) woody plants. Only native species were considered in this paper. Non-native species were infrequently encountered and included only sparse cover of a small number of species (e.g. *Taraxacum officinale* in upland sites). It should be noted, however, that plots were not directly on human disturbances, such as vegetated well sites, pipelines, or clearcuts, but were in the region of where general forest disturbances create conditions of habitat fragmentation. We are not therefore testing here the direct effect of footprints from industrial practices on plant richness.

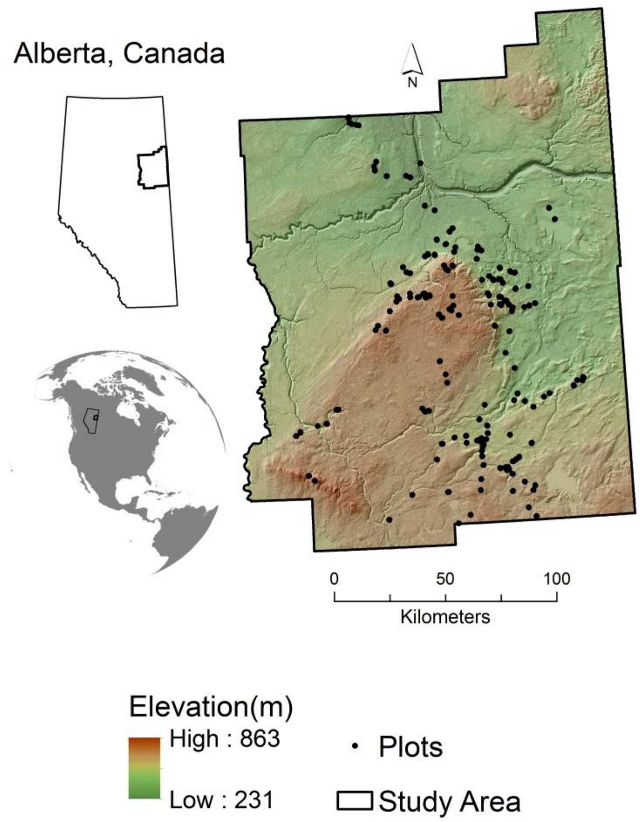

Figure 3.1. Study area in Alberta, Canada and plot locations.

Airborne laser scanning metrics and environmental variables

Airborne laser scanning data were generated from aerial surveys conducted between 2005 and 2013. Point densities averaged 1.9 returns/m^2 with the data processed using the “area-based” technique (Reutebuch *et al*. 2005; Wulder *et al*. 2008). Specifically, ALS point clouds were processed with FUSION software (McGaughey 2016) to derive vegetation height and canopy metrics (Coops *et al.* 2016). Most generally, ALS data can be divided into three different forest vegetation attributes that relate to the horizontal and vertical vegetation structure (1) canopy height at different percentiles; (2) percent of returns above a specified height of the ground to indicate vegetation cover at that height stratum; and (3) return proportion at specified height intervals or variability of return heights to indicate vertical structure (McGaughey 2016; Coops *et al*. 2016). Since many of these metrics are highly correlated with each other, we selected a suite of variables that we considered to have greater ecological meaning to biodiversity. Previous research has demonstrated that metrics based on first returns are more stable than those based on all returns (Goodwin *et al*. 2006; Næsset 2009; Bater *et al*. 2011). We considered the following nine LiDAR-derived variables: the 95^{th} percentile of observed first return heights above ground to represent canopy height, percentage of first returns above 1.37 m (i.e. breast height) represent percent canopy, percentage of first returns above mean height, proportion of first returns for the height strata of: below 0.15 m and between 0.15 m to 1.37 m, 1.37 m to 5 m, 5 m to 10 m, 10 m to 20 m, and 20 m to 30 m (Table 3.1). We used LiDAR-derived canopy height at the 95^{th} percentile of observed heights to measure the maximum height of vegetation at a site rather than using maximum height measured by LiDAR. This reduced sampling bias from extreme conditions (e.g., birds in flight, communication towers, etc.) or possible errors from LiDAR returns (Kane *et al*. 2010; Bolton *et al*. 2013).

Water availability at a site, soil moisture, and local disturbances caused by flood erosion are considered to be important factors shaping local biodiversity (Nilsson *et al*. 1999; Sala *et al*. 2000; Xiong *et al*. 2003). To indicate the effects of water availability on plant richness at each plot, depth to water (DTW) was estimated for the same study region using 'Wet Areas Mapping' (WAM) data derived from ALS point clouds (http://watershed.for.unb.ca). Depth to water is an index that indicates the vertical distance (elevation) to available water, thus indicating drier to wetter conditions of the soil (Murphy *et al*. 2007; White *et al*. 2012; Oltean *et al*. 2016). Terrain variability within a site is also a factor influencing local patterns in plant richness (Webb *et al*. 1999). We used terrain slope within plots to represent the effects of topography, including its effects on promoting environmental heterogeneity within a site. Terrain slope was calculated using ALS-derived digital terrain model (DTM).

Mean annual precipitation (MAP) and mean annual temperature (MAT) were used to account for the effect of broad-scale environmental variability in the size of the local species pool (Gaston 2000; Kreft & Jetz 2007). Mean annual precipitation and MAT were extracted for each plot using climate normals from Climate-AB data (http://tinyurl.com/ClimateAB). We note that because of the regional geographic extent of the study (the distance between the furthest plots is *ca.* 150 km) and the lack of mountainous terrain in the area, climate variables did not substantially vary across the region, but they did indicate general temperature and moisture gradients from colder and wetter to warmer and drier conditions.

Relationships between plant biodiversity hotspots, oil sands, and woodland caribou

Here we assess the threats to plant biodiversity hotspots from oil sands developments, as well as the effectiveness of woodland caribou (*Rangifer tarandus*) conservation in protecting these hotspots. To do this we compared plant species richness for sample plot locations inside active oil sands leases versus areas outside of active leases. Sites within lease boundaries represent natural forest conditions surrounding *in-situ* developments and are potentially impacted by edge or indirect effects, not by the footprint itself. Second, we compared sample plot locations of plant richness for areas inside versus outside of woodland caribou range, given that woodland caribou represent the main focus of conservation and restoration in Canada's boreal forest (Schneider *et al*. 2010), but little is known about the effectiveness of caribou in conserving other taxa. To map locations of caribou habitat, we used caribou range maps from Alberta Environment and Parks (http://aep.alberta.ca). These ranges are utilized for recovery monitoring and conservation initiatives. Oil sands lease boundaries were current to 2013 and based on data from Alberta Environment and Parks (http://osip.alberta.ca). Surface mine leases were removed from comparisons and predictive maps of plant richness to account for the amount and severity of disturbance within mines. Active oil sands surface mining is devoid of vegetation and we considered these mining leases to have no conservation value in the near-term. Instead, we focus on in situ oil sands developments were bitumen is extracted from sub-surface wells and represent overall a larger combined footprint than that of the more well-known oil sands surface mines.

Statistical analysis

Natural logarithm, $\log_{10}$, or square-root transformations were used to normalize ALS and environmental variables exhibiting highly skewed distributions, while a natural logarithm transformation was used to normalize species richness values. All statistical analyses were performed in R program (R Core Team 2015). Simultaneous Autoregressive (SAR) models with a spatial error model were used to account for spatial autocorrelation in plots (Kissling & Carl 2008). Richness of total vascular plants, herbaceous plants, forbs, graminoids, and woody plants were then regressed against ALS metrics and environmental variables using SAR models. SAR models were estimated using the package 'spdep' (Bivand *et al*. 2013; Bivand & Piras 2015). We first used spatial autoregressive one-predictor regression to examine the effects of individual factors (Table 3.1). We then used multivariate regression models of plant richness against different combinations of those variables to assess overall relationships. Pearson correlations among all ALS metrics and environmental variables were first examined to avoid multi-collinearity in multivariate regression models. Where variable pairs had correlation coefficients $|r|>0.7$, the one with more ecological relevance and higher explanatory power for single factor regression models was kept (Dormann *et al*. 2013). After considering all variable correlations, the following uncorrelated variables were considered in models: mean annual precipitation (MAP), mean annual temperature (MAT), the 95th percentile of canopy height (CH), the proportion of first returns below 0.15 m (P0-0.15), proportion of first returns between 0.15 m to 1.37 m (P0.15-1.37), proportion of first returns between 1.37 m to 5 m (P1.37-5), proportion of first returns between 5 m to 10 m (P5-10), depth to water (DTW), and slope of plots (Slope). Since responses of biodiversity to environmental variables are not always linear (Gaston 2000), we assessed quadratic effects for all ALS metrics by comparing linear and quadratic effects of all investigated ALS metrics using Akaike Information Criterion (AIC) (Table 3.1 and Table 3.2). It has been proposed that if the ΔAIC between two models is smaller than 2, both models could be considered as having similar support (Burnham & Anderson 1998; Mazerolle 2004). Thus, if the AIC of a regression model with a linear response was more than 2 AIC points larger than a quadratic response, the model with a quadratic function was used (Table 3.1 and Table 3.2). As a result, the quadratic of P5-10 was considered for explaining richness of vascular, herbaceous, woody, and forb plants, while P0.15-1.37 and P1.37-5 were considered for graminoids (Table 3.2; Figure 3.4). Since different combinations of canopy height and depth-to-water could potentially indicate types of forest habitats in this area, we also assessed the interactive effect canopy height and depth to water (i.e. CH×DTW). Finally, AIC was used to rank support among models with competing variable combinations. The model with the lowest AIC was considered the most parsimonious model and the results from this model were reported (Table 3.3). Akaike weights (w) were estimated for each variable based on the full set of models to compare relative importance of each variable (Burnham & Anderson 2002).

To assess the effects of locations of in situ oil sands leases and the effectiveness of woodland caribou conservation as an umbrella for areas of high plant biodiversity, we overlaid predicted plant species richness with oil sand leases (Figure 3.6) and woodland caribou ranges (Figure 3.7). We also directly compared plant richness from field data among treatment categories (leased vs. non-leased; caribou vs. no caribou) using t-tests of $\log_{10}$ transformed species richness (Figure 3.5).

3.4 Results

Results of univariate responses in plant richness

Total species richness of vascular plants was significantly positively associated with mean annual temperature (MAT), canopy height (CH), the percentages of LiDAR returns above 1.37 m (PR1.37), mean canopy height (PRmean), the slope of plots (Slope), and the return proportion within 10 m to 20 m (P10-20) and within 20 m to 30 m (P20-30) (Table 3.1; Figure 3.3). In contrast, mean annual precipitation (MAP) and the return proportion below 0.15 m were significantly negatively associated with total species richness (Table 3.1). Richness of vascular plants was not significantly related to depth to water (DTW), the return proportion within 0.15 m to 1.37 m (P0.15-1.37), within 1.37 m to 5 m (P1.37-5), and within 5 m to 10 m (P5-10) (Table 3.1).

Table 3.1. Simultaneous Autoregressive (SAR) univariate models of species richness for total vascular plants, herbaceous plants, woody plants, forbs, and graminoids against each explanatory variable*. The pseudo-r squares (r^2) of SAR models are given in the table, and symbols in brackets represent the trends of relationships between species richness and variables. The two most supported models (lowest AIC) for each growth form are shown in bold.

	Vascular			*Herbaceous*			*Woody*			*Forbs*			*Graminoids*		
Variables	r^2	*AIC*	*p-value*	r^2	*AIC*	*p-value*	r^2	*AIC*	*p-value*	r^2	*AIC*	*p-value*	r^2	*AIC*	*p-value*
MAP	0.155(-)	**387.0**	0.000	0.122(-)	**539.0**	0.000	0.098(-)	**221.1**	0.000	0.192(-)	**568.3**	0.000	0.025(-)	597.2	0.034
MAT	0.054(+)	418.9	0.000	0.063(+)	557.3	0.000	0.029(+)	241.8	0.006	0.083(+)	604.1	0.000	0.021(+)	598.6	0.099
CH	0.100(+)	**404.9**	0.000	0.069(+)	**555.5**	0.000	0.111(+)	**216.8**	0.000	0.149(+)	**583.1**	0.000	0.054(-)	588.6	0.000
PR1.37	0.049(+)	420.4	0.001	0.028(+)	567.7	0.029	0.058(+)	233.3	0.000	0.090(+)	602.1	0.000	0.088(-)	578.3	0.000
PRmean	0.045(+)	421.8	0.002	0.025(+)	568.6	0.051	0.053(+)	234.6	0.000	0.084(+)	603.9	0.000	0.094(-)	576.4	0.000
DTW	0.019(+)	429.4	0.130	0.012(+)	572.3	0.834	0.033(+)	240.5	0.005	0.030(+)	620.2	0.011	0.112(-)	**570.7**	0.000
Slope	0.036(+)	424.3	0.005	0.021(+)	569.7	0.093	0.060(+)	232.7	0.000	0.036(+)	618.3	0.003	0.024(-)	597.6	0.054
P0-0.15	0.074(-)	413.1	0.000	0.047(-)	562.2	0.001	0.072(-)	228.9	0.000	0.135(-)	587.6	0.000	0.062(+)	586.3	0.000
P0.15-1.37	0.011(-)	431.6	0.887	0.013(+)	572.1	0.607	0.009(-)	247.7	0.463	0.012(-)	625.3	0.269	0.108(+)	**572.1**	0.000
P1.37-5	0.011(-)	431.5	0.752	0.013(-)	571.9	0.477	0.007(+)	248.1	0.749	0.008(-)	626.4	0.685	0.013(+)	600.6	0.475
P5-10	0.024(+)	428.0	0.055	0.013(+)	572.0	0.514	0.041(+)	238.4	0.002	0.028(+)	620.7	0.015	0.034(-)	594.7	0.011
P10-20	0.068(+)	414.7	0.000	0.043(+)	563.2	0.002	0.077(+)	227.4	0.000	0.109(+)	596.2	0.000	0.068(-)	584.4	0.000
P20-30	0.056(+)	418.3	0.000	0.050(+)	561.2	0.001	0.042(+)	238.0	0.001	0.095(+)	600.5	0.000	0.046(-)	591.2	0.001

*CH, canopy height; PR1.37 and PRmean, the percentages of returns above 1.37 m and mean height, respectively; P0-0.15, P 0.15-1.37, P1.37-5, P5-10, P10-20, P20-30 represent the return proportion at 0 to 0.15 m, 0.15 to 1.37 m, 1.37 m to 5 m, 5 m to 10 m, 10 m to 20 m and 20 m to 30 m, respectively; MAP, mean annual precipitation; MAT, mean annual temperature; Slope, the terrain slope of the plot; DTW, the depth to water at the plot.

Of the variables assessed, MAP and CH were the two strongest predictors of species richness having the lowest AICs and individually explaining 15.5% and 10.0% (*pseudo* r^2) of the variation in vascular plant richness, respectively. MAP and CH were also the most supported predictors in single-regression models for herbaceous, forb, and woody plant richness, but not for richness of graminoids, which was better explained by DTW and the return proportion within 0.15 m to 1.37 m (P0.15-P1.37) (Table 3.1). Mean annual precipitation (MAP) was consistently negatively associated with richness of herbaceous, forb, graminoid, and woody plants, explaining 12.2%, 19.2%, 2.5%, and 9.8% of the variation, respectively. Canopy height was negatively associated with richness of graminoids, but only explaining 5.4% of the variation (Table 3.1; Figure 3.3). Unlike total vascular, herbaceous, woody, and forb plant richness, plant richness of graminoids was negatively associated with depth to water explaining 11.2% of the variation (Table 3.1; Figure 3.3). Comparing results of linear and quadratic responses, quadratic relationships for P5-10 significantly explained richness of vascular, herbaceous, woody, and forb plants (Table 3.1; Table 3.2; Figure 3.4). In contrast, for graminoids, the quadratic terms were significant for P0.15-P1.37 and P1.37-5. The interactive effect of canopy height and depth to water (CH x DTW) explained 6.5% of the variation in richness of graminoids.

Table 3.2. Simultaneous Autoregressive (SAR) models for quadratic regression for plant richness against selected ALS metrics and interactive effects of canopy height and water to depth (CH×DTW). The pseudo-r square (r^2) of SAR models are given in the table. ΔAIC is the difference in AIC value between these models and the corresponding linear SAR model (Table 3.1). If the AIC value of the linear SAR model was more than 2 points greater than the quadratic SAR model, the ΔAIC is shown in bold.

	Vascular			*Herbaceous*			*Woody*			*Forbs*			*Graminoids*		
Variables	r^2	*AIC*	*ΔAIC*	r^2	*AIC*	*ΔAIC*	r^2	*AIC*	*ΔAIC*	r^2	*AIC*	*ΔAIC*	r^2	*AIC*	*ΔAIC*
CH	0.100	406.9	2.02	0.071	556.8	1.31	0.121	215.8	1.04	0.149	584.9	1.82	0.055	590.5	1.89
DTW	0.019	431.3	1.90	0.012	574.3	2.00	0.036	241.6	1.14	0.030	622.1	1.93	0.115	571.9	1.24
Slope	0.040	425.1	0.76	0.025	570.6	0.94	0.063	233.6	0.85	0.038	619.8	1.50	0.028	598.3	0.71
P0-0.15	0.074	414.9	1.82	0.047	564.0	1.78	0.074	230.2	1.32	0.137	589.1	1.47	0.072	585.3	0.98
P0.15-1.37	0.011	433.6	2.00	0.013	574.1	2.00	0.010	249.4	1.71	0.017	625.9	0.63	0.122	569.6	**2.55**
P1.37-5	0.011	433.5	2.01	0.014	573.7	1.76	0.008	249.8	1.69	0.008	628.3	1.91	0.034	596.8	**3.82**
P5-10	0.061	419.0	**9.05**	0.050	563.2	**8.81**	0.071	231.1	**7.26**	0.074	608.9	**11.84**	0.040	594.8	0.10
CH x DTW	0.015	430.4	-	0.020	570.1	-	0.009	247.5	-	0.008	626.4	-	0.065	585.3	-

*CH, canopy height; P0-0.15, P 0.15-1.37, P1.37-5, P5-10 represent the return proportion at 0 to 0.15 m, 0.15 to 1.37 m, 1.37 m to 5 m, 5 m to 10 m, respectively; Slope, the slope of the plot; DTW, the depth to water at the plot.

Results of multivariate simultaneous autoregressive models of plant richness

Simultaneous Autoregressive (SAR) multivariate models explained 19.5% to 35.0% (*pseudo-r^2*) of species richness across the five growth forms of plants based on combinations of ALS vegetation metrics and other environmental variables (Table 3.3). In multivariate regression models, canopy height (CH) remained the most consistent and important variable overall explaining species richness for all growth forms except graminoids. Non-linear quadratic responses of P5-10 were also important for forbs, woody species, and total vascular plants. Depth to water was negatively associated with richness of total vascular, herbaceous, graminoid, and forb plants. Consistent with single-predictor regression models, MAP was an important predictor of plant richness and was included in the most supported models (lowest AIC values) for all growth forms, with MAP being inversely related to species richness. Predictions from multivariate SAR models suggested that plant richness was highest in the major river valleys for total vascular plants and herbaceous, woody, and forb species (Figure 3.2 a, b, c and e), while species richness of graminoids was highest in the flattest parts of the study area, representing fens (Figure 3.2 d).

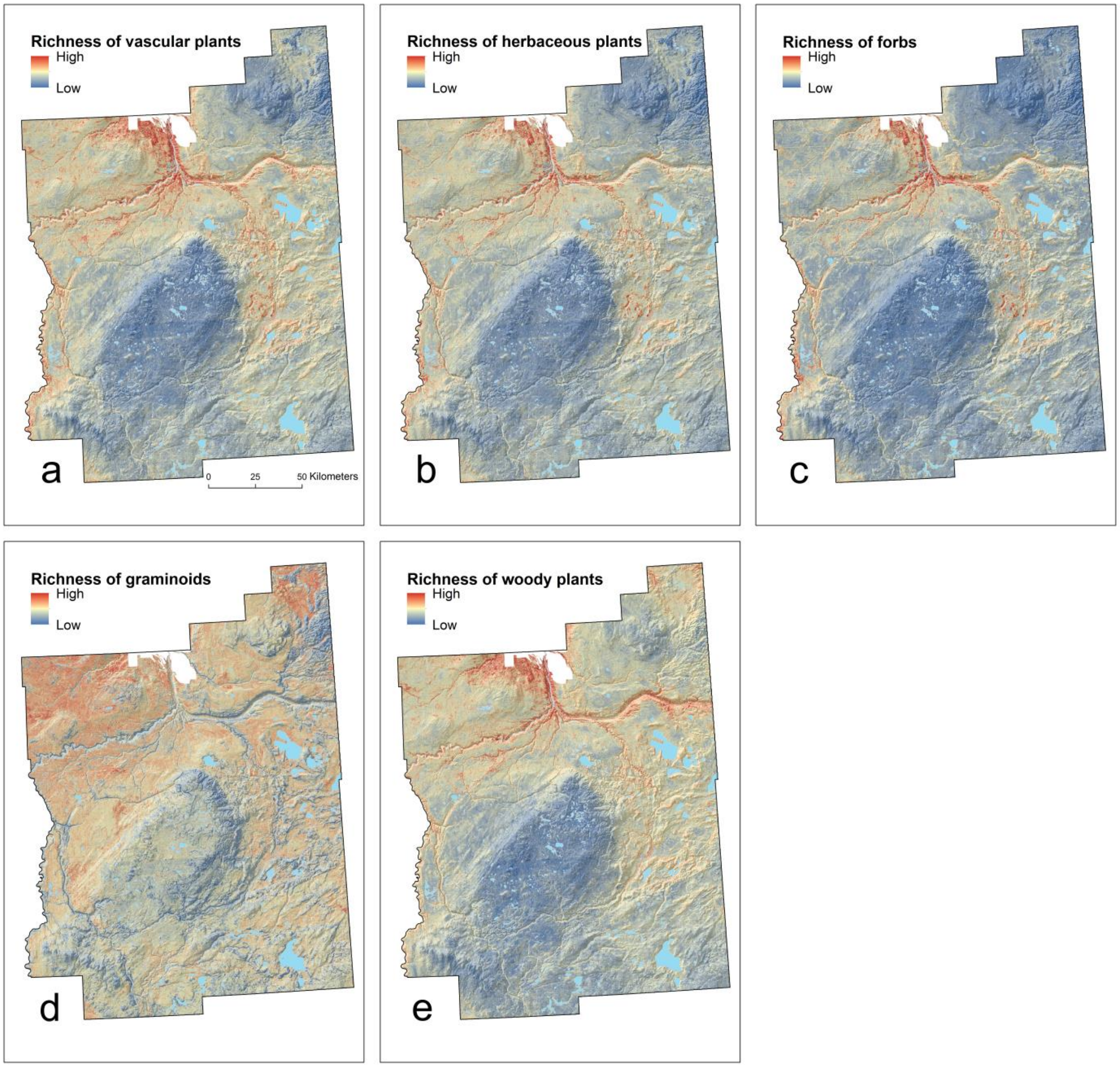

Figure 3.2. Predicted species richness for northeast Alberta, Canada based on Simultaneous Autoregressive (SAR) models for richness of vascular (a), herbaceous (b), forb (c), graminoid (d), and woody plants (e). Results indicated that the areas associated with the highest plant richness were in or around river valleys, except for graminoids which peaked in richness in the flattest areas typified as being fens and bogs. Note, oil sands surface mine leases in the far north of the map were removed (shown in the maps in white).

Table 3.3. Simultaneous Autoregressive (SAR) multivariate models of richness of vascular plants, herbaceous plants, woody plants, forbs, and graminoids against combinations of explanatory variables*. The combinations with the lowest AIC (Akaike Information Criterion) were considered the most parsimonious models with the z-value for each coefficient given in the table. Pseudo r^2 of the most supported model for all five growth forms are reported. The Akaike weight (*w*) is based on a full model (combination of thirteen variables) and used to indicate the

relative importance of individual variables. The two highest values of *w* for each growth form are in bold.

Variables	*Vascular*		*Herbaceous*		*Woody*		*Forbs*		*Graminoids*	
	z-value	*w*	*z-value*	*w*	*z-value*	*w*	*z-value*	*w*	*z-value*	*w*
MAP	-6.44	**0.996**	-3.97	**0.982**	-8.61	**1.000**	-7.66	**1.000**	-2.55	0.697
P0.15-1.37	3.12	**0.899**	3.21	**0.960**	2.67	**0.799**	2.90	0.942		0.494
CH	3.15	0.859	3.40	0.951	2.90	0.785	3.28	0.874		0.366
DTW	-3.04	0.688	-3.49	0.931		0.469	-3.04	0.794	-4.42	**0.913**
Slope		0.344		0.291	2.10	0.794		0.279		0.365
P0.15	-2.42	0.833	-3.06	0.900		0.433	-4.88	**1.000**		0.333
MAT	2.55	0.617	2.11	0.578		0.357	5.39	0.984		0.417
P1.37-5	-2.78	0.819	-2.76	0.904	-1.61	0.500	-3.42	0.988		0.438
P5-10	1.65	0.386		0.353	2.05	0.418		0.346	2.07	0.575
$P0.15\text{-}1.37^2$									-4.94	**0.919**
$P1.37\text{-}5^2$									2.42	0.601
$P5\text{-}10^2$		0.379		0.364		0.384		0.358		
CH × DTW		0.479		0.390	-2.64	0.791		0.419		0.361
Model performance										
pseudo r^2	0.240		0.223		0.222		0.350		0.195	

*CH, canopy height; P0-0.15, P0.15-1.37, P1.37-5 and P5-10 represent the return proportion at 0 to 0.15 m, 0.15 to 1.37 m, 1.37 m to 5 m and 5 m to 10 m, respectively; MAP, mean annual precipitation; MAT, mean annual temperature; Slope, the slope of the plot; DTW, the depth to water; CH × DTW, the interactive effects of CH and DTW.

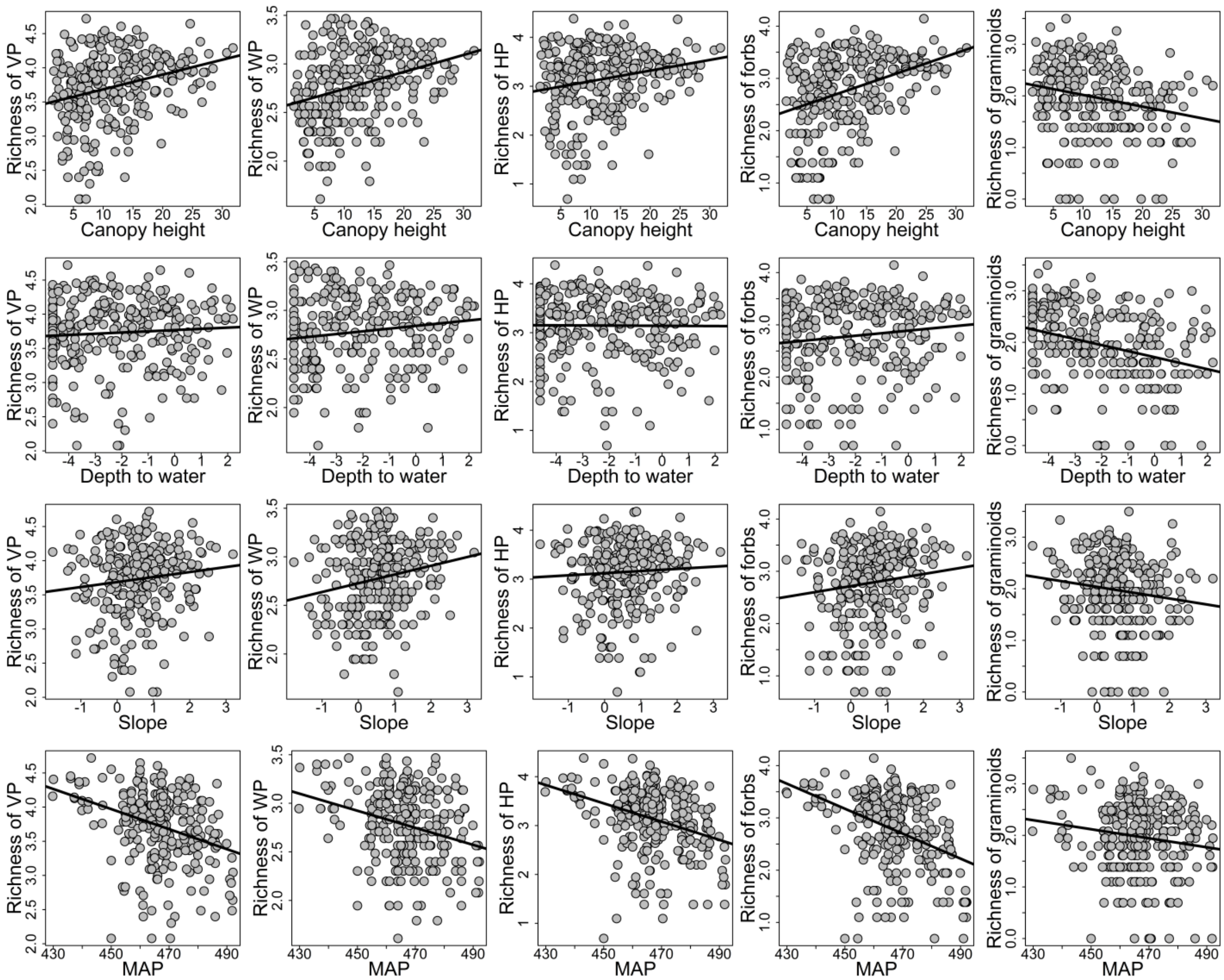

Figure 3.3. Scatter plots for richness of total vascular, woody, herbaceous, forb, and graminoid plants and canopy height, depth to water, slope, and mean annual precipitation. Richness, depth to water and slope were log-transformed. Lines are ordinary least squares linear regressions for relationships between those variables and plant richness for each of the five groups. VP, vascular plants; WP, woody plants; HP, herbaceous plants, and MAP, mean annual temperature. Units for canopy height, depth to water, slope and mean annual temperature are meter, meter (log-scaled), degree (log-scaled) and mm, respectively.

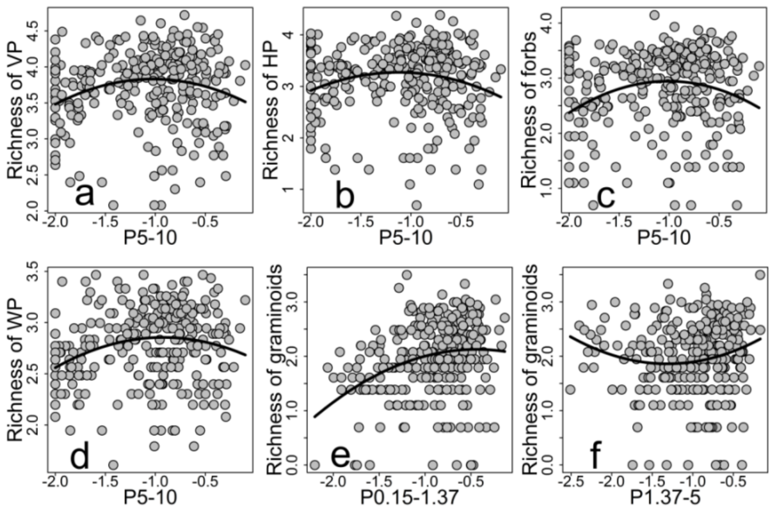

Figure 3.4. Non-linear relationships (i.e. quadratic) for richness of total vascular (a), herbaceous (b), forb (c) and woody (d) plants, and return proportion at 5 to 10 m (P5-10) and for richness of graminoids and return proportion at 0.15 to 1.37 m (P0.15-1.37, e) and 1.37 m to 5 m (P1.37-5, f). Richness data, P0.15-1.37 and P1.37-5 were log-transformed. Lines are quadratic regressions for relationships between those variables and plant richness. VP, vascular plants; WP, woody plants; and HP, herbaceous plants.

Relationships between plant biodiversity hotspots, oil sands, and woodland caribou

The t-tests demonstrated that $\log_{10}$-scaled richness of vascular, woody, and forb plants were significantly different between plots inside and outside of caribou ranges ($p<0.05$) with caribou ranges having lower plant richness (Figure 3.5). Significant difference in plant richness were also found for plots inside versus outside of oil sands leases, except for richness of woody plants, with richness slightly higher inside leases than outside of leases (Figure 3.5). These results also reflected regional patterns based on predicted maps of plant richness, although substantial variation was evident among oil sands leases (Figure 3.6). As observed in predictive maps of multivariate SAR models, most caribou ranges occurred in areas with relatively low plant diversity. Thus, conservation of caribou ranges will not act as a surrogate to conserve those areas of highest vascular plant species richness (i.e. richness hotspots) (Figure 3.7).

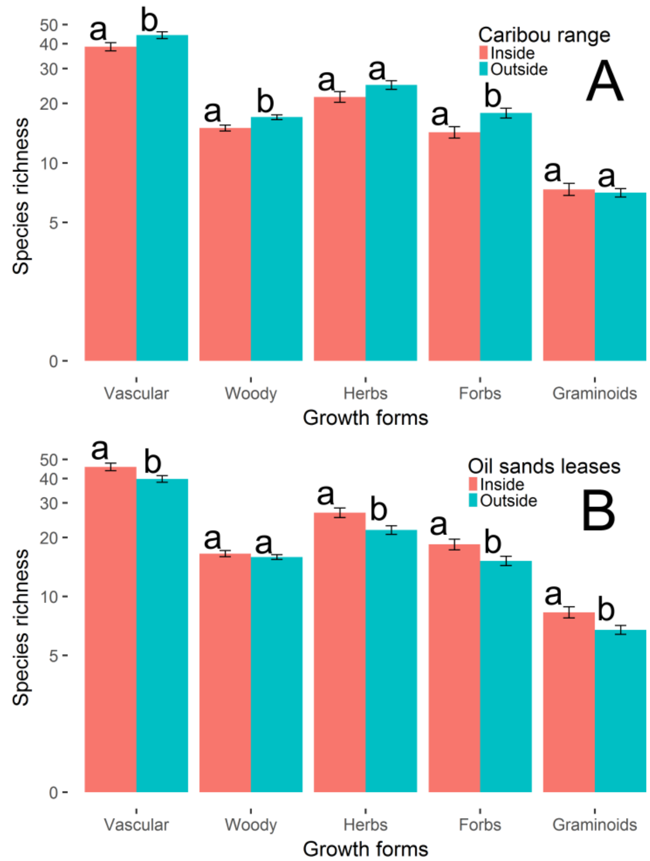

Figure 3.5. Bar graphs for species richness of vascular plants, herbaceous plants, forbs, graminoids, and woody plants for field plots inside vs. outside of caribou ranges (A) and leased vs. non-leased in situ oil sands (B). Richness data were $\log_{10}$-transformed. Different letters indicated that groups are significantly different (p <0.05) from one another based on a t-test.

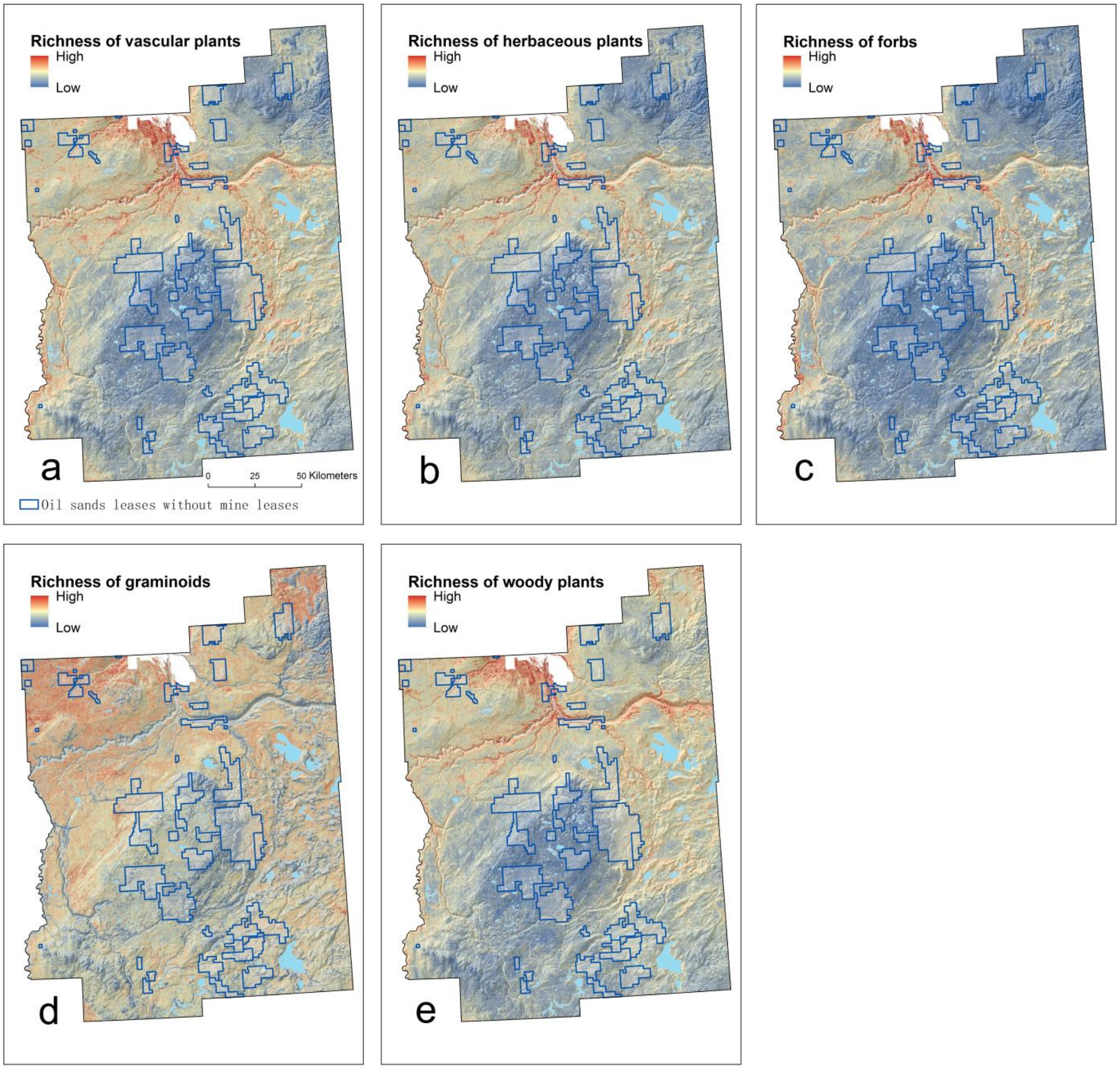

Figure 3.6. Location of in situ oil sands leases and predicted species richness for northeast Alberta, Canada according to: vascular (a), herbaceous (b), forb (c), graminoid (d), and woody (e) plant groups. Blue polygon lines represent boundaries of current in situ oil sands leases.

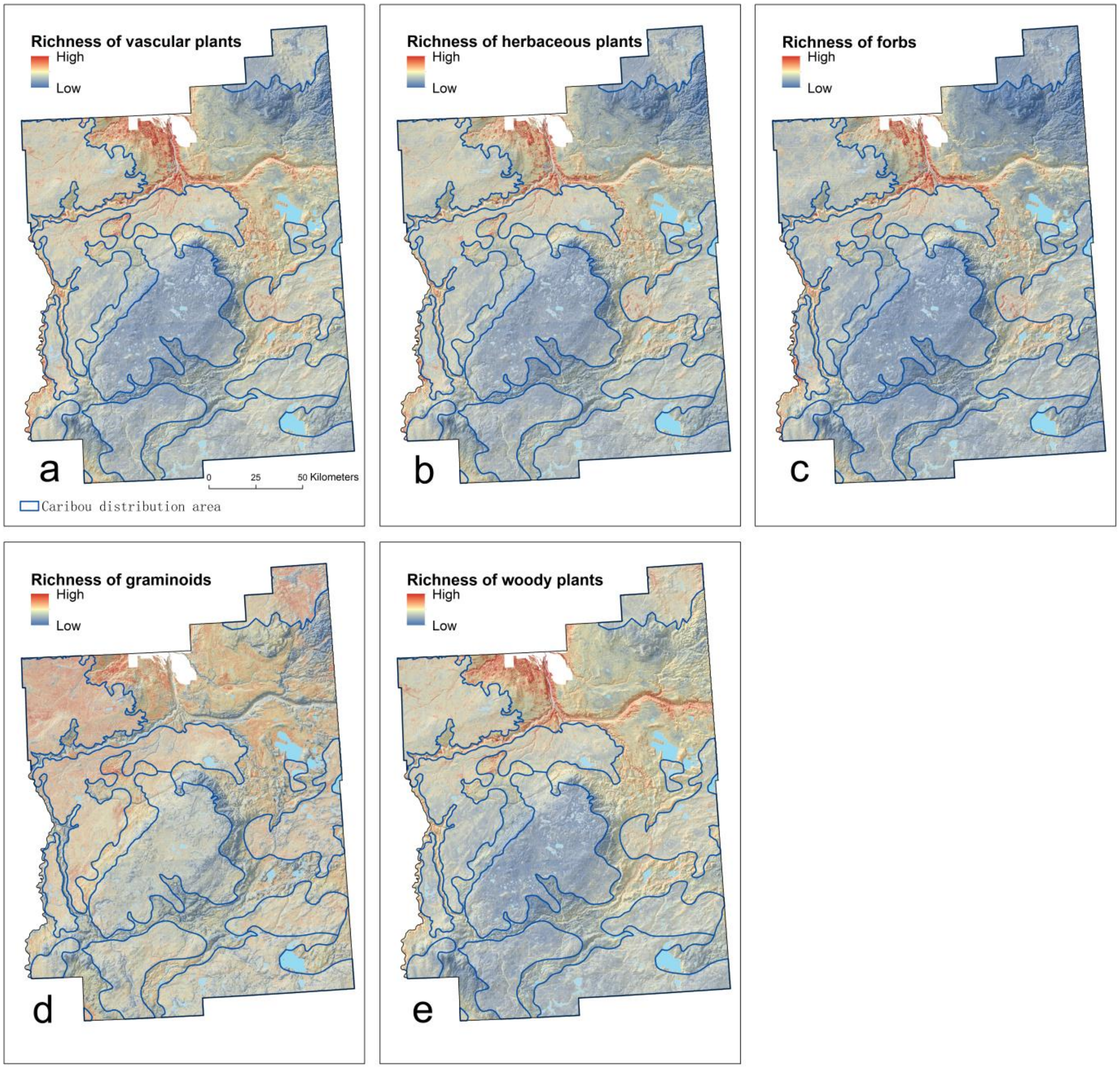

Figure 3.7. Location of woodland caribou (*Rangifer tarandus*) ranges and predicted species richness for northeast Alberta, Canada according to: vascular (a), herbaceous (b), forb (c) graminoid (d), and woody (e) plants groups. Blue polygon lines represent mapped caribou herds.

3.5 Discussion

Combining the effects of habitat-terrain characteristics (e.g. slope, depth to water), including climatic conditions, and the horizontal and vertical structure of vegetation, we examined patterns in local measures of plant richness in the boreal forest of northeast Alberta, Canada using ALS-derived vegetation structure measures, ALS-derived terrain measures, and climate. Our results demonstrate that climate, vertical structure of vegetation, and terrain-derived slope and depth to water explained (*ca.* 20% to 35%) local patterns in native plant species richness. However, the effects of local variables on plant diversity differed across plant growth forms (Table 3.1; Table

3.3; Figure 3.3). Overall, canopy height and mean annual precipitation (MAP) were the best predictors of vascular, herbaceous, forb, and woody plant richness (Table 3.1; Table 3.3).

Many hypotheses have been suggested to explain spatial patterns in plant richness at global and regional scales (Auerbach & Shmida 1987; Kreft & Jetz 2007; Fine 2015). Determinants of biodiversity may, however, change with spatial scale (Auerbach & Shmida 1987; Gaston 2000). Although our study plots were located within a relatively narrow geographic area of one ecosystem – the boreal forest (Figure 3.1), factors affecting large scale processes would be expected to influence regional species richness and thus richness of the plant community (Eriksson 1993). To examine this question further, we explored the effects of mean annual precipitation (MAP) and mean annual temperature (MAT) on the spatial variation in plant species richness of all vascular plants and the four growth forms of herbaceous, woody, forb, and graminoids. Our results demonstrated that, at a community level, these two variables significantly explained local variation in plant diversity (Table 3.1). For multivariate regression models, precipitation was consistently selected in models predicting richness of vascular plants and the four growth forms. MAP and MAT are considered two key factors in the water-energy hypothesis of global biodiversity patterns (Hawkins *et al*. 2003; Kreft & Jetz 2007). However, in our research, precipitation was negatively related to plant richness (Table 3.1), while temperature was positively related to plant richness across all growth forms. This supports previous studies suggesting that plant diversity in colder regions is primary limited by energy inputs where water availability is not a key limitation (Hawkins *et al*. 2003).

We measured local environmental conditions using ALS-derived measures of vegetation structure (height and cover) and terrain characteristics to assess their influence in explaining local patterns in plant diversity. Remote sensing data are usually linked to measures of productivity and canopy cover which are known to be related to species assembly and richness (Gillman & Wright 2006; John *et al*. 2008). We found that ALS metrics describing vegetation density (e.g. the percentage of returns above 1.37 m), and especially describing vegetation height, were useful predictors of plant diversity at local (community) scales (Table 3.1; Table 3.3). ALS-derived canopy cover has been previously demonstrated as a useful descriptor of vegetation structure (Coops *et al*. 2007; Smart *et al*. 2012). Our results further demonstrated that the effects of canopy on plant diversity differed among plant growth forms. The two related variables, i.e. the percentage of returns above 1.37 m (PR 1.37) and percentage of returns above mean height (PRmean), were positively associated with species richness of total vascular, forb, herbaceous, and woody plants, but negatively associated with species richness of graminoids. As would be expected, more open habitats had a higher capacity to maintain graminoid-rich communities, while older and more productive forests were more suitable for maintaining total vascular species and herbaceous, forb, and woody plants.

Overall, canopy height was one of most important factors associated with patterns of plant diversity (positively related) in both univariate and multivariate analyses (Table 3.1; Table 3.3). Canopy height may be a surrogate for structural complexity of vegetation (McElhinny *et al*. 2005) illustrating a positive association between structural complexity and plant diversity in the boreal forest. More complex structure is well accepted as one of the primary drivers of biodiversity (Wolf *et al*. 2012; St. Pierre & Kovalenko 2014; Loke & Todd 2016). However, most previous studies using LiDAR-derived vegetation structure relate to birds (e.g., Goetz *et al*.

2007; Coops *et al*. 2016), with few studies focused on plant species richness where it is more difficult to argue for a direct increase in niche space. Light is a basic resource that limits plant growth (Craine & Dybzinski 2013) and plant communities with taller plant heights potentially provide more possible options for plants in competition for light (Falster & Westoby 2003). Our results showed ALS-derived canopy height was positively associated with species richness across plots for all growth forms, excluding graminoids, where canopy height was negatively associated with species richness (Table 3.1). These results may be due in part to the physiological adaption of plants to different types of habitats with species in the graminoid group represented by the families of Cyperaceae, Poaceae and Juncaceae, which are common to grasslands and peatlands (Edwards *et al*. 2010). In the case of the boreal forest of Alberta, open habitats are most often peatlands, including graminoid-dominated fens (Rooney *et al*. 2012). Other vertical measures of vegetation structure were associated with plant richness (Table 3.1). For example, species richness of graminoids was positively associated with the proportion of first returns below 15 cm (low ground layer; P0-0.15). In contrast, the relationship between richness of vascular, forb, and woody plants was negatively related to this same ground layer stratum (P0-0.15). These metrics depict characteristics of vertical stratification directly (Coops *et al*. 2007; Smart *et al*. 2012), which are related to the complexity of the canopy within the community. The physical structure of vegetation has been proposed as a key factor limiting diversity of ecosystems, particularly for birds that are dependent on forest structure (MacArthur & MacArthur 1961). Our results support the theory that vertical structure of vegetation is positively associated with plant diversity, not just birds (MacArthur & MacArthur 1961; Su & Bork 2007; Bergen *et al*. 2009).

Our study also demonstrated that hydrological conditions (represented by depth to water) and terrain slope in the boreal forest were associated with local plant diversity (Table 3.1; Table 3.3), which is supported by other studies (Webb *et al*. 1999; Sass *et al*. 2012). In our study, areas with steeper slopes had higher plant diversity for all growth forms except graminoids. Incised valleys and steeper terrain may therefore be potential hotspots for plant diversity in boreal forests. This supports hypotheses of species diversity-environmental heterogeneity where greater terrain variation results in more microsites and thus niches. Depth to water was negatively correlated with the richness of graminoid species (Table 3.1; Table 3.3), again indicating the specificity of many graminoid species to wet environments (i.e. fens).

Environmental and ALS measures used here represent only part of the factors associated with conditions affecting plant richness in the boreal forests. Plant diversity is also affected by other factors not measured in this study including land use, natural disturbances (e.g. fire), soil conditions, and species interactions (Perroni-Ventura *et al*. 2006; Kouba *et al*. 2015; Soliveres *et al*. 2015). Models that incorporate these variables may be more generalizable and have broader application to monitoring. Regardless, ALS-derived measures of vegetation structure show promise in directly measuring vegetation structure and thus indirectly monitoring plant biodiversity (e.g. Su & Bork 2007) across large (regional) scales. We suggest that measures of vegetation structure are more likely to relate to measures of plant diversity than data from multispectral passive optical sensors assessing horizontal features of sites (Krishnaswamy *et al*. 2009).

One of the most important goals for biodiversity monitoring is to conserve species from threats and set conservation priorities since biodiversity is unevenly distributed in space (Brooks *et al*. 2006; Freudenberger *et al*. 2013). In situ (non-mineable) oil sands leases were significantly different in plant biodiversity to non-leases for native habitats for all five groups except woody plants with plant richness typically being higher. However, when considering predictions across the region, many of oil sands leases are located in the areas with moderate to relatively lower vascular plant richness. In general, there was trend towards leases further north having higher total vascular plant richness (Figure 3.6). This suggests that the placement of oil sands leases within the landscape is not random with respect to the region's plant biodiversity with some sites having greater conservation value and thus threats. In contrast to oil sands leases, vascular plant richness was lower inside woodland caribou ranges than outside of caribou ranges suggesting that the conservation of caribou, a threatened flagship species for Canada's boreal forest (Weclaw & Hudson 2004; Festa-Bianchet *et al*. 2011; Moreau *et al*. 2012), will have little value for protecting hotspots of vascular plant biodiversity (Figure 3.7). Identifying this conservation gap is important for prioritizing future conservation efforts in Canada's boreal forest that extend beyond a single, albeit charismatic, species.

Implications for management

Exploration of the utility of ALS-derived metrics is ongoing in the literature and research in this field is still developing, with datasets for the entirety of Alberta not yet complete. Based on findings from this investigation, we summarize the applicability of analyses using ALS-derived vegetation metrics for oil and gas related activities below. Determining which areas of a given lease may harbor the highest vascular plant diversity is important, and our findings suggest that these areas may not align with those considered of high value for other taxa (e.g. caribou). Our findings of a positive relationship between diversity and vertical vegetation structure and unique landforms (areas of topographic relief in the relatively flat boreal landscape) can inform lease-level summaries of expected diversity and assist in pre-survey planning stages for environmental assessments by highlighting target areas. Special attention should be paid toward structurally diverse and topographically variable areas. Local-scale spatial predictions of plant diversity may also prove effective for identifying where proposed developments (e.g. roads, well pads, processing plants) would have the least impact.

CHAPTER 4.0: Observer error in vascular plant surveys: evaluating pseudoturnover and the number of missed species

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4.1 Summary

Observer error related to imperfect detection of species is widely regarded as an important issue for vascular plant surveys. However, it is seldom formally estimated despite direct implications for assessing changes in biodiversity. Estimating the magnitude of error and understanding the factors affecting this will allow for more accurate conclusions to be drawn from survey data and facilitate improvements to sampling protocols. Inter-observer error can be estimated through the calculation of pseudoturnover and the number of species missed per plot, which are determined by comparing species lists between observer pairs. These two-error metrics were calculated for a subset of the Rarity and Diversity plots in the Lower Athabasca Region of Alberta (n = 67) and were related to site richness, ecosite type, and sampling effort, both for all species collectively and individual plant growth forms. Average pseudoturnover for all species was 15.4%, which is low compared to previous studies, and an average of 7.8 species were missed per plot. Observer error increased with species richness, and varied by growth form and ecosite type, but was not influenced by sampling effort. These findings indicate that the species richness of a given plot can inform estimates of the magnitude of observer error present, and suggest that plant functional groups should be assessed individually when examining the factors that affect observer error and how these can be addressed.

4.2 Introduction

Imperfect detection of species during vegetation sampling is a common source of error in monitoring programs (Nilsson & Nilsson 1985; Chen *et al.* 2013), and thus a challenge for inventorying and assessing changes in biodiversity. Observer errors can be classified as either those of omission (false-negatives), when a species present at a site is not detected, or commission (false-positives), when a species is detected but misidentified (Miller *et al.* 2011). Most often there is greater concern of omission errors, while commission is assumed to be less significant and more difficult to deal with than omission errors. Estimates of the magnitude of observer error and insight into the factors that potentially influence these errors, such as species richness, plant growth form, and ecosite type, enable more accurate inferences and improvements in sampling protocols (Morrison 2016). Although the issue of observer error is often acknowledged in the literature, it is seldom formally estimated despite its implications for research findings (Chen *et al.* 2013).

As observer detection accuracy is challenging to quantify because true species presence at a site is rarely known, observer error is instead typically evaluated in terms of precision by comparing the results of multiple observers (Morrison 2016). Inter-observer error involves differences in species detection among individual observers for a given survey site, which can arise due to both omission and commission errors (Morrison 2016). Comparing species lists among observers allows for the calculation of pseudoturnover (Lynch & Johnson 1974) and the average number of species missed per site. Pseudoturnover refers to inter-observer error that suggests false changes in species assemblages and is based on unique species numbers and total site richness, with lower values indicating greater similarity in detection between observers (Nilsson and Nilsson 1985). A review of observer error in vegetation surveys found that mean pseudoturnover across studies was 10-30%, suggesting that most species lists produced by the sampling process are likely incomplete (Morrison 2016). The number of species missed represents only the unique species per observer for each site which were not detected by the other.

To assess observer error for the vascular plant sampling conducted at Rarity and Diversity plots established in the Lower Athabasca Region, a subset of sites surveyed by multiple observers was examined. Previous work by Zhang *et al.* (2014) evaluated observer error using an earlier version of this dataset, but additional sampling has since been conducted thus allowing for error to be estimated across a larger number of survey sites and observer pairs. Specifically, our objectives here were to (1) quantify percent pseudoturnover for all species collectively, as well as for individual growth forms (forbs, graminoids, shrubs, and trees), (2) determine the average number of species missed for all species and per growth form, and (3) evaluate relationships between these metrics and site richness, ecosite type, and sampling effort.

4.3 Methods

Repeat survey dataset

Plant species detection lists were calculated from 67 same-day repeat surveys that were randomly completed by 16 field technicians on a proportion of the 602 Rarity and Diversity plots sampled, with the goal of re-surveying at least 10% of all plots to assess observer accuracy (see Chapter 1 for sampling methodology). This subset included 63 plots that had been surveyed by two observers and four that had been surveyed by three observers, amounting to 75 pair-wise comparisons and thus 150 values for unique species per observer. In total, 11 ecosite categories were represented with only marsh (VD) unrepresented (Table 4.1).

Table 4.6. Number of Rarity and Diversity plots included in the repeat survey dataset (n = 67 plots) for each of the 11 ecosite categories.

Ecosite	Number of Plots
NT - Not Treed	1
PX – Poor Xeric (poor, dry forests)	3
PM – Poor Mesic (moist conifer)	9
PD – Poor Hydric (bog)	4
MX – Medium Xeric (dry mixedwood)	3
MM – Medium Mesic (mesic mixedwood)	20
MG – Medium Hygric (moist mixedwood)	7
MD – Medium Hydric (poor fen)	5
RG – Rich Hygric (rich, moist forests)	1
RD – Rich Hydric (rich fen)	11

SD – “Swamp” Hydric (swamp)	3
VD – Very rich Hydric (marsh)	0
Total	67

Calculation of observer error metrics

Species lists were compared between observers for each repeat plot to determine total richness and number of unique species that had been detected per individual. Percent pseudoturnover (PT) was calculated following the approach of Nilsson & Nilsson (1985). For comparisons of species lists per plot, if observers’ A and B detect S_{AA} and S_{BB} unique species, respectively, and S_A and S_B species in total, pseudoturnover can be calculated as:

$$PT = \frac{S_{AA} + S_{BB}}{S_A + S_B} \times 100$$

The number of unique species per observer was averaged among plots, both for all species collectively and per growth form, to indicate the number of species missed by the other individual in the pair. Variation in sampling effort per observer pair was quantified as the difference in total plot survey time.

Model development

Linear regression models were estimated for pseudoturnover and number of species missed as a function of total species richness and species richness per growth form, as well as ecosite category. Log_{10} transformations were used to normalize all data in pseudoturnover analyses, with a constant of one added to percent pseudoturnover beforehand to account for zero values. Analyses of the number of species missed had transformations for only some variables, based on model fit per growth form. The effect of sampling effort was assessed only within the pseudoturnover analysis that considered all species collectively. The ecosite reference category for comparisons was designated as MM (*Viburnum edule*/*Shepherdia canadensis*) where this variable was included in the models.

4.4 Results

Pseudoturnover

A total of 379 vascular plant species were detected in the subset of plots for which repeat surveys were conducted. Average survey time per plot was 90 minutes and ranged from 26 to 193 minutes. Average difference in survey time between observers per plot was 23 minutes and ranged from 0 to 109 minutes. Average percent pseudoturnover for all species collectively was 15.4%, with values ranging from 0% to 29.2% (Table 4.2). Growth forms differed in regards to mean pseudoturnover and the range of values observed. Graminoids had the highest mean pseudoturnover overall with an average of 20.4%, while shrubs had the lowest mean pseudoturnover at 12.9% (Table 4.2). Moderate variation in pseudoturnover was observed across and within ecosite categories (Figure 4.1).

Table 4.7. Number of species and percent pseudoturnover (n = 75 pair-wise comparisons) for all vascular plant species collectively (n = 379 species) and per growth form for the repeat survey dataset (n = 67 plots).

Growth Form	Number of Species Overall	Mean Percent Pseudoturnover	Minimum Percent Pseudoturnover	Maximum Percent Pseudoturnover
Forb	212	15.9	0	44.4
Graminoid	96	20.4	0	81.8
Shrub	50	12.9	0	33.3
Tree	21	15	0	100
All Growth Forms	379	15.4	0	29.2

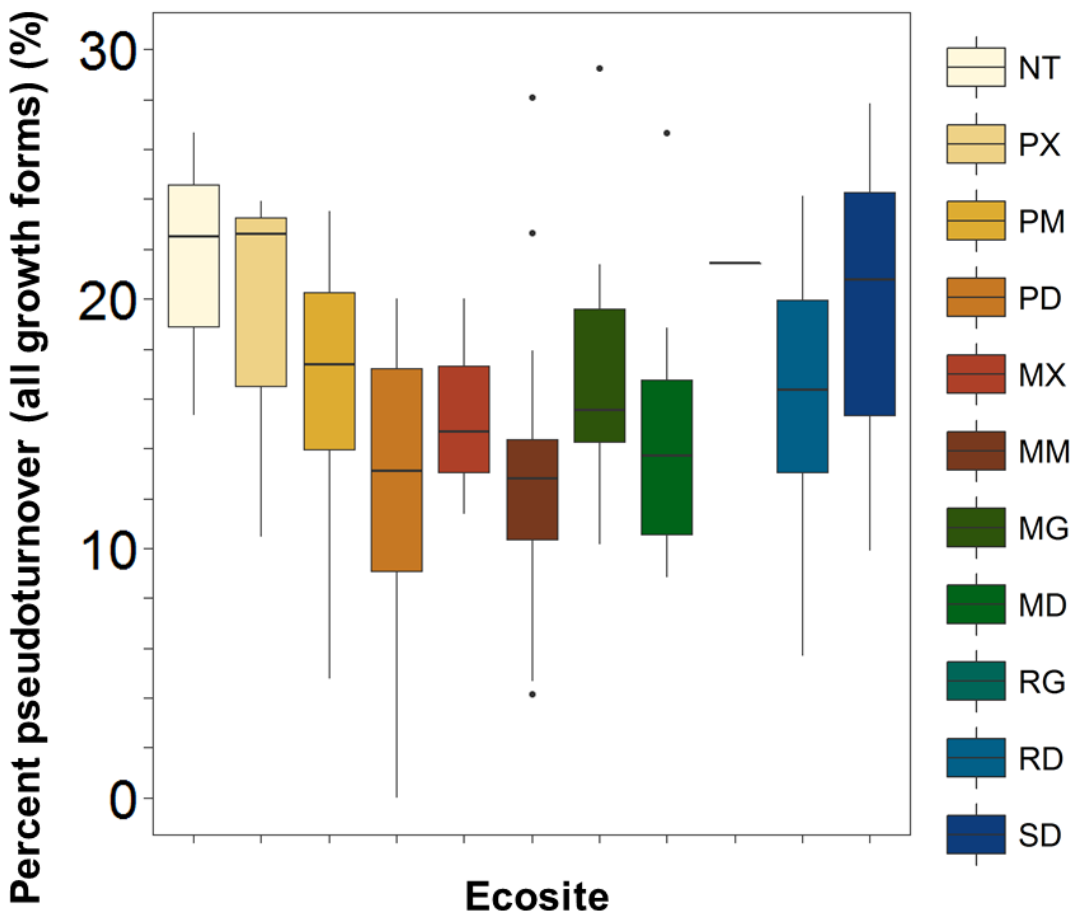

Figure 4.1. Variation in percent pseudoturnover (n = 75 pair-wise comparisons) for all vascular plant species collectively (n = 379 species) across the 11 ecosite categories included in the repeat survey dataset (n = 67 plots).

Models for pseudoturnover

Total species richness was positively related to pseudoturnover for all species (p = 0.002; R^2 = 0.113) (α = 0.05) (Table 4.3; Figure 4.2). However, neither sampling effort nor ecosite type significantly affected pseudoturnover when considering all species.

Table 4.8. Summary of linear models examining relationships between percent pseudoturnover (n = 75 pair-wise comparisons) for all vascular plant species collectively (n = 379 species) and total richness, sampling effort, and ecosite category for the repeat survey dataset (n = 67 plots). Log_{10} transformations were applied to all continuous variables except sampling effort.

Model Variable	**Coefficient**	**S.E.**	***p***
Relationship with species richness (all growth forms): R^2 = 0.113			
Intercept	0.551	0.194	0.006
Richness	0.363	0.112	0.002
Relationship with species richness and sampling effort: R^2 = 0.110			
Intercept	0.523	0.198	0.010
Richness	0.392	0.118	0.001
Sampling effort	-0.001	0.001	0.405
Relationship with ecosite: R^2 = 0.029			
Intercept	1.116	0.046	<0.001
NT	0.226	0.132	0.090
PX	0.161	0.132	0.227
PM	0.089	0.085	0.295
PD	-0.141	0.098	0.157
MX	0.088	0.132	0.506
MG	0.133	0.093	0.158
MD	0.059	0.093	0.528
RG	0.235	0.219	0.286
RD	0.095	0.079	0.231
SD	0.162	0.132	0.221

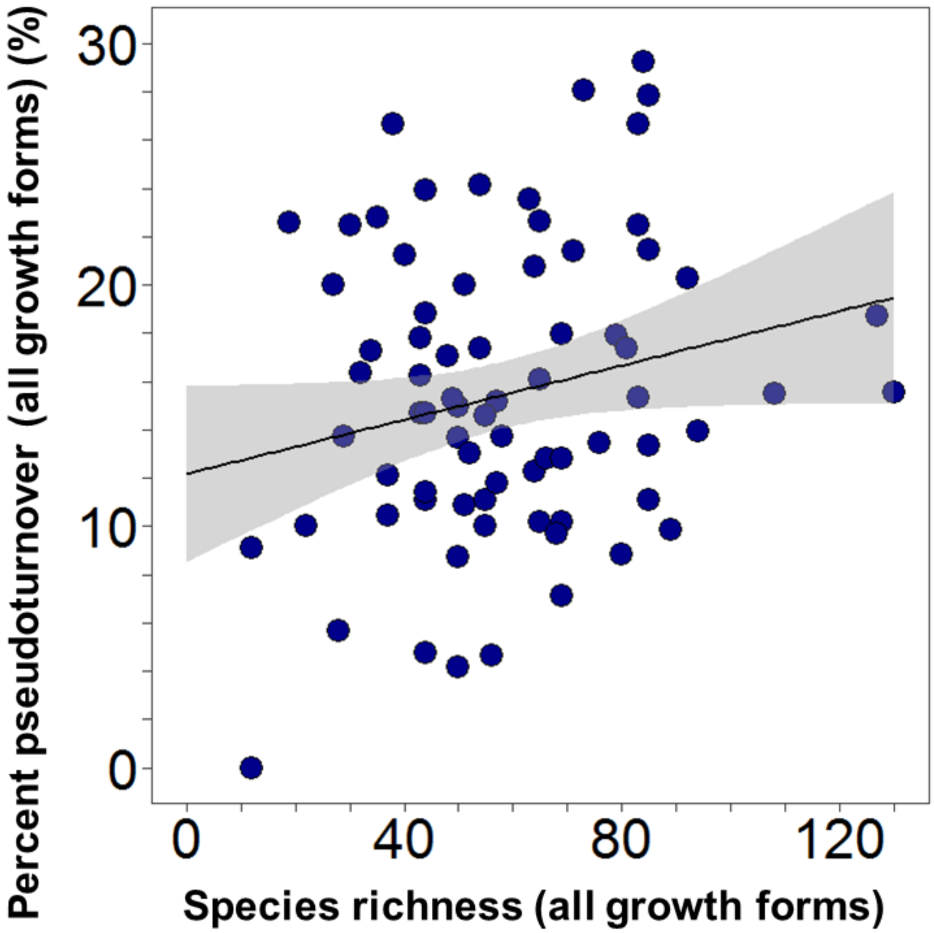

Figure 4.12. Relationship between percent pseudoturnover (*n* = 75 pair-wise comparisons) for all vascular plant species collectively (*n* = 379 species) and total richness for the repeat survey dataset (*n* = 67 plots). Axes were not log_{10}-transformed for legibility purposes; however, these variables were transformed in the linear model.

Total richness was most strongly correlated with pseudoturnover in graminoids and trees with pseudoturnover positively related to species richness (p <0.001, R^2 = 0.187; and p <0.001, R^2 = 0.169, respectively), although relationships with individual growth form richness were more pronounced (p <0.001, R^2 = 0.297; and p = <0.001, R^2 = 0.277) (see Appendix 4.1 for individual growth form models). Species richness in both total and individual growth forms were weakly related to pseudoturnover for forbs and shrubs with their effects being positive and near-significant in most cases. No general relationships were apparent between ecosite and pseudoturnover for any of the growth forms, although certain ecosite categories had a significant effect in some instances.

Number of species missed

Individual observers missed an average of 7.8 species per plot, ranging from 0 to 31 total species, with forbs comprising the majority of species missed (Table 4.4). For context, among all Rarity and Diversity plots, overall average species richness was 45.4 and ranged from 26.5 to

71.9 species among ecosite categories (see Chapter 1). Moderately high variation in the number of species missed was observed across ecosite categories with inconsistency in the amount of variation per category (Figure 4.3).

Table 9.4. Number of species missed per plot (*n* = 150 values for unique species) for all vascular plant species collectively (*n* = 379 species) and per growth form for the repeat survey dataset (*n* = 67 plots).

	Number of Species Missed per Plot		
Growth Form	**Average**	**Minimum**	**Maximum**
Forb	3.8	0.0	19.0
Graminoid	1.7	0.0	7.0
Shrub	1.5	0.0	6.0
Tree	0.8	0.0	5.0
All Growth Forms	7.8	0.0	31.0

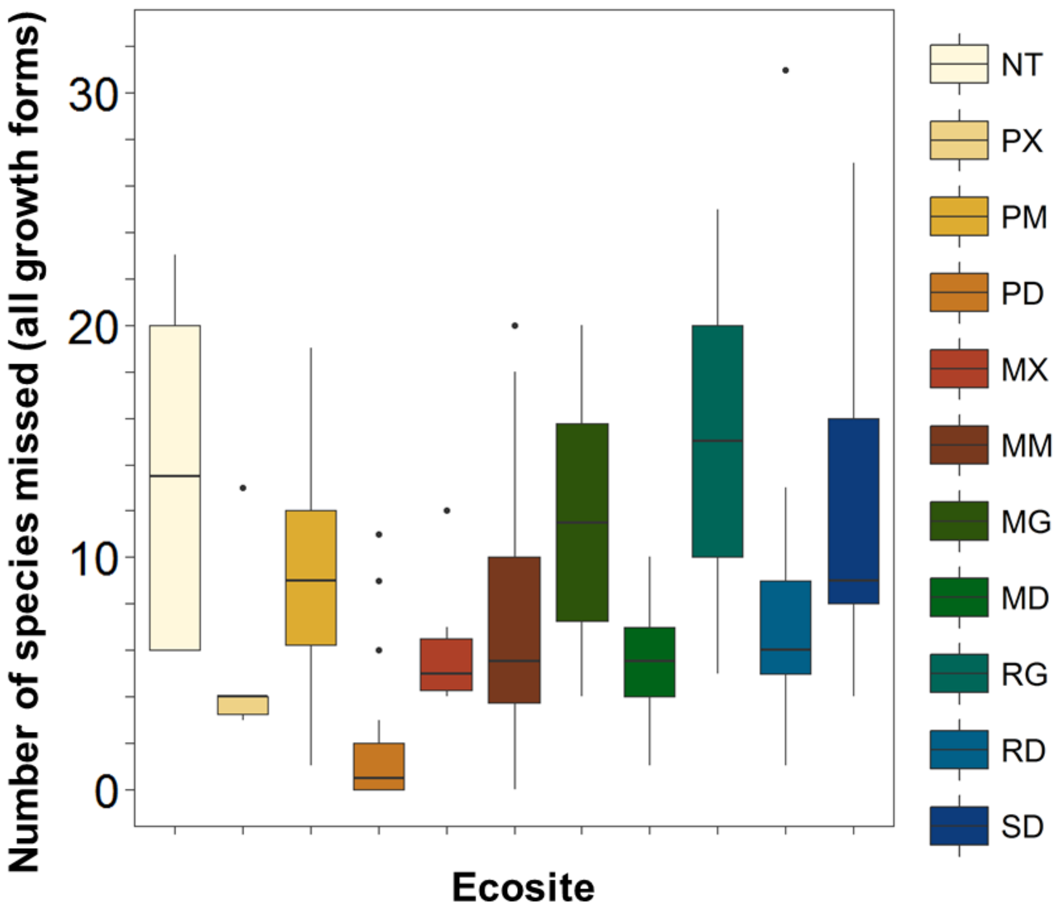

Figure 4.13. Variation in the number of species missed per plot (*n* = 150 values for unique species) for all vascular plant species collectively (*n* = 379 species) across the 11 ecosite categories included in the repeat survey dataset (*n* = 67 plots).

Models for the number of species missed

Total richness demonstrated a strong and significant positive relationship with the number of species missed by a single observer for all species collectively (p <0.001, R^2 = 0.545) (Table 4.5; Figure 4.4). Ecosite was also strongly related to the number of species missed for all species, with certain categories having a significant effect on number of species missed (R^2 = 0.406) (Table 4.5).

Total richness was most strongly related to the number of forb species that were missed, and was moderately related to that of the remaining three growth forms (Appendix 4.1). Individual growth form richness was strongly related to the numbers of forb and graminoid species missed, while relationships with those of shrubs and trees were moderate. Both total and individual growth form richness, however, had significant effects on the number of species missed for all growth forms. Ecosite had the strongest relationship with the number of forb species missed, and was moderately related to those of the other growth forms, with significant effects for certain categories.

Table 4.10. Summary of linear models examining relationships between the number of species missed per plot (n = 150 values for unique species) for all vascular plant species collectively (n = 379 species) and both total richness and ecosite category for the repeat survey dataset (n = 67 plots). Log_{10} transformations were applied to all continuous variables.

Model Variable	**Coefficient**	**S.E.**	***p***
Relationship with species richness (all growth forms): R^2 = 0.545			
Intercept	-0.893	0.112	<0.001
Richness	1.009	0.066	<0.001
Relationship with ecosite: R^2 = 0.406			
Intercept	0.819	0.035	<0.001
NT	0.300	0.071	<0.001
PX	-0.078	0.112	0.490
PM	0.139	0.071	0.052
PD	-0.515	0.064	<0.001
MX	0.010	0.112	0.931
MG	0.236	0.078	0.003
MD	-0.072	0.062	0.245
RG	0.278	0.188	0.141
RD	0.055	0.066	0.404
SD	0.244	0.112	0.031

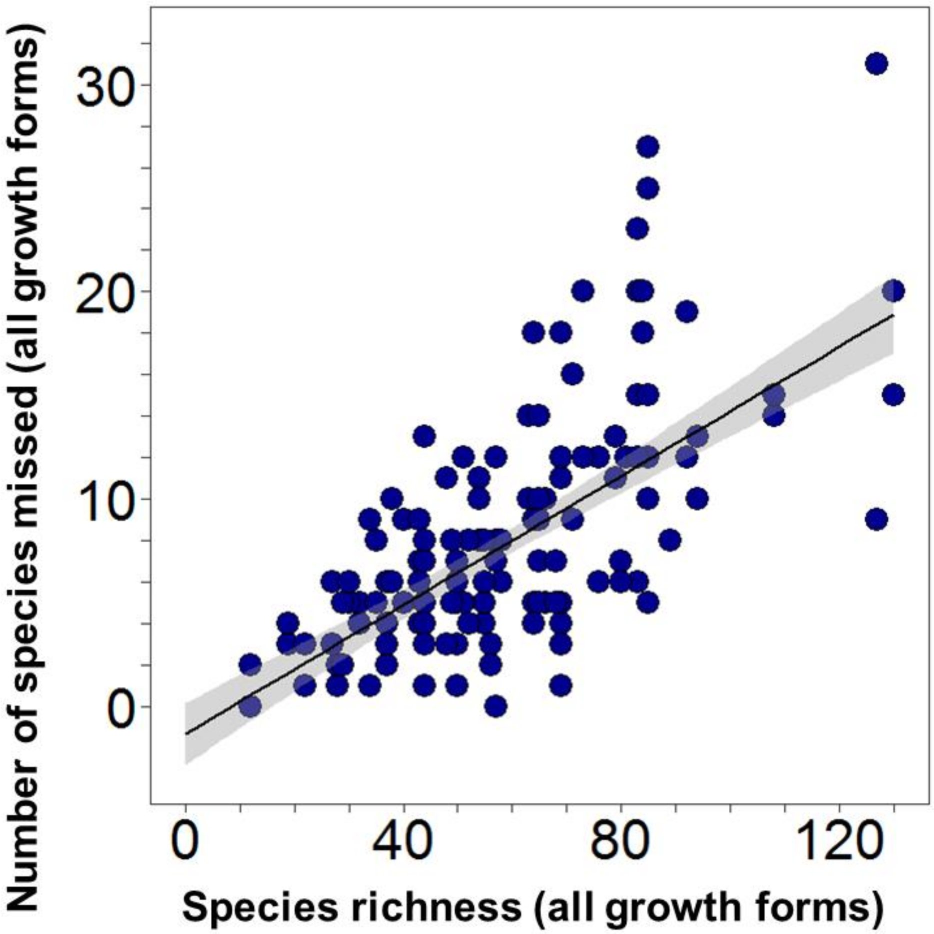

Figure 4.4. Relationship between the number of species missed per plot (*n* = 150 values for unique species) for all vascular plant species collectively (*n* = 379 species) and total richness for the repeat survey dataset (*n* = 67 plots). Axes were not $\log_{10}$-transformed for legibility purposes; however, these variables were transformed in the linear model.

4.5 Discussion

Effective management and conservation of biodiversity is predicated on the ability to detect ecological trends, which itself is contingent upon the recognition and minimization of error. Observer error during vascular plant sampling, represented here as percent pseudoturnover and the number of species missed per plot, generally increases with species richness. The magnitude of the error and the strength of relationships with richness, as well as ecosite, vary by plant growth form and depend on the error metric used. Observers missed an average of 7.8 species per plot. The observed average pseudoturnover of 15.4% for all species was low compared to previous studies, and was not influenced by differences in sampling effort between observers. It is likely that the time-unlimited sampling protocol allowed observers to survey to their saturation point and thus reduced observer error. Previous work based on a portion of this dataset by Zhang *et al*. (2014), which contrasted time-unlimited with a time-limited protocol, suggested that time limits may result in far higher discrepancies in species lists between observers.

Further, these findings indicate that the species richness of a given plot can inform estimates of the magnitude of observer error present, and suggest that plant functional groups should be assessed individually when examining the factors that affect this and how these can be addressed. Graminoids had the poorest repeatability between observers here, speaking to the need for careful training on the families Cyperaceae, Juncaceae, and Poaceae. Further, particular attention should be paid to this group during surveys.

Implications for management

The analysis of pseudoturnover across a large, multi-year study indicates that observer error occurs even among well-trained observer pairs with similar vegetation experience backgrounds. Observer error therefore cannot be ignored when interpreting the results of vegetation inventories. Reported absences of species of conservation concern should be interpreted with respect to measures of total site richness and the field sampling protocol used (time unlimited vs. limited). We encourage the use of time-unlimited protocols in vegetation surveys to reduce pseudoturnover. Smaller plot sizes would further decrease pseudoturnover, but would reduce the likelihood of encountering rarer microhabitats that would increase rare plant encounters. Finally, graminoids are a challenging group which may require extra consideration during surveys.

CHAPTER 5.0: Experimental detectability trials using decoy species

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5.1 Summary

Successfully detecting rare vascular plant populations during field surveys prior to oil and gas developments has direct implications for conservation of rare species. Industry cannot mitigate for populations of which they are unaware. Imperfect detection leads to underestimates of species presences on leases and thus decreases the reliability of survey data. The issue of imperfect detection has not been examined in detail within boreal environments where vegetation structure would be expected to influence detection rates. Here, we address this issue by using detectability trials with decoy plants, where species are targeted by volunteer observers unaware of their true presence or abundance in survey plots. Our findings indicate that the detectability of cryptic species is very low when abundance is low (0 - 35%) and plot size is large (< 50% in ≥ 100 m^2). We suggest that future surveys in the oil and gas area consider species characteristics of target (rare) species, provide records of search effort, and limit plot size through alternative search methods.

5.2 Introduction

Ecological survey data are used to understand species presence and abundance across landscapes and to help guide conservation decisions. When survey data are inaccurate or biased, it affects our knowledge of species distribution, rarity, and conservation status, and conservation efforts. As with other taxa, detection of plants in surveys is imperfect (MacKenzie *et al.* 2005; Morrison 2016). Factors demonstrated to influence plant species detectability include the observer, abundance, phenology, habitat attributes, and morphology (Chen *et al.* 2009; Moore *et al.* 2011; Alexander *et al.* 2012; Garrard *et al.* 2013; McCarthy *et al.* 2013; Ng & Driscoll 2014; Morrison 2016). Work on plant detectability in forested systems is more limited, but studies thus far suggest low detectability (as low as 9%) of target species in species rich forest plots in China (Chen *et al.* 2009). Imperfect detection of rare species is of specific concern, as one key attribute of rarity is small population size (abundance), a trait shown to correlate with poor detection success.

In the oil sands area of Alberta, Pre-Disturbance Assessment (PDA) surveys are conducted prior to construction of in situ oil sands developments in order to locate populations of rare vascular plant species, which can then be managed through mitigation measures (see Chapter 6). Failure to detect rare species in areas which will undergo development could result in oil and gas-related losses in rare plant populations. Provincial Pre-Disturbance Assessment guidelines direct oil and gas companies and contractors to the Alberta Native Plant Council (ANPC) guidelines for survey methodology (Alberta Native Plant Council 2012; Alberta Energy Regulator 2014). These guidelines advise upon observer experience, pre-survey planning, and survey methodology, but do not explicitly include recommendations or discussion around imperfect detection. Because plants are static during survey, appropriate effort (time and area covered) during a single visit at peak flowering can ensure detection success, rather than using costly repeat site visits over a single season (Bornand *et al.* 2014).

Presently, ANPC guidelines for rare plant surveys are not explicit regarding search area or effort (time). Although individuals may search a large geographic area in a single day on a typical oil and gas project, research has demonstrated a lack of repeatability between surveyors on plots of sizes ranging from 4 m^2 to 2500 m^2 (Leps & Hadincova 1992; Archaux, Bergès & Chevalier 2007; Zhang *et al.* 2014). Additionally, observer experience is expected to improve survey outcomes, although this character has not always been correlated with increased success (Moore *et al.* 2011; Alexander *et al.* 2012). In Alberta, it is recommended that observers have 4 months (1.5 to 2 field seasons) of taxonomic experience before commencing Pre-Disturbance Assessment (PDA) surveys (Alberta Native Plant Council 2012). Understanding how observers, survey attributes, and species characters interact to affect detection rates and incorporating measures to improve detection in survey guidelines will ensure reliable survey data and increase confidence in reported absences of rare or target species.

Here, we conducted controlled field trials in the manner of Moore et al. (2011), first used in Australia in an invasive species application. Populations of target species (decoys) that are not currently growing in the plot are planted prior to surveys, allowing for the manipulation of species-related factors (e.g. abundance, phenology) and determination of their influence on detectability. Results from the initial study showed that observer identity and plant abundance were the best predictors of observer success (Moore *et al.* 2011). The goal of our experimental decoy trials was to test the influence of plot size and observer experience (2015), abundance and distribution (patchiness) of target species, observer movement paths (2016), and species characteristics (both years).

5.3 Methods

Study site and decoy planting methods

Both experimental trials were located west of Edmonton, Alberta at Woodbend, a research area owned by the University of Alberta. Upland forest type across the property is predominantly mixedwood with moderate shrub cover, mainly *Corylus cornuta* (Beaked Hazelnut). While plots differed slightly in tree and shrub density, we considered them to have been effectively similar in structure. Plot boundaries were marked using wooden stakes and string or nylon rope to deter observers from leaving the plots during survey. Start locations were fixed and marked using large signs; observers were asked to meander survey plots beginning from the marked corner, but given no further directions on type of search effort. Decoy plants were planted using garden trowels at randomly determined locations within plots based on two random numbers representing the number of paces along the axes of the plot (i.e. first north/south, then east/west). Every effort was made to reduce disruption during planting. Excess soil was removed from the area and litter was sprinkled around the decoy plant. We watered and checked individuals regularly over both trials and replaced any specimens which were damaged (e.g. herbivory, chlorotic). We used two target species in each year, *Symphiotrichum lanceolatum* and *Viola pedatifida* (2015), and *Allium cernuum* and *Petunia* sp. (2016) (Figure 5.1).

Figure 5.1. Photographic illustrations of the four species used in two detectability trails at Woodbend research forest west of Edmonton, Alberta. Clockwise from upper left: *Symphiotrichum lanceolatum*, *Viola pedatifida*, *Allium cernuum*, and *Petunia* sp.

Volunteer observers in both years were recruited through email and word of mouth. In 2015 we targeted individuals with specific years of vascular plant survey experience and time since their last survey. In 2016 we recruited individuals who had experience conducting targeted surveys, but did not require that these observers be experienced with vascular plants (e.g. we accepted individuals with experience surveying amphibians and bryophytes). Immediately prior to beginning their surveys, observers were shown example specimens of decoy species and told that neither, one, or both species may be present. They were able to revisit the example specimens throughout the day. We instructed observers to survey plots until they felt they had adequately surveyed the area and recorded the total time of survey, as well as the time at which they encountered any target species. Observers were not asked to make full species inventories, thus simulating targeted rare plant surveys. Ethics approval was granted for both trails through the University of Alberta Research Ethics Office (PRO00059103 in 2015 and PRO00064852 in 2016). Participants were debriefed once they had completed all surveys. At that time, study objectives and species presence within plots were disclosed.

Effects of observer experience and plot size (2015 detectability trials)

In the 2015 detectability trials, we focused on manipulating plot size and observer experience. We maintained species abundance in all plots at 1 individual/plot/species across the following five plot sizes: 1 m^2, 10 m^2, 100 m^2, 1000 m^2, and 2500 m^2 with three replicates per size (n = 15). Observers were categorized as: 1) *Expert botanist* with > 5 field seasons of rare plant and plant survey experience, 2) *Intermediate botanist* with 2-3 field seasons of general plant survey experience and had completed surveys within the preceding 4 months, and 3) *Intermediate observers* with > 2 field seasons of experience who had not completed a survey within the last 4 months (i.e. that field season). Group 2 (intermediate botanist) aligns with ANPC's suggestion of 120 days of taxonomic experience for individuals conducting rare plant surveys. Sixteen recruited observers were asked to complete one replicate of each plot size if possible (a minimum of 5) and to complete additional plots if they were so inclined. The order in which plot sizes were completed and the replicate plot identity were randomized for each individual, although complete randomization was forgone at the end of the trial to ensure all plots had at least one observation in each observer experience category.

The two species targets (*Symphiotrichum lanceolatum* [Western willow aster] and *Viola pedatifida* [Crowfoot violet]) (Figure 5.1) were procured from Wild About Flowers, a native seed and plant nursery near Calgary, Alberta. Neither species was flowering at the time of the trial. We recorded the height and maximum width of each planted individual and the number of leaves in *V. pedatifida*. We did not count leaves in the aster as they were too numerous (>100 individual). We measured horizontal cover around each individual decoy plant using a range pole from a distance of 5 and 10 m in all four cardinal directions.

We used mixed-effect logistic regression models to relate detection success to the variables of interest, namely observer experience and plot size, and AIC model evaluation to rank support among candidate models (Burnham & Anderson 2002). Plot size was log transformed. To account for repeated measures in a plot across observers and observers across plots, we used a random effect on both observer and plot replicate. All analyses were completed in R (R Core Team 2015) using the package 'lme4' (Bates *et al.* 2015).

Effects of population size and distribution (2016 detectability trials)

In 2016 detectability trials, we maintained a constant plot size of 1000 m^2 and recruited 13 observers that had a background in targeted field surveys. In these trials, we manipulated abundance (1, 5, and 10 individuals) and distribution (clumped or diffuse) of two target species (*Allium cernuum* and *Petunia* sp.) across 15 plots using the design illustrated in Figure 5.2. Both species were in flower throughout the trial. To achieve the desired well-spaced arrangement of individuals within "diffuse" plots, we used the same random number pacing system described for the 2015 trials, however when a set of random numbers meant that an individual would be planted in close proximity (< 2 m) to another, we used the next number set to create a minimum distance between patches.

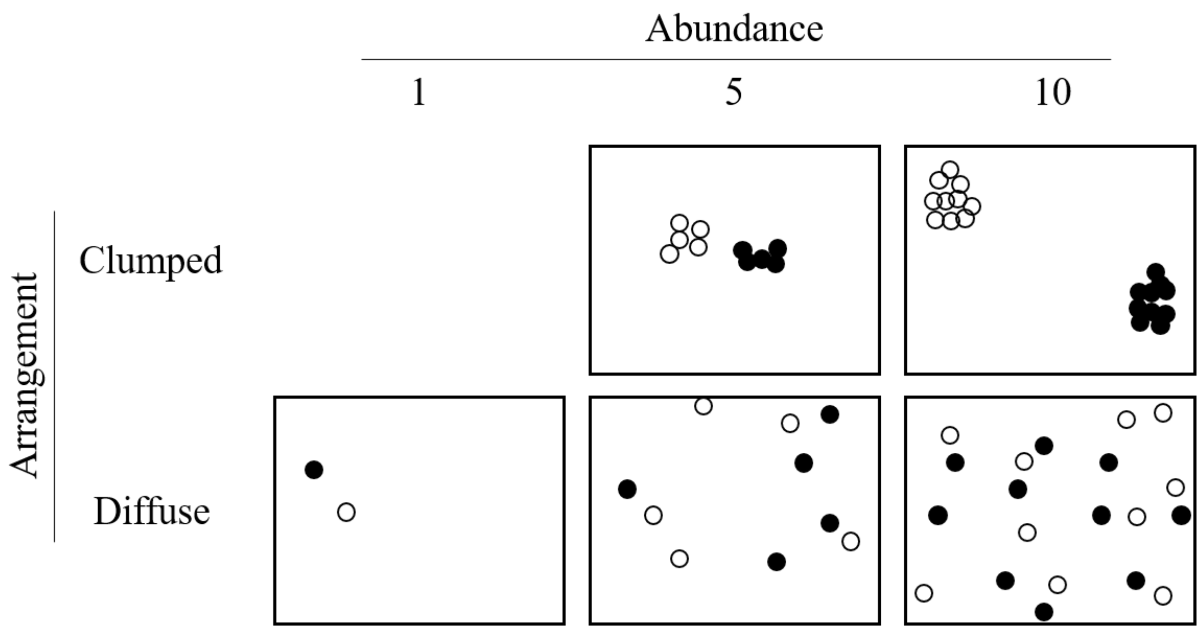

Figure 5.2. Study design used in a 2016 detectability trial. Closed circles indicate *Petunia* sp., open circles *Allium cernuum*. This design was replicated 3 times for a total of 15 experimental plots.

We asked participants to wear Columbus V990 GPS data loggers (Victory Technology Co., Ltd.) during surveys to generate location data suitable for analyzing movement paths. To relate detection success to movement patterns of observers, we measured observer movements as effective search paths in a GIS (ESRI 2015). Specifically, we created steps from GPS log waypoints (sample intensity of 1 location per second) using Geospatial Modeling Environment (Beyer 2015) and calculated tortuosity from these steps. Next, lines were buffered by a 1 m radius (2 m wide path) in ArcMap (ESRI 2015). Total search area by each individual in each plot was then calculated as the proportion of each plot searched (total search area divided by plot size). We then used mixed-effect logistic regression models with AIC model evaluation to determine the relationship between species identity, abundance, arrangement, and observer movement metrics on success. To account for repeated measures, we used a random effect on observer and plot replicate. Models were built using the package 'lme4' (Bates *et al.* 2015) in R (R Core Team 2015).

5.4 Results

The influence of observer experience and plot size on detectability (2015 trials)

Sixteen volunteer observers completed 4 to 8 (although most often 5) surveys each, for a total of 83 surveys and 166 species-level observations. Overall, detection of both species was lower than anticipated, less than 50% in plots > 100 m^2 (10 x 10 meters) and declining rapidly with plot size (Figure 5.3). The more morphologically distinct *V. pedatifida* was found more frequently (57% success across all plots) than *S. lanceolatum* (47%), a more cryptic species that "blended" with similar *Asteraceae* species and *Galium boreale* within survey plots. In plots of 1000 m^2, the size used in the 2016 trial, total success of *V. pedatifida* was 35%, as compared to 23% success in *S. lanceolatum*.

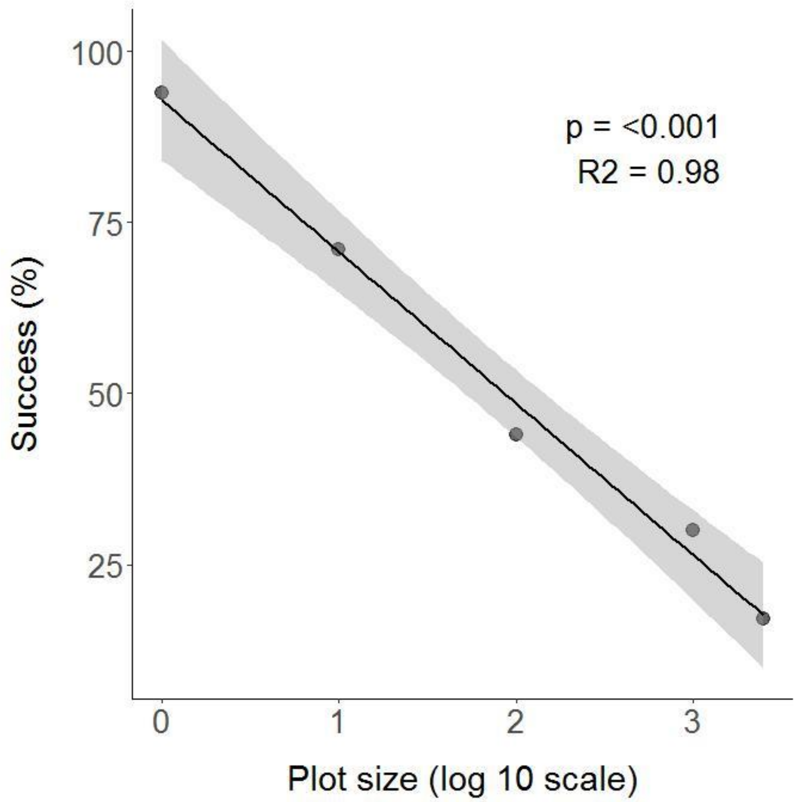

Figure 5.3. Total success in observing 2 target species across 5 plot sizes for 16 volunteer observers in a 2015 decoy plant detectability trial (*n* = 166).

Results of logistic regression demonstrated equivalent support for the top five ranked candidate models (ΔAIC < 2) (Table 5.1). All five models indicated that plot size was the major determinant of detection success, with target species having a weakly significant influence (*V. pedatifida* found more frequently), and an observed weak positive effect of height of plant. The lowest AIC ranked model parameters are summarized in Table 5.2. Observer experience level was not a significant factor in any candidate model.

Table 5.1. Results of logistic regression models of detection success for two species in the 2015 detectability trials (*n* observations = 166). Plot area was log transformed in all models. Aster was used as the reference category in the variable “Species”. Survey order refers to the order in which plots were completed by a given observer.

Model	K	AIC	ΔAIC
success ~ plot area + species + height + (1 | observer) + (1 | plot)	5	177.8	0
success ~ plot area + species + (1 | observer) + (1 | plot)	4	178.5	0.7
success ~ plot area + (1 | observer) + (1 | plot)	3	179	1.2
success ~ plot area + species + experience level + (1 | observer) + (1 | plot)	5	179.4	1.6
success ~ plot area + species * height + (1 | observer) + (1 | plot)	6	179.7	1.9
success ~ plot area + species + visibility + height + (1 | observer) + (1 | plot)	6	181.4	3.6
success ~ plot area + species + visibility + experience level + survey order + (1 | observer) + (1 | plot)	7	183.3	5.5
success ~ (1 | observer) + (1 | plot)	2	199.6	21.8

Table 5.2. Parameters and standardized coefficients with associated standard error values for the most supported AIC model of detection success (Table 5.1). Aster was used as the reference category for the variable "Species". Plot area was log transformed, (n = 166).

Parameter (units)	Standardized coefficient	Standardized standard error	p-value
Intercept	0	0	0.61
Plot area (m^2)	-3.22	0.64	*<0.001*
Species (violet or aster)	2.09	1.01	*0.04*
Height (cm)	1.6	1.01	0.12

We built logistic regression models per species and observed differences in explanatory variables included in the best supported models. Observer experience and survey order were weakly significant in the best supported model for *V. pedatifida*, however there was equivalent support for a model containing only plot size (ΔAIC = 2.1) (Tables 5.3 and 5.4). In contrast, for *S. lanceolatum* the most supported model contained species height and visibility (Tables 5.5 and 5.6).

Table 5.3. Results of AIC model comparison of candidate models relating the success of detecting *Viola pedatifida* to explanatory survey variables (n = 83).

Model	K	AIC	ΔAIC
success ~ plot area + survey order + experience level + (1 | observer) + (1 | plot)	5	83.3	0
success ~ plot area + experience level + (1 | observer) + (1 | plot)	4	84.4	1.1
success ~ plot area + (1 | observer) + (1 | plot)	3	85.4	2.1
success ~ plot area + height + visibility + (1 | observer) + (1 | plot)	5	86.7	3.4
success ~ plot area + height + (1 | observer) + (1 | plot)	4	87.4	4.1
success ~ plot area + height + leaf number + average width + (1 | observer) + (1 | plot)	6	89.4	6.1
success ~ (1 | observer) + (1 | plot)	2	106.3	23

Table 5.4. Parameters of the best-fitting model of *Viola pedatifida* detection success (n = 83) as determined by AIC model evaluation (Table 5.3). Plot area was log transformed in all models. Survey order refers to the order in which plots were completed by a given observer. Expert observers (those with > 5 years of experience) were withheld as a reference category in the variable "experience level".

Parameter (units)	Standardized coefficient	Standardized standard error	p-value
Intercept	0.00	0.00	*<0.001*
Plot area (m^2)	-3.79	0.79	*<0.001*
Survey order	1.06	0.62	0.09
Intermediate observers w/ recent exp.	-1.54	0.79	0.05
Intermediate observers w/o recent exp.	-0.06	0.73	0.94

Table 5.5. Results of AIC model comparison of candidate models relating the success of detecting *Symphiotrichum lanceolatum* (n = 83) to explanatory survey variables. Plot area was log transformed in all models. Survey order refers to the order in which plots were completed by a given observer. Expert observers (those with > 5 years of experience) were the reference category in the variable "experience level".

Model	K	AIC	ΔAIC
Success ~ plot area + height + visibility + (1 | observer) + (1 | plot)	5	90.5	0
Success ~ plot area + height + (1 | observer) + (1 | plot)	4	93.3	2.8
Success ~ plot area + (1 | observer) + (1 | plot)	3	94.2	3.7
Success ~ plot area + height + average width + (1 | observer) + (1 | plot)	6	95.1	4.6
Success ~ plot area + experience level + (1 | observer) + (1 | plot)	4	97.8	7.3
Success ~ plot area + survey order + experience level + (1 | observer) + (1 | plot)	5	99.1	8.6
Success ~ (1 | observer) + (1 | plot)	2	107.2	16.7

Table 5.6. Parameters of the best-fitting model of *Symphiotrichum lanceolatum* detection success (n = 83) as determined by AIC model evaluation (Table 5.5). Plot area was log transformed in all models.

Parameter (units)	Standardized coefficient	Standardized standard error	p-value
Intercept	0	0	*0.043*
Plot area (m^2)	-3.36	0.963	*<0.001*
Visibility (proportion of range pole)	1.804	0.854	*0.035*
Plant height (cm)	1.713	0.807	*0.034*

Thus, we found limited support for the influence of observer experience in 2015. While we recorded variation in success between observers, these differences could not be attributed to their previous experience when considering both species (Table 5.1). Further, we did not observe any significant difference in effort (time) by experts as compared to intermediate groups with and without recent experience (Figure 5.4).

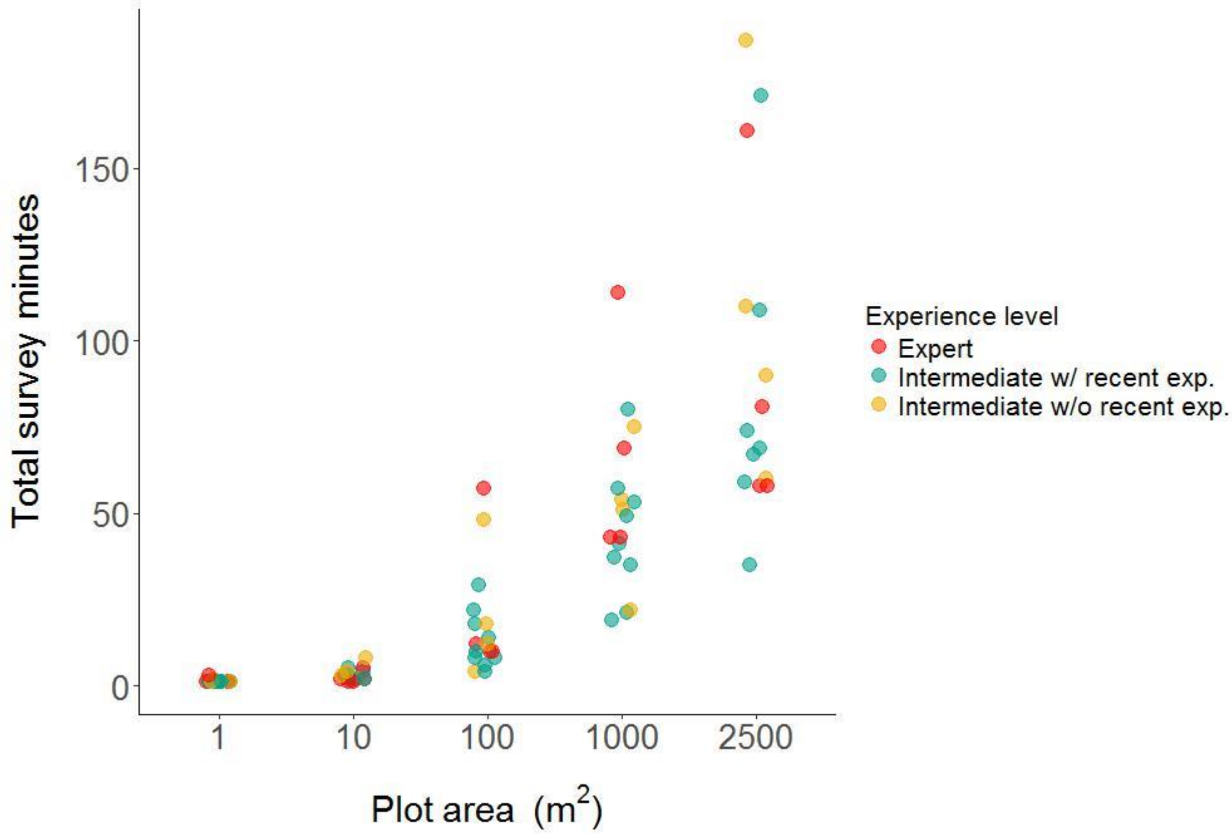

Figure 5.4. Time expenditure by 16 volunteer observers across 5 plot sizes in a 2015 detectability trial using 2 decoy target species (*n* = 83). Note that data points are jittered on plot area in order to increase clarity.

The influence of population size and distribution on detection success (2016 trials)

Thirteen observers completed between 3-5 surveys resulting in 53 total surveys with 106 observations of both species. We excluded one individual in movement analyses as their data logger malfunctioned and two plots from two other unique observers due to similar data logger failures. This left 12 individuals with 46 movement paths for analysis.

Detection success varied substantially between the showy (*Petunia* sp.) and cryptic (*A. cernuum*) species used in the trial (96% and 38%, respectively). Overall, the showy *Petunia* sp. was nearly perfectly detected and thus, given little variation among experimental treatments, not further considered. Diffusely arranged individuals of *A. cernuum* were 25 - 34% more likely to be detected than the same number planted in a clump with perfect detection failure for single individuals within plots (Table 5.7).

Table 5.7. Detection success of nodding onion (*Allium cernuum*) by 13 observers in 5 arrangement/abundance combinations across 15 experimental plots (*n* = 53) in 2016.

	1	5	5	10	10
	Single	Clumped	Diffuse	Clumped	Diffuse
Undetected	11	7	3	7	5
Detected	0	4	7	3	6
n observations	11	11	10	10	11
% success	**0**	**36**	**70**	**30**	**55**

Results of logistic regression analyses of individual detections demonstrated a significant positive effect of abundance on detection with a weak trend of lower detection rates of clumped individuals. AIC values < 2 AIC points apart indicate equivalent support of the top 4 candidate models (Table 5.8). Thus, we suggest that abundance and arrangement of target species act together to influence success, but abundance is the more important predictor (arrangement was often only weakly significant). Overall, there was a weak positive relationship with survey order in all top models (see Table 5.9). The number of seasons completed by an individual observer was included in a single top candidate model, but was not significant. We also completed models independently for *A. cernuum* since this species had greater variation in detectability (see Appendix 5.1, Tables A5.1.1 and A5.1.2)

Table 5.8. Candidate models of detection success regressed against explanatory variables and ranked using AIC model evaluation (n = 106). Species abundance was log transformed in all models. No. of seasons refers to the number of seasons of vascular plant surveys conducted by an individual observer, and survey order is the order in which a given individual completed survey plots. *Petunia* sp. was withheld as the reference category in all models.

Model	K	AIC	ΔAIC
success ~ species + abundance + survey order + (1 | plot) + (1 | observer)	5	82	0
success ~ species + arrangement + abundance + survey order + (1 | plot) + (1 | observer)	6	82.4	0.4
success ~ species + abundance + survey order + no. of seasons + (1 | plot) + (1 | observer	6	83.1	1.1
success ~ species + arrangement * abundance + survey order + (1 | plot) + (1 | observer)	7	83.6	1.6
success ~ species + arrangement * abundance + (1 | plot) + (1 | observer)	6	84.8	2.8
success ~ species + arrangement + abundance + (1 | plot) + (1 | observer)	5	85.3	3.3
success ~ species + abundance + survey order + (1 | plot) + (1 | observer)	5	87.9	5.9
success ~ species + (1 | plot) + (1 | observer)	3	91.6	9.6
success ~ species + survey order + no. of seasons + (1 | plot) + (1 | observer)	5	92.2	10.2
success ~ (1 | plot) + (1 | observer)	2	140.5	58.5

Table 5.9. Parameters and standardized coefficients with associated standard error values for the most supported AIC model of detection success (Table 5.8) (n = 106). Species abundance was log transformed and survey order is the order in which an individual completed survey plots. *Petunia* sp. was used as the reference category for the variable "Species".

Parameter	Standardized coefficient	Standardized standard error	p-value
Intercept	0.00	0.00	0.68
Species	-5.35	0.69	0.03
Abundance	2.83	0.92	0.00
Survey order	1.50	1.20	< 0.001

Observers had quite variable backgrounds (plant surveys within Alberta, Canada, and internationally) and number of years of vascular plant survey experience (range = 0 – 14, median = 3). Observer identity or experience was not, however, related to detection success. Tortuosity and proportional search area did not differ among observers. We observed very uniform speeds across individuals ($\overline{x}$ = 0.16 meters/second, SE = 0.009), although interestingly there was a trend in that the majority of *A. cernuum* detections occurred when ~ 30% of the plot had been surveyed. Further search effort did not improve success rate suggesting a possible saturation effect for this species (Figure 5.5).

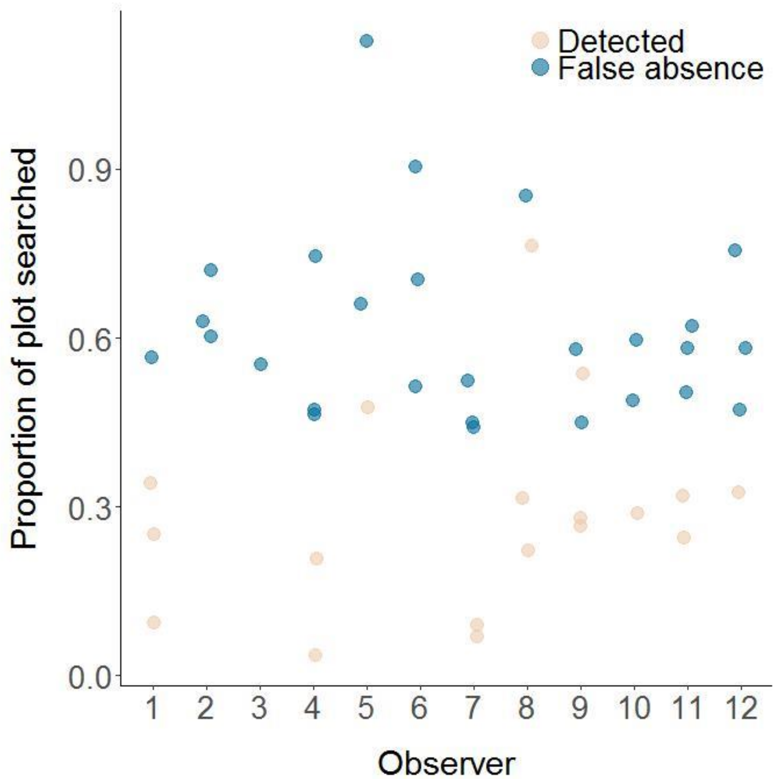

Figure 5.5. Detection success for 12 observers of *Allium cernuum* in 15 experimental plots, as compared to the proportion of the 1000 m^2 plot covered by each individual's buffered search path (n = 46).

5.5 Discussion

Detection trials have two major advantages to uncontrolled field experiments. First, the truth is known, and thus each false absence can be accounted for. Second, variables of interest can be manipulated with regard to target species in ways which would otherwise be unfeasible. Here, we tested the influence of plot size and observer experience with constant target species abundance (2015) and the influence of observer movement and target species morphology, abundance, and arrangement (2016) on detection success. Understanding how detection success changes with survey variables allows for the development of improved survey guidelines (e.g. future iterations of ANPC survey guidelines) and best practices.

Together these trials have clearly demonstrated that probability of detecting cryptic species at low abundance (i.e. 1 individual/1000 m^2) is very low overall (< 35%). The showy *Petunia* sp. used here demonstrates that consistently high detection rates (96%) can occur even at low abundance when the species is flowering and highly visible. However, a minority of boreal species bear flowers of this size or are as brightly coloured, suggesting that most species would go undetected when rare within plots and when not flowering. Many understory species in the boreal have low overall flowering rates and are most often encountered in their vegetative state. We observed perfect failure at detecting *A. cernuum* in 1000 m^2 plots, as compared to 35% in *V. pedatifida* and 23% in *S. lanceolatum*, despite *A. cernuum* being in flower at the time of survey with a distinctive (if slender) inflorescence. The larger size of the two vegetative species likely made them more detectable to observers. Thus, despite the advantages of distinct morphology and phenology, detection of cryptic species is likely far poorer than is currently recognized in plant studies and surveys using larger search areas.

As demonstrated in other work, detection success increased with target species abundance in our 2016 trial, a product of increased encounter rate between the observer and a larger number of individuals (Moore *et al.* 2011; McCarthy *et al.* 2013). Considering species arrangement, we recorded a 30% increase in detection success for clumps over single individuals of *A. cernuum*, presumably due to increased visibility of clustered individuals. However, clumps of 5 and 10 were detected at similar rates (~ 30%), suggesting that this visual advantage may not scale with clump size. These findings have applicability to the allocation of survey effort during targeted rare plant surveys. We suggest that surveys targeting species which are known to occur at high densities or in large, tufted growth forms (e.g. sedges such as *Carex oligosperma* and *C. vulpinoidea*) may require less effort than those targeting species which consistently occur at low densities (e.g. some *Botrychium* sp., and members of the Orchidaceae), and second that all reported absences of species should include a measure of survey effort (spatial scale and temporal sampling intensity).

Considering all four species targets and two trials, the neutral relationship between observer experience and detection success was surprising. Literature suggests that observer experience is often positively correlated with accuracy and success in detecting species (Morrison 2016) and socially, surveys completed by expert botanists regarded as more reliable. First, we suggest that targeted surveys are not subject to observer effects to the degree that complete site inventories may be. Complete knowledge of the flora would serve a considerable advantage in full species inventories, in both time expenditure and presumably, accuracy. It is also possible that trial search conditions differed from those in the field such that the advantage increased experience is expected to convey was negated. For example, many botanists use microsite associations when searching for target species with which they are familiar. These associations were not present in this study due to random assignment of planting locations. However, the surveyed area in 2015 trials was often small (3 of 5 plot sizes ≤ 100 m^2) and thus microsite associations can be considered irrelevant at this scale. We did not observe an advantage of using expert botanists in small plots when searching for a few target species that are first shown to the observer.

Implications for management

Below we summarize considerations that should be made during targeted surveys of rare plants. First, plot size should be limited where possible, possibly through search techniques that divide the total search area into sections with each section searched independently. This contrasts with meandering surveys of larger areas. It is noteworthy that 1000 m^2, the size used in 2016 trials, is $1/10^{th}$ the size of the average wellpad footprint in the oil sands area, further highlighting the need for careful consideration of search area. Second, observer experience may not be as important as traditionally considered when hiring botanists for targeted surveys of one or few species. While experienced observers may lend an increased feeling of confidence to reported absences, particularly when searching for rare taxa, our results suggest that novice botanists can achieve very similar results in targeted searches. Finally, search effort should be documented and considered when evaluating reports of species absence, both in terms of time and of area searched in Pre-Disturbance Assessment surveys. Use of GPS data-loggers that track search paths should be considered when possible. Recording time to detection for target species will also allow for further understanding of patterns in detection in field surveys within the oil sands area.

CHAPTER 6.0: Evaluating translocation of rare species in peatlands as a mitigation technique

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6.1 Summary

Mitigative translocation is a conservation tool employed infrequently, but consistently by oil and gas companies in northeastern Alberta. Translocations are resource intensive projects which may fail to meet conservation goals due to shortcomings in planning, execution, or monitoring. We used experimental translocations in the oil sands region to evaluate this tool and to inform future mitigation efforts. Specifically, we focused on peatlands and two fen species, *Sarracenia purpurea* and *Carex oligosperma*. Transplanting occurred in the growing season of 2014 with follow up monitoring over a span of 3 years. Factors that were anticipated to influence transplant success were measured and include species composition and cover, and nutrient status. Results of monitoring in 2015 and 2016 indicate high transplant survival for both species and little variation between recipient sites despite differences in major nutrients. *Sarracenia purpurea* transplants had consistent high survival and flowering rates over both years, while *Carex oligosperma* transplants had reduced growth and survival between 2015 and 2016. Translocations are most often conducted under time and logistical constraints and may be most effective if employed on species which are known to have broad environmental tolerances.

Project status: Results current to 2016, final field monitoring and project completion in 2017.

6.2 Introduction

In situ oil sands developments in Alberta result in vegetation and topsoil disturbance that alters habitat for vascular plants. Mitigating the loss of populations of rare vascular plant species from human developments is a conservation priority. Mandatory Pre-disturbance Assessment (PDA) surveys are conducted prior to development on oil and gas lease areas to locate populations of concern (Alberta Energy Regulator 2014). Once rare species are identified, companies undertake mandatory or voluntary conservation measures to preserve these populations. Mitigative measures employed in the oil and gas industry include shifting the footprint to avoid direct loss of the population during construction, no action, seed collection, and translocating individuals. Recently distinguished in the literature from traditional translocation projects, mitigative translocation is the movement of plant material or animals which are at risk of imminent destruction due to development (Germano *et al.* 2015).

This practice is used infrequently, but consistently in Alberta for vascular plants, receiving criticism as a conservation measure when the species ecology and determinants of success are poorly understood (Fahselt 2007; Maslovat 2009). Results from prior studies indicate a mixed success at best for re-introduction and augmentation projects (Fahselt 2007; Godefroid *et al.* 2011; Primack & Drayton 2011; Lawrence & Kaye 2011; Drayton & Primack 2012; Clements

2013). A widely recognized failing of traditional translocations is poor recipient site selection, presumably caused by a lack of understanding of species' niches (Godefroid *et al.* 2011). Mitigative translocations conducted by oil and gas companies are limited in three main ways which differ from traditional projects. First, follow up monitoring is lacking, presumably through lack of allocation in resources and/or high turnover in the consulting industry leading to a loss of information around transplants. Second, public reporting of projects, even those which do receive monitoring, is rare. This reduces the ability to determine efficacy and understand the factors influencing successful translocations across species and projects. Finally, these projects are often more time sensitive than reintroduction or augmentation projects. This puts limitations on the pre-translocation planning process resulting in recipient sites being selected quickly, in some cases without consideration of methodology and knowledge of the ecology of the species being translocated.

Despite these potential obstacles, well-planned mitigative translocations in the oil sands region have the capacity to inform definitions of environmental tolerances of boreal species. Boreal environments are unique in that they are often dominated by peatlands and wetlands, habitat types which have not been the focus of translocation research in Canada (Clements 2013). In the oil sands region fens, groundwater fed peatlands, contain a greater number of rare species than other habitat types (Zhang *et al.* 2014; Chapter 2). Further, these habitats are more likely to be disrupted during oil and gas development with minimal likelihood of successful reclamation due to the complexity of replicating hydrological flow regimes (Rooney & Bayley 2011; Rooney, Bayley & Schindler 2012; Raab & Bayley 2013). Given the conservation focus and knowledge gaps associated with this habitat, we chose to conduct experimental translocations for two rare peatland obligate species, *Sarracenia purpurea* and *Carex oligosperma*, in 2014. Our specific objectives were to determine overall survival and growth of these transplants and determine how recipient site characters may improve or reduce survival as they relate to characters at donor sites. In practice, oil and gas companies may have a limited time in which to select recipient sites and thus relating survival to recipient site characters can be used to direct future translocation efforts. Further, the success of our methodology can inform future guidelines and best practices for boreal plant translocations. This project has recorded 2 years of post-translocation data with the final year of monitoring to occur in 2017. Results presented here are based on the first 2 post-translocation field seasons where transplant survival, growth, and flowering were recorded.

6.3 Methods

Donor and recipient study sites

Donor populations were selected from known large (> 1000 individuals), healthy populations encountered during Ecological Monitoring Committee for the Lower Athabasca (EMCLA) Rare Plant Project surveys (now the Terrestrial Vascular Plant Monitoring Project for the Lower Athabasca Rarity and Diversity plots, see Chapter 1 for a detailed description). Three independent donor and recipient sites were selected for each species. Each focal species therefore has 6 experimental sites. No donor sites contained both focal species and no recipient sites had existing populations. Recipient sites were selected to vary in physical structure and vegetation composition from donor sites. All 6 *S. purpurea* sites are located in the vicinity of Conklin, Alberta. Three *C. oligosperma* sites were located near Fort Mackay, Alberta, while the other 3 were located near Conklin (Figure 6.1).

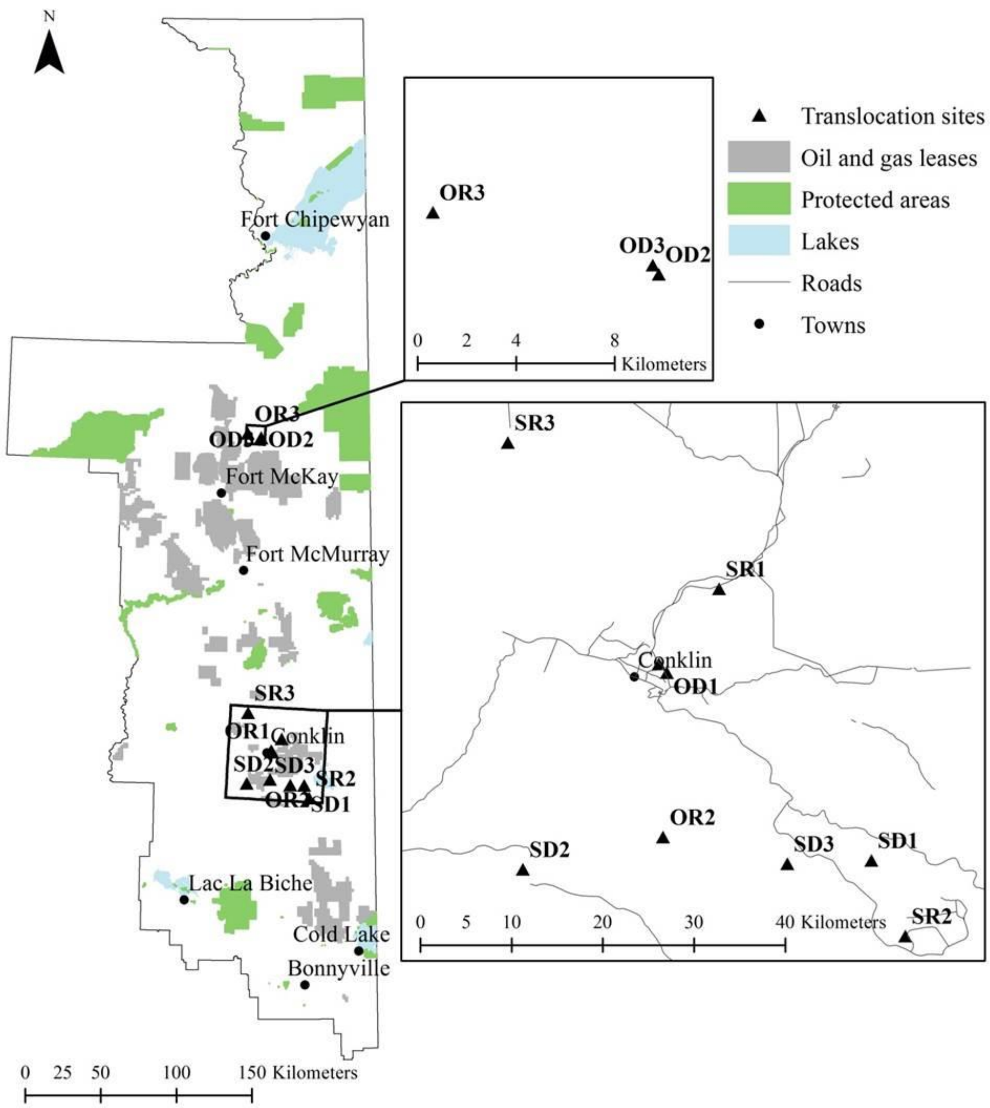

Figure 6.1. Location of 12 experimental translocation sites in northeast Alberta. *Sarracenia purpurea* sites are denoted by S, *Carex oligosperma* sites by O. The letters R and D refer to recipient and donor sites, respectively. Numbers 1, 2, and 3 indicate replicates.

Study design, removal, and planting methodology

Translocations were conducted between late August and mid-September of 2014. We selected 70 transplants at each donor site for both species. Twenty of these transplants were removed and immediately replanted within each donor site as a control for the effect of transplanting. The remaining 50 transplants from each donor site were distributed among the three recipient sites in groups of 17, 17, and 16. Therefore, each recipient site for each species has a founder population of 50 individuals, from 3 different donor locations (Figure 6.2). This provided the minimum suggested founding population size of 50 individuals (Franklin 1980). In total, 210 transplants of each species were translocated. No transplants were moved between donor locations.

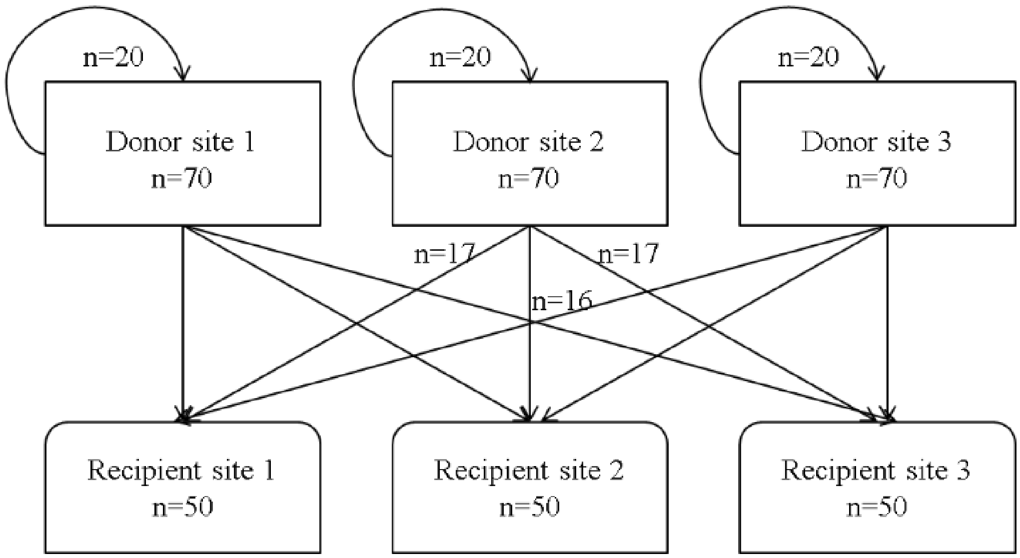

Figure 6.2. Study design schematic used in 2014 mitigative transplantations, where 210 transplants for each *Sarracenia purpurea* and *Carex oligosperma* were moved among three donor and recipient sites, respectively.

To limit damage to the donor population, selected individuals were taken from as small an area as possible with no individuals closer than 2 m to prevent overlap of vegetation plots. As both species were abundant (> 1000 individuals) at all six donor locations, this resulted in removal from an area of roughly 40 m^2. Replanting was conducted over a similarly sized area at all three recipient sites per species. A benefit to planting transplants in a small area is the increased likelihood of locating them in the future, noted to be a problem in previous work with *S. purpurea* (Linda Halsey, pers. comm.).

Prior to removal, each transplant was given an identification code with a metal washer attached to a loop of string and flagging tape to allow relocation in the peatland environment. A 0.25 m^2 quadrat (0.5 x 0.5 m PVC frame) was then placed around the transplant and percent cover was estimated for all surrounding species within the quadrat. Transplants were cut from the peat as small monoliths averaging 50 cm^2 with substrate attached. We removed healthy adult plants with a focus on obtaining significant amounts of root material rather than the precise removal of a single individual. *Carex oligosperma* is strongly rhizomatous and thus each transplant contained multiple vegetative and flowering stems, most likely ramets of a single genet. Transplants of *S. purpurea* often contained more than one individual. When transplants were first removed at their donor site, vegetative and flowering stems of *C. oligosperma* and pitchers of *S. purpurea* were counted and recorded. We transported plants in coolers or tubs with icepacks between donor and recipient sites.

Planting in peat substrate was straightforward and only troublesome at sites with high root density. We cut slits in the peat (through the roots of other plants), widened them by hand if necessary, and packed the transplant in with a moderate amount of force to avoid air space around the roots. Vegetation plots with cover estimates (0.25 m^2) were repeated when plants were translocated, giving two complete vegetation surveys for each transplant. This was also completed for donor site controls.

Spring relocation checks and water chemistry sampling

In early June of 2015 and 2016 spring relocation checks and water chemistry sampling was conducted at all experimental translocation sites. Spring checks consisted of re-marking all individuals with flagging tape overhead and replacing unique id tags. Due to corrosion of aluminum plated washers, plants were remarked in June 2016 using engraved metal 'racetrack' tags attached to 2 or 3 ft. pigtails inserted into the peat at each transplant. Each tag is engraved with the transplant's identification code (visible in Figure 6.5).

Sampling of water chemistry at each site was used to determine the nutrient status of donor and recipient sites. For water sampling we laid out a transect in the orientation that water was expected to flow (e.g. perpendicular to open water or upland slopes) through the fen. This transect was set out to bisect the founder population at recipient sites and the control individuals at donor sites and was generally 15 – 20 m in length. We then collected three water samples using piezometers inserted ~ 30 centimeters into the peat at the beginning, mid-point, and end of each transect. Piezometers were siphoned out upon insertion, left to refill, and then siphoned again until ~ 500 ml of water had been collected. Samples were not filtered in the field. The samples were then analyzed for the following: nitrite and nitrate (NO_2- and NO_3-, respectively), total nitrogen (N), total kjeldahl nitrogen, total phosphorus (P), sodium (Na+), potassium (K+), calcium (Ca_2+), and magnesium (Mg_2+). This protocol will be repeated one last time in June, 2017. All analyses were conducted by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta.

Summer survival, growth, and flowering checks

All experimental translocation sites were revisited between late July and early August to conduct summer survival, growth, and flowering checks. By this time of year *Carex oligosperma* is fully mature but has not begun to shed perigynia and *Sarracenia purpurea* flowers are generally fully mature or beginning to senesce. For this project, we defined transplants to be deceased when no green stems were produced in *C. oligosperma* and all pitchers were completely brown (i.e. non-living tissue) in *S. purpurea*. Flowering and survival were recorded as binary variables. Growth in *S. purpurea* was determined by counting the number of living pitchers. Pitchers persist over at least one winter in this species and grow from the center of the plant, such that dead pitchers often form a ring around the exterior. Leaves in *C. oligosperma* senesce annually and new above ground material is produced each spring (Ryser & Kamminga 2009). For *C. oligosperma* we determined growth by first counting all stems and then measuring the tallest vegetative stem or culm (flowering stem). When transplants produced flowers, we recorded the average length, average width, number, and gender of spikes borne on culms using calipers.

Finally, at each donor site we measured 30 non-transplanted individuals of *C. oligosperma* to determine average height and spike measurements under normal growing conditions in 2015 and 2016. We conducted similar counts of pitchers and flowering rates at *S. purpurea* sites using a different set of 30 individuals in 2015 and 2016. As such, only the data for *C. oligosperma* will be considered here and used as a benchmark for transplant growth. Measurements of summer survival, growth, and flowering will be repeated one last time in 2017.

6.4 Results

Water chemistry

Differences in water chemistry were observed among recipient and donor sites for both species (Figures 6.3 and 6.4). SR3 and OD2 are located very close to gravel and paved roads, respectively, which corresponds to high sodium (not shown) and calcium levels from road salt and hardener applications.

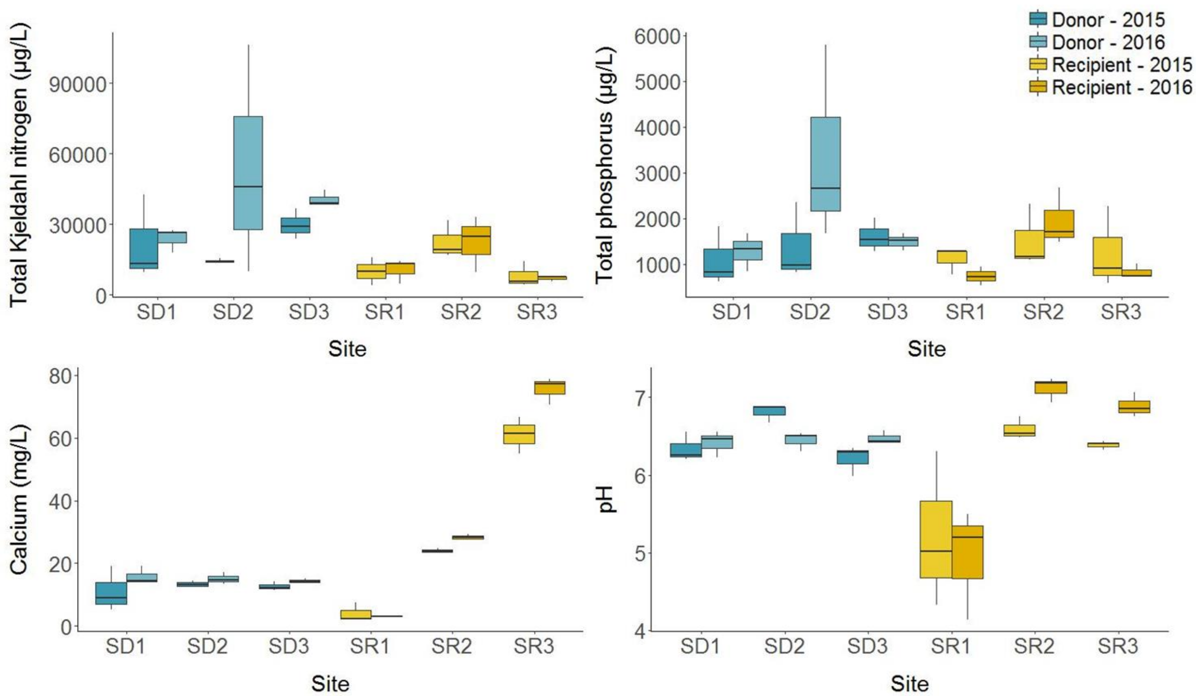

Figure 6.3. Water chemistry variables (Total kjeldahl nitrogen, total phosphorus, calcium, and pH) over 2 years of sampling at *Sarracenia purpurea* donor (SD1-3) and recipient (SR1-3) sites.

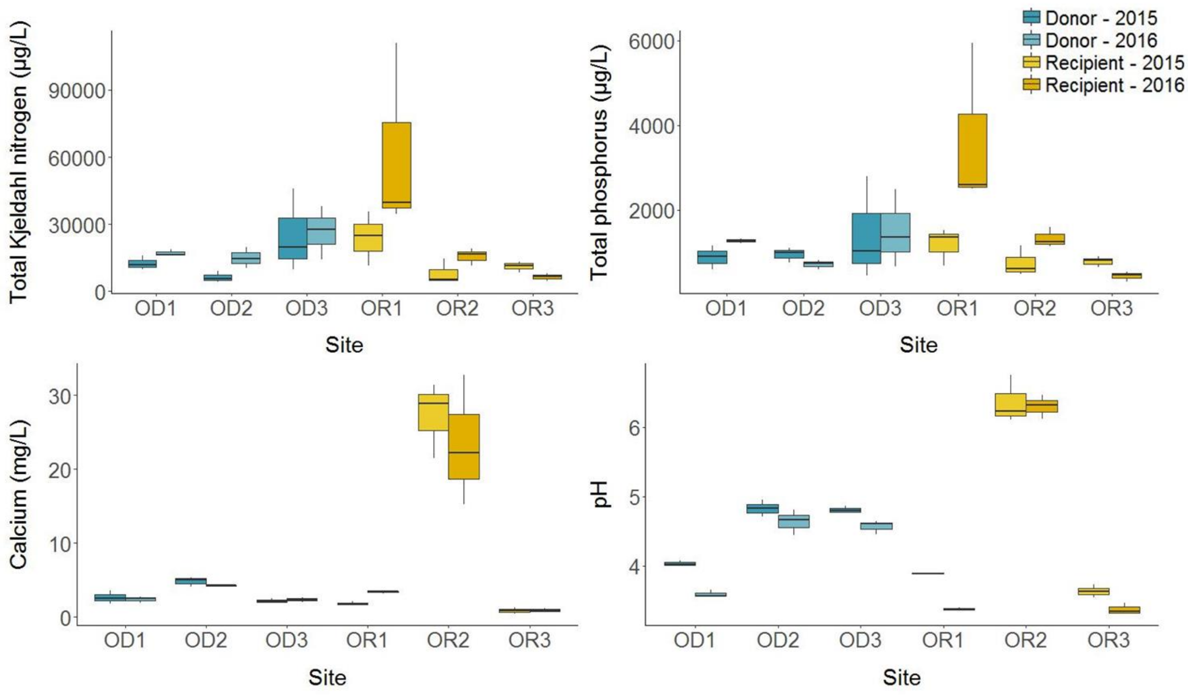

Figure 6.4. Water chemistry variables (Total kjeldahl nitrogen, total phosphorus, calcium, and pH) over 2 years of sampling at *Carex oligosperma* donor (OD1-3) and recipient (OR1-3) sites.

Survival, growth, and flowering

Transplant survival was high overall declining minimally between 2015 and 2016 (Table 6.1). *Sarracenia purpurea* transplants at recipient sites are virtually all extant (99% in 2015 and 98% in 2016), with an interesting case at recipient site SR3 where an individual believed dead in 2015 grew new leaf material in 2016. Transplants showed a net gain of pitchers between 2015 and 2016 at all recipient sites (Table 6.1). Anecdotally, transplants of *S. purpurea* appear robust at all recipient sites (Figure 6.5).

Figure 6.5. A transplanted *Sarracenia purpurea* at SR2, near Conklin, Alberta. This transplant contains a minimum of 7 individuals as this species produces only one flowering stalk per individual per year.

Carex oligosperma survival decreased from 94% in 2015 to 88% in 2016. Flowering rates for both focal species declined in 2016, although to a greater extent in *C. oligosperma* (Table 6.1). Comparison of average height between all *C. oligosperma* transplants at recipient sites and 90 un-transplanted individuals at donor sites confirmed field observations that transplants appear stunted (Figure 6.6). Average height of all transplants was 38.2 cm compared to controls (un-transplanted) averaging 83 cm in 2015. This disparity decreased slightly in 2016 to 52.9 cm and 68.9 cm, respectively

Table 6.1. Survival, growth, and flowering counts at recipient sites of transplanted *Sarracenia purpurea* and *Carex oligosperma* over 2 years (percentages in brackets). Average change in pitchers is the difference in the count of pitchers per transplant between 2015 and 2016. Average change in stems in the difference in vegetative stems or culms per transplant between 2015 and 2016.

Sarracenia purpurea		2015			2016		
	Living	**Flowering**	**Relocated**	**Living**	**Flowering**	**Relocated**	**av. Δ pitchers**
Recipient 1	50 (100)	21 (42)	50	47 (96)	8 (16)	49	5.6
Recipient 2	49 (100)	25 (51)	49	48 (98)	22 (45)	49	4
Recipient 3	44 (98)	18 (40)	45	48 (100)	28 (58)	48	1.6
Total	143 (99)	64 (44)	144	143 (98)	58 (40)	146	3.7

Carex oligosperma		2015			2016		
	Living	**Flowering**	**Relocated**	**Living**	**Flowering**	**Relocated**	**av. Δ stems**
Recipient 1	44 (96)	17 (37)	46	42 (89)	4 (8)	47	0.4
Recipient 2	45 (90)	18 (36)	50	41 (82)	4(8)	50	-0.7
Recipient 3	46 (98)	15 (32)	47	42 (93)	7 (15)	45	-0.4
Total	135 (94)	50 (35)	143	142 (88)	15 (10)	142	-0.3

Table 6.2 reports control transplants where 20 individuals were immediately replanted at their donor site for evaluating the effects of transplanting. Survival, growth, and flowering trends were similar among these individuals and translocated (founder) populations at recipient sites for *S. purpurea* (Table 6.1).

Table 6.2. Survival, growth, and flowering counts at recipient sites of control transplants of *Sarracenia purpurea* at donor sites. Average change in pitchers is the difference in the count of pitchers per transplant between 2015 and 2016.

Sarracenia purpurea		2015			2016		
	Living	**Flowering**	**Relocated**	**Living**	**Flowering**	**Relocated**	**av. Δ pitchers**
Donor 1	20 (100)	9 (45)	20	17 (100)	8 (47)	17	3.25
Donor 2	18 (100)	7 (39)	18	17 (100)	12 (71)	17	6.25
Donor 3	20 (100)	5 (25)	20	20 (100)	2 (10)	20	2.55
Total	58 (100)	21 (36)	58	54 (100)	22 (41)	54	3.9

Figure 6.6. The inflorescence of a transplanted *Carex oligosperma* in 2016. Aside from shorter stature, transplants sometimes developed fewer perigynia and more male flowers than usually observed in this species.

Failure to relocate transplants
As can be seen in Tables 6.1 and 6.2, not all transplants were successfully relocated at recipient sites. For *C. oligosperma*, 4 individuals were never relocated at recipient sites, and 7 were only relocated in one monitoring year. Relocation of *S. purpurea* was similar, with 1 transplant never relocated and 9 only relocated in one monitoring year. Relocation of *S. purpurea* at donor sites was similar, with 1 individual never relocated and 6 only found in one monitoring year.

The identification of control transplants at *C. oligosperma* donor sites was unexpectedly complicated by the species' rhizomatous growth form. This sedge forms dense mats and tends to dominate wetlands where it is found. We were unable to determine if shoots in the region of the original transplant tag originated from the transplant or from neighbouring individuals. Further, rapid peat growth at one donor site (OD3) resulted in the burial of original transplant markers after a single season. Due to these factors, data collected on control transplants will not be used.

6.5 Discussion of 2015 and 2016 results

Mitigative translocations are being conducted at high costs under time and logistical constraints in the oil sands region of Alberta. These projects are rarely publicly reported with regional success rates largely unknown. Evaluating this conservation practice for peatland species provides an opportunity to consider the efficacy of this approach and determine factors which may increase success. Here, we conducted experimental transplants of two rare peatland species with the objective of determining if environmental factors at recipient sites influence survival and growth. Monitoring of these transplants will conclude in the summer of 2017 for 3-years post-transplant. To date we have observed high transplant survival and low variability in growth and flowering among recipient sites, despite demonstrated variation in major nutrient levels and field measured variation in community composition and vegetation structure. This suggests that the environmental tolerances of these two species may be broader than the conditions under which they established at their sites of origin, and that these rare species are more dispersal than environmentally limited. Production of a second generation at recipient sites would confirm the ability to regenerate under these conditions, another dimension of site suitability, although this project considers success to be transplant survival, rather than reproduction (Godefroid *et al.* 2011).

The initial high survival of transplants demonstrated here is supported by examples from the literature (Drayton & Primack 2000; Godefroid *et al.* 2011; Cypher 2014), although initial success may not always correlate with long term success (Drayton & Primack 2012). For instance, we are anticipating further declines in survival for *C. oligosperma* in 2017 based on evidence of decreased stem production from 2015 to 2016 and two years of stunted growth that would potentially reduce stored carbohydrates. Reduction in flowering rates between 2015 and 2016 may indicate weakened plants, but could also be the result of individuals not flowering in consecutive years, a trait which is not uncommon in understory vascular plants. *Carex oligosperma* was shown to germinate at very low rates (< 1%) despite reasonable seed viability (33%) in peatland reclamation experiments in Quebec (Laberge *et al.* 2015). This is in contrast to greater germination and establishment of two ecologically similar species, *Carex limosa* and *Carex magellanica* (Laberge *et al.* 2015). Although the use of seed in translocation often yields poor results (Godefroid *et al.* 2011), these findings may indicate a lack of amenability of *C. oligosperma* to movement from its natal site.

Sarracenia purpurea transplants show very little variation in flowering and growth rates among recipient sites and between recipient and donor sites. This species is relatively well studied and has demonstrated a fairly broad range in habitat tolerances (e.g. acidic to alkaline fens) in the eastern United States (Karberg & Gale 2013) and a tendency toward rapid colonization and growth when introduced to Swiss peatlands (Parisod, Trippi & Galland 2005). It is possible that over a longer timeframe then what is considered here *S. purpurea* may form self-sustaining populations at recipient sites. We suggest that our documented success to date with this species serve to reinforce the idea of restricting mitigative translocations to species whose ecology is relatively well understood or which have demonstrated success across environmental gradients in other research. Use of species whose tolerances are unknown may be best approached on an experimental basis, rather than considered as an active conservation strategy. This may be the most effective use of resources available for mitigative translocations.

CHAPTER 7.0: Persistence of historic rare vascular plant populations in the oil sands region of Alberta

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7.1 Summary

Rare vascular plant species are of management and conservation priority due to increased susceptibility to extirpation. Related decision making processes rely on understanding which species are rare and where their populations occur. In Alberta, the Alberta Conservation Information Management System (ACIMS) manages species-level spatial data and provides the ranks used to define rarity at the provincial level. However, a proportion of the population records maintained by ACIMS were obtained through surveys for oil and gas-related projects conducted prior to disturbance. If populations are extirpated due to construction of associated infrastructure, rarity ranks may be misapplied and the effect of energy development on species persistence may not be properly understood. We completed remote sensing-based assessments and field visits for historic ACIMS rare plant populations in the oil sands area to determine the prevalence of disturbance footprint across populations and the rate of extirpation. The majority of populations in the region are located within 500 m of footprint, but small-scale disturbances such as seismic lines tend to be the most prevalent footprint type. Field observations indicated approximately 30% of historic populations had been extirpated and that the likelihood of persistence declined with increasing proximity to disturbance. These findings suggest revisitation surveys in disturbed landscapes such as the oil sands area should be encouraged to both improve the accuracy of the provincial rare plant database and to understand how oil and gas-related activities may threaten plant populations.

***Project status*:** Field and remote sensing work completed in 2016 is summarized here. Additional field site visits are planned for 2017.

7.2 Introduction

The maintenance of rare vascular plant species at provincial and national scales is both culturally and ecologically significant. The ability to create and achieve conservation and management goals for rare species requires accurate categorization of rarity and conservation statuses. In turn, rarity ranking schemes rely on accurate data representing the location and status of populations for each species (Rabinowitz, Cairns & Dillon 1986; Hartley & Kunin 2003; Master *et al.* 2012). Extirpations of historic recorded populations can introduce bias into conservation rankings if these records are considered in rarity assessments. Specifically, inclusion of extirpated records can result in species appearing prevalent on the landscape and cause inaccurate rarity ranks to be applied. In Alberta, rare element occurrences of species (populations) are maintained by the Alberta Conservation Information Management System (ACIMS). Records of rare species, or those of conservation concern, are submitted by the public to the provincial government, most often by amateur botanists or those employed by consulting, government, or research agencies.

ACIMS uses NatureServe methods to assign sub-national ranks (S-Ranks) to all native vascular plant species for which data are available (Master *et al.* 2012). The rank calculator used in this method includes entry fields for, among others, range extent, area of occupancy, number of occurrences, population size, habitat specificity, and population trends. Although the calculator is comprehensive, arguably the majority of species have substantial data gaps for these attributes. As such, ranking is often based primarily on two factors: the range extent as determined by a minimum convex polygon of known populations, and the number of occurrences within this geographic area (Master et al. 2012; Lorna Allen, pers. comm.). At a sub-national level, this provides species or community level ranks of S1-S5, with S1 being especially vulnerable to extirpation and S5 being secure. Additional ranks indicate cases where species are unable to be assessed due to extinction, provincial extirpation, lack of taxonomic resolution, or insufficient data (e.g. SU). Uncertainty is expressed through combined ranks (e.g. S1S2).

Population records are often collected and submitted to ACIMS by consultants as part of Pre-disturbance Assessment (PDA) rare plant surveys conducted on oil and gas leases (Alberta Native Plant Council 2012; Alberta Energy Regulator 2014). While submission to ACIMS is recommended, only the PDA survey itself is mandatory (Alberta Energy Regulator 2014). Submitted records correspond to proposed development projects that may result in imminent direct or indirect disturbance to identified populations of conservation concern. Changes in land use have been identified as the primary cause of extirpation of local populations (Fagan, Kennedy & Unmack 2005; Pergl *et al.* 2012; Gerke, Farnsworth & Brumback 2014). For instance, a revisitation study for 63 historic populations of a single species in Switzerland observed that 24% of extirpations were associated with increased levels of agricultural disturbance and fragmentation (Lienert, Fischer & Diemer 2002). This raises concerns regarding the use of records associated with Pre-disturbance Assessments to inform provincial rankings of rarity and conservation status, as including populations (element occurrences) at high risk of extirpation may artificially inflate record numbers and thus result in status ranks being more secure than true conditions. Presently, we do not know the extent of footprint in proximity to historic vascular plant records or the regional rate of population extirpation related to oil and gas development.

Here, we addressed this knowledge gap in two parts. First, we used a remote-sensing imagery-based approach to quantify the amount and type of footprint in proximity to 188 ACIMS rare vascular plant records within the oils sands area. Second, we visited a subset of 40 populations during peak flowering periods within the oil sands area of northeast Alberta in 2016. At each site we identified whether historic rare plant populations were indeed still present to better understand whether oil sands developments affected the persistence of known rare plant populations. We plan to visit an additional 20 sites in 2017 to increase sample size and to better understand regional patterns of population loss.

7.3 Methods

Study area

Our study area was defined by the boundaries of the provincial oil sands area (OSA) and associated surface mineable area (SMA) (Figure 7.1). The oil sands area covers roughly one-fifth of the province (21% or 140,000 km^2), encompassing all three major provincial oil sands deposits and nine natural sub-regions, and predominately consists of boreal mixedwood and other boreal sub-region types. Within the oil sands area, the surface mineable area occupies only 4,800 km^2 (3.4% of the OSA) of land surrounding the urban areas of Fort McMurray and Fort McKay, Alberta. The surface mineable area contains bitumen deposits which can be extracted via conventional methods (i.e. surface mining) and encompasses all provincial surface mining operations. Oil extraction activities in the oil sands area are comprised of in-situ oil sands developments that typically use steam assisted gravity drainage (SAGD) or other solvents to extract bitumen via wells. We considered these two areas separately in analyses as footprints of these oil sands developments are vastly different (Rooney, Bayley & Schindler 2012)

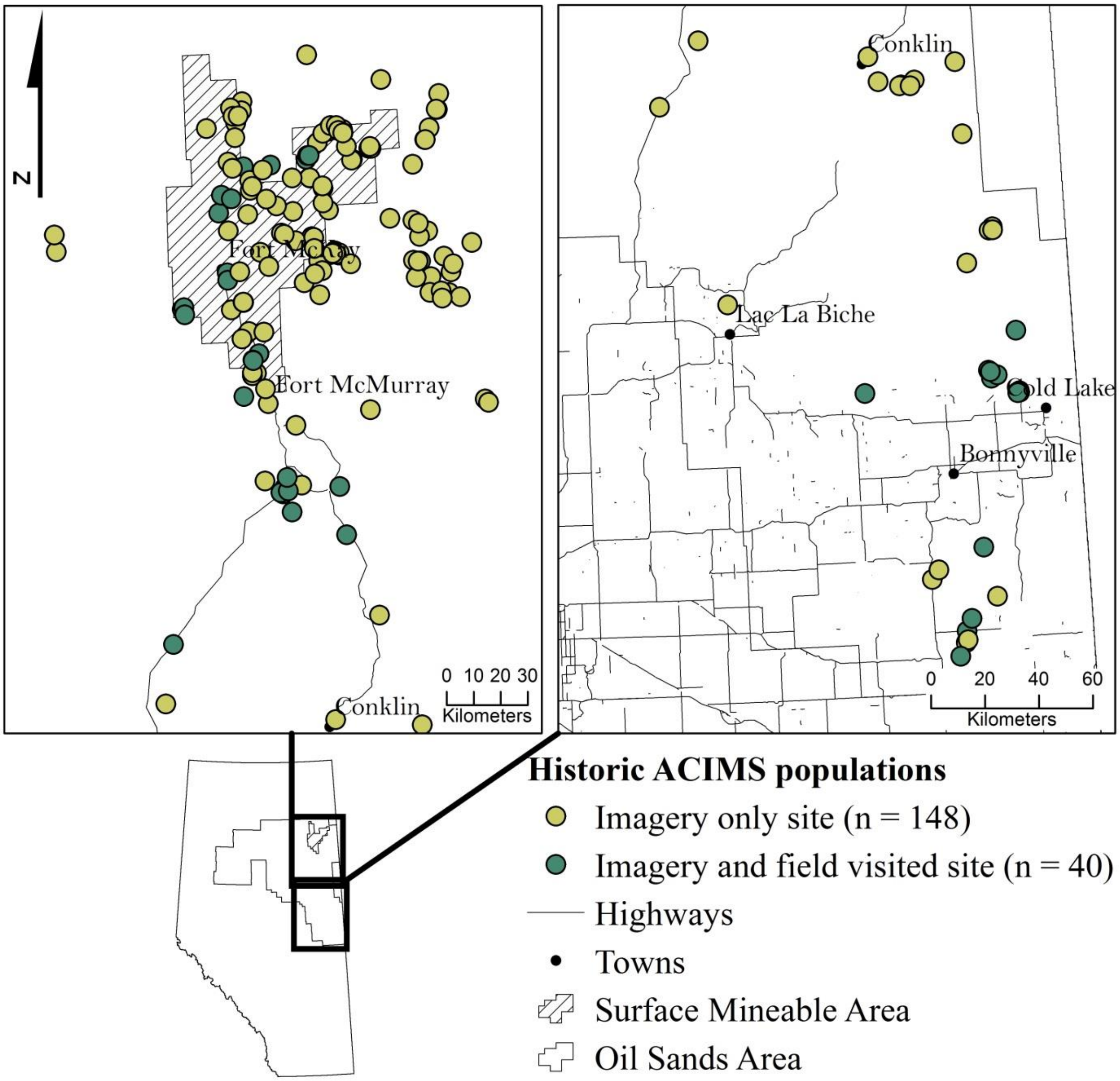

Figure 7.1. Study area and locations of rare plant populations in the oil sands and surface mineable areas (*n* = 188) considered in a revisitation project.

Assessing historic rare plant populations using remote sensing imagery

Locations of rare plant populations were obtained from the publicly available ACIMS database (ACIMS 2016). ACIMS tracks the conservation status of both individual vascular plant species and species communities and refers to these records as element occurrences. Here, we focused on element occurrences of single species (populations) that were contained within the oil sands area boundary, which amounted to 188 records of 47 unique species (Figure 7.1). ACIMS records are represented digitally in a GIS by polygons of varying size based on population extent and/or spatial accuracy of the original field observation. Median polygon size was 2,600 m^2, with populations falling both within and outside of oil sands leases. Publicly available provincial oil sands lease boundaries, current to 2013, were examined to determine whether records occurred within lease areas (Government of Alberta, 2016).

We used three metrics to evaluate the human footprint in proximity of historic rare plant populations. First, we determined the number of records for which footprint occurred within the original polygon boundaries, using the Alberta Biodiversity Monitoring Institute Human Footprint Mapping Layer (2012) (ABMI 2016) (footprint frequency). Second, we buffered the centroid of each record by radii of 100 m, 500 m, and 1 km and estimated the proportion of footprint in each buffer class using the ABMI layer (footprint proportion). We compared the proportion of footprint within these buffer classes using a Wilcoxon Rank Sum test. Finally, we exported ACIMS polygons to Google Earth and visually examined each record using the most current and clear imagery available (2008 - 2016) (DigitalGlobe 2016). Based on the visual extent of disturbance, we categorized records as having high, moderate, or low footprint (footprint severity). A high footprint was associated with polygons that were entirely disturbed by anthropogenic activities (e.g. Figure 7.2A and 7.2B). Moderate records were those with substantial amounts of disturbance, but also intact habitat remaining within the original polygon (e.g. Figure 7.2C). Records classified as having a low footprint were either undisturbed or had little disturbance within the original polygon. This could include minor vegetated (early seral) disturbances such as exploratory seismic lines, or small scale disturbances adjacent to the polygon (e.g. Figure 7.2D, 7.2E, and 7.2F).

Figure 7.2. Examples of footprint types associated with provincial records of rare vascular plant populations in the oil sands area of Alberta. **A)** Population likely lost to conventional surface mining, **B)** Population likely lost to commercial in-situ, **C)** Developing in-situ likely impacting population, **D)** Developing in-situ adjacent to population, **E)** Exploratory seismic development adjacent to population, **F)** Undisturbed population. All maps created from Google Earth version 7.1.7.2026, imagery from DigitalGlobe 2016.

Assessing status of historic rare plant populations in the field

We visited 40 ACIMS populations representing 19 species within the oil sands area between June and August of 2016 (Figure 7.1). Site locations and target species are provided in Appendix 7.1. Sites were stratified based on logistical constraints and chosen to encompass a range of habitat and disturbance types in both terrestrial and aquatic habitats. Two observers with survey experience were trained using specimens from the University of Alberta herbarium (ALTA) prior to conducting surveys. The observers visited each site during the expected flowering period to increase detectability (Moore *et al.* 2011). The centers of the original ACIMS polygons were used as the plot centers for all rare plant searches. At terrestrial sites (n = 32), surveyors searched a circular plot with a radius of 50 m around the record center (maximum search area of 7,850

m^2). For sites that had been cleared of forest cover and are maintained as disturbed ground (i.e. wellpad surface), the cleared area was given a precursory scan and the search radius was established around the edge of the feature, if possible (e.g. radius began from the vegetated edge of a wellpad). For aquatic open water sites (n = 8), a small inflatable boat was used for all surveys with one observer paddling in concentric rings inward from the wetland margin while the other observer searched for the species. To address concerns regarding detectability of cryptic and/or low abundance populations, both observers wore GPS data loggers during surveys to track search paths and recorded the total search time (effort) for all sites (see Appendix 7.2 for results and discussion of survey time analysis). Transect tapes and a handheld GPS were used to ensure that the search radius was adhered to and the total search area was covered. These protocols will be used in all 2017 surveys.

For each site surveyed we assigned a broad habitat type based on four categories. These included (1) aquatic (i.e. open water), (2) lowland (i.e. a singular fen), (3) upland (a general category consisting largely of mixedwood stands), and (4) anthropogenic-altered. Field sites included two wetland margin sites (beaver pond edge and river margin) and a single lowland fen connected to a large lake. These three sites were included in our aquatic habitat category as they were highly hydrologically regulated, resulting in three final habitats (aquatic, upland, and anthropogenic-altered). We classified a site as anthropogenic-altered where the soils had been modified by human activity such that they were no longer in a natural state (e.g. vegetated gravel berms surrounding wellpads). It should be noted that disturbance was present across all habitat types, with the anthropogenic-altered classification only assigned to those modified to the extent described.

Statistical analysis of field data

Persistence of rare plant populations across all sites was assessed using logistic regression, To assess the effect of oil sands footprint on persistence of rare plant populations surveyed in the field, we considered 3 different measures of disturbance: (1) minimum distance to nearest disturbance from the reported population boundary, (2) type of nearest disturbance, and (3) proportion of total mapped human footprint within 100 m, 500 m, and 1 km. All continuous variables were log transformed. We also considered record age, reported initial population size, and habitat type as explanatory variables. Given that detectability of rare plants cannot be assumed to be perfect (MacKenzie, Nichols & Lachman 2002; McCarthy *et al.* 2013), reported rates of persistence are likely underestimated, although we do not expect bias in detectability based on covariates tested here. All analyses were conducted in R (R Core Team 2015) using the package ‘lme4’ (Bates *et al.* 2015) with a series of candidate models compared using Akaike Information Criteria (AIC) (Burnham & Anderson 2002).

7.4 Results

Oil sands footprint in proximity to historic rare plant populations

Across the region, 38% and 48% of recorded populations occurred on oil and gas lease areas within the oil sands area (45 of 119) and surface mineable area (33 of 69 populations), respectively. In estimating footprint frequency, we expected to see a greater number of undisturbed populations outside of lease areas. Instead, we observed similar frequency between both on and off lease areas and between the oil sands and surface mineable areas (Table 7.1).

Table 7.1. Proportion of all ACIMS recorded rare vascular plant records (*n* = 188) within the surface mineable and oil sands areas in Alberta with human footprint within the originally reported polygon, reported by footprint type and whether the record occurred on or off an oil and gas lease area. More than one footprint type could occur within a given polygon.

	Oil sands area Number of populations (%)	**Surface mineable area Number of populations (%)**
Populations on lease	n = 45	n = 33
Mine Site	-	5 (15%)
Seismic	16 (36%)	6 (18%)
Pipeline/Transmission line	8 (18%)	3 (9%)
Wellpads	12 (27%)	7 (21%)
Forestry	1 (2%)	2 (6%)
Industrial infrastructure	5 (11%)	4 (12%)
Roads	2 (4%)	2 (6%)
Agriculture	-	-
None	25 (56%)	16 (48%)
Populations off lease	n = 74	n = 37
Mine Site	-	-
Seismic	23 (31%)	9 (24%)
Pipeline/Transmission line	10 (14%)	2 (5%)
Wellpads	12(16%)	8 (22%)
Forestry	4 (5%)	-
Industrial infrastructure	9 (12%)	2 (5%)
Roads	12 (16%)	1 (5%)
Agriculture	12 (16%)	-
None	38 (51%)	21 (57%)

Results of footprint proportion estimates indicate that, in both regions, ~ 65% of rare plant populations have disturbance within 100 m of the record centroid. This figure increases to ~ 90% at distances of 500 m and 1 km. Wilcoxon tests suggested a significantly higher proportion of footprint in proximity to records on lease when compared to off lease areas and no significant difference between the surface mineable and oil sands area at all buffer distances (Table 7.2).

Table 7.2. Results of Wilcoxon Rank Sum tests on the proportion of footprint across 3 buffer sizes compared for on and off lease areas and the surface mineable and oil sands areas (*n* = 188).

Buffer radius (m)	**On and off lease sites**	**Oil sands area and surface mineable area sites**

100	$p = 0.004$	$p = 0.706$
500	$p < 0.001$	$p = 0.421$
1000	$p < 0.001$	$p = 0.473$

Visually classified amounts of human footprint (footprint severity) for the 188 rare plant records across both regions included 36 populations (19%) with moderate or high footprints (Appendix 7.3). Seven populations (4%) were entirely dominated by footprint within the polygon and surrounding area (5 within the surface mineable area, 2 within the oil sands area; Figure 7.2A) suggesting the loss of those populations. Level of footprint affecting 9 populations (5%) could not be determined as the polygon area was so large as to encompass multiple land cover types and disturbances. Thus, visually, the majority of populations in the oil sands area had no, low, or indirect (adjacent) footprint (Figure 7.2E, 7.2F).

Field surveys of population persistence

Rare plant populations were relocated at 27 of 40 sites (68%). Three sites are suspected to have been misidentification of species in the original records based on similar species found at the site (see Appendix 7.4 for details). These records were removed from statistical analysis. Thus, the minimum estimated rate of persistence of rare plants in the study area was 73%. Of the 10 presumed extirpations, 4 populations were located within oil sands leases resulting in an on lease persistence of 67%, versus off lease persistence of 76% across the entire region (Table 7.3). Of the sites visited thus far, 17 were located within the surface mineable area and 12 of these are currently persisting (70%). Of the 20 surveyed sites within the oil sands area, 15 are persisting (65%).

Table 7.3. Number of rare plant records (populations) detected in the summer 2016 by location on or off oil sands leases (*n* = 37).

	Off lease	On lease	Total
Extirpated (0)	6	4	10
Persisting (1)	19	8	27
Total	25	12	37
% persisting	76%	67%	73%

The 19-species targeted in habitats ranging from open water wetlands to dry, sandy uplands, and the rate of persistence varied among these habitats. All populations persisted in aquatic-related habitats (open water wetlands, a single lowland, and two riparian margins, *n* = 11), 67% persisted in upland sites (*n* = 18), and finally 50% persisted in anthropogenic-altered sites (*n* = 8). Where species were persisting, we observed small population sizes (≤ 30 individuals) at 14 of the 27 sites (52%). Persistence by species and population size where encountered is reported in Table 7.4.

Table 7.4. Persistence across populations of 19 rare vascular plant species at 37 field sites within the oil sands area.

Species	S-Rank	No. records	% persisting	average pop^n where persisting	Pop^n range
Botrychium crenulatum	S3	1	0	n/a	n/a
Carex oligosperma	S3	1	100	1000	n/a
Carex vulpinoidea	S3	2	50	10	n/a
Cypripedium acaule	S3	7	71	37	4-150
Dryopteris cristata	S3	3	100	36	15-80
Gratiola neglecta	S3	2	50	3	n/a
Houstonia longifolia	S3	1	100	1	n/a
Isoetes echinospora	S2	2	100	17	5-30
Lactuca biennis	S3	4	50	1.5	1-2
Lathyrus palustris	S1	1	100	100	n/a
Liparis loeselii	S2	1	100	40	n/a
Najas flexilis	S3	1	100	100	n/a
Nymphaea leibergii	S2	4	100	62	50-100
Nymphaea tetragona	S2	1	100	75	n/a
Phegopteris connectilis	S3	1	100	75	n/a
Polygaloides paucifolia	S2	1	100	1000	n/a
Potentilla bimundorum	S2	1	0	n/a	n/a
Sceptridium oneidense	S1	2	50	20	n/a
Spiranthes lacera	S2	1	0	n/a	n/a

Statistical analysis of field survey data

Results of logistic regression with AIC model comparison suggest that population persistence is equally well-explained by and negatively related to increasing proximity to footprint and habitat type (ΔAIC < 2), but not related to record age, footprint type or proportion (Table 7.5). Model fit as evaluated by AIC was virtually identical across all buffer sizes (footprint proportion), hence, only the 100 m model is shown (Table 7.5). However, coefficient estimates (ß) and standard error values in the habitat model suggest weak fit (Table 7.6); thus, we consider distance to footprint to be the best candidate model. Footprint metrics and other explanatory variables were too highly correlated to be included within the same model, therefore all models contained a single variable. Reported initial population size was not available for all records and therefore could not be used in model comparison, however, examination of the data suggested no relationship with persistence.

Table 7.5. Ranking of candidate models comparing support for factors predicting the persistence of rare plant records in the oil sands region using field site data (*n* = 37). Both distance to closest disturbance and proportion of disturbed area within 100 m were log transformed.

Model	K	AIC	ΔAIC
Presence ~ distance to closest footprint	1	38.48	0
Presence ~ broad habitat class	1	40.05	1.57
Presence ~ proportion of footprint within 100 m	1	44.28	5.8

Presence ~ 1	1	45.18	6.7
Presence ~ record age	1	46.01	7.53
Presence ~ imagery based level of footprint	1	49.09	10.61
Presence ~ closest footprint type	1	53.02	14.54

Table 7.6. Model parameters for the two most-supported models based on AIC comparison (ΔAIC < 2, Table 7.5). Distance to disturbance reflects the minimum distance to the closest footprint type from the record polygon and was log transformed. Upland habitat was withheld as the reference category for habitat class.

Model and parameters	ß value	Std. error	p-value
Distance to footprint model			
Intercept	-0.056	0.502	0.911
Distance to disturbance	1.23	0.497	0.013
Habitat class model			
Intercept	0.693	0.5	0.166
Habitat: Aquatic		All sites persisting	
Habitat: Anthropogenic-altered	-0.693	0.866	0.423

7.5 Discussion

Our remote sensing imagery-based estimation of the frequency, proportion, and intensity of footprint around 188 rare vascular plant populations in the oil sands and surface mineable regions suggests that, while footprint is common in close proximity to records, it is most often of low intensity. Populations on lease areas have higher proportions of surrounding footprint than those off lease, and populations within the more heavily developed surface mineable region do not differ from those within the larger oil sands area. Field visits to a subset of these sites (n = 37) recorded a minimum persistence rate of 73%. Persistence was best explained by distance to nearest footprint, with populations further from disturbance being more likely to persist. Our results suggest that proximity is more indicative of persistence than footprint type or total amount. Although sites on oil and gas lease areas were suspected to be at greater risk of extirpation, we did not observe large discrepancies in persistence between on and off lease populations (67 and 76%, respectively). Model results suggested weak support for lower persistence on anthropogenic-altered sites when compared to intact upland sites and we observed persistence rates in these habitats of 50 and 67%, respectively. Together, results of imagery-based analysis suggesting close proximity of footprint to records and field visits suggesting a negative effect of proximity to disturbance indicate the need for future revisitation efforts.

We relocated species growing in environments where we had expected them to be extirpated (e.g. *Carex vulpinoidea* growing on gravel berms surrounding wellpads). It is important to note that populations persisting on sites with highly modified soils or those where local hydrology may be affected by past or future construction may not persist into the future. Population recruitment, health, and species longevity are beyond the scope of this project. Long-term monitoring would be required to fully understand the dynamics of extirpation of rare plant populations in the oil sands region. As far as we know, this is the first attempt at a dedicated reinventory of ACIMS records within the oil sands region. Field visits in 2017 will be highly valuable for the continued updating of the ACIMS provincial dataset and understanding the influence of large- and small-scale footprint on rare vascular plant populations.

Implications for management

Human disturbance poses a threat to vascular plant species due to the potential alteration or destruction of habitat. We advocate for the development of revisitation standards for assessing the status of rare plant populations within oil and gas leases. In the case of surveying for small populations in the field, search efforts need to be intensive enough to ensure adequate species detection; here, a maximum of 2 person hours were necessary to encounter a single individual plant. If our initial findings from these surveys are representative of the condition of rare plant populations across the region tracked by ACIMS, it is presumable that some ranks may be misapplied in the future if historical records are not verified prior to inclusion. Revisitation of populations suspected to be extirpated based on mapped proximity to human footprints should be prioritized, but we do not consider this alone to be a reliable proxy. As extirpation occurred even on sites with little disturbance, some degree of stochasticity is apparent. These findings indicate that rare plant populations located in altered habitats may not persist into the future, and emphasize the need for further study to assess this potential trend and its possible effects on conservation status of plants in the region.

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APPENDIX 1.1: Target rare vascular plant species list compiled from the EMCLA database for the Rarity and Diversity plot surveys in the Lower Athabasca Region.

Vascular species	Conservation Status Rank (2014)	Flowering time	Highest detectability	Previous collections by month (%)	Identified vegetatively	Habitat	
				July	Aug.		Site description
Carex houghtoniana	S3S4	June-July	June-July	17	42	dry	Fire beneficial; dry acidic sandy soils; often with pine
Carex supina			July	100		dry	Dry sandy gravelly habitats, eroding slopes
Carex umbellata	S2	April-July	July	89	0	Dry-mesic	sandy habitats in the boreal, especially disturbed areas, open woods particularly pine.
Potentilla multifida	S1	July	July	73	9	dry	sandy areas, often in slightly disturbed areas
Spiranthes lacera	S1	mid-July to August	mid-July to August	43	57	dry	dry woodlands and grasslands; often with *Vaccinium myrtilloides*
Stellaria arenicola	S1	July to August	Summer	0	22	dry	sandy areas only
Tanacetum bipinnatum huronense	S2	May-July	Summer			dry	gravely or sandy areas
Carex backii	S3	May-July	Early	38	25	both	dry (to moist) shady woods. Elsewhere in riparian woodland.

			Summer				Assoc. with disturbance-fire
Chrysosplenium tetrandrum	S3S4	May-July	May-July			both	rock crevices, wet conifer forests
Artemisia tilesii spp. elatior	S3	July-Sept; fruits late summer and fall	Summer	17	50	both	woodlands, river flats and alpine slopes
Cypripedium acaule	S3	Late June and July	June-July	23	16	both	Wetlands, woods, and overgrown sand dunes; deceptive orchid- poor pollination
Malaxis paludosa	S1	June-August		40	60	wet	wet bogs, in sphagnum moss
Cardamine pratensis	S3	May-June	Summer	11	0	wet	along creeks, in swamps; high water table
Carex capitata	S3	June-August	Summer	42	32	wet	wet areas, calcareous fens
Carex oligosperma	S3?	Late June and July	Summer	21	56	wet	wet meadows and bogs
Carex retrorsa	S3	May-September	Late spring to early fall	45	27	wet	swamps and wet meadows
Chrysosplenium iowense	S3?	May-July	May-July			wet	shady moist to wet stream banks and marshes in montane areas
Drosera linearis	S3	mid June to early July	Summer			wet	marl fens, either in shallow water or on soil hummocks
Eupatorium	S1S2	Late July to early	Summer			wet	wet to moist meadows and open

maculatum		September					woods
Hypericum majus	S2	Late June to September	Summer	75	5	wet	wet sites in the boreal forest
Juncus brevicaudatus	S2	July to August (fruits)	Summer	64	7	wet	very moist to wet substrate; lake shores and marshes
Sarracenia purpurea	S3	spring flower; pitcher in late spring/summer; fruits summer	Summer			wet	Bogs, fens, wet meadows
Carex heleonastes	S2	June - August		50	0	wet	Wet open calcareous sites on fens and marshes. Also in bogs, muskegs, lake shores, swamps, wet sandy roadsides, seeps
Panicum acuminatum	SU			0	13	wet	Moist sandy soils at woodland edges, marshy places, around hot springs
Lycopodiella inundata	S2					wet	Sphagnum bogs; elsewhere on sand shores and in marshes and other wet sites

APPENDIX 11.2: Location of Rarity and Diversity plots.

Table A1.2. Plot ID, location, and date of field surveys conducted in the Rarity and Diversity plots (n = 602) in the Lower Athabasca Region between 2012 and 2015. Plot identification codes with A2 or B2 indicate those surveyed twice by the same observer in different seasons of the same year (i.e. early and late summer visits) (n = 8).

Plot ID	Year	Field Date	Easting (UTM NAD83 Z12)	Northing (UTM NAD83 Z12)	Ecosite	Number of Surveys
009A	2013	7/28/2013	499329	6007464	RD	1
009B	2013	7/28/2013	499328	6007404	RD	1
1003A	2013	07/04/2013	467162	6368784	MX	2
1003B	2013	07/04/2013	467066	6368884	MX	1
1008A	2013	07/08/2013	465774	6366192	MM	1
1008B	2013	07/08/2013	465890	6367561	MM	1
1015A	2014	7/25/2014	465960	6368996	RD	1
1015B	2014	7/25/2014	466013	6368829	PM	1
101A	2012	8/27/2012	478082	6146446	MD	1
101B	2012	8/27/2012	478390	6146441	MD	1
102A	2013	08/10/2013	517010	6166402	PM	1
102B	2013	08/10/2013	516891	6166255	PM	1
1039A	2014	7/24/2014	470681	6369862	PX	1
1039B	2014	7/24/2014	470734	6369691	MX	1
1044A	2013	8/26/2013	489240	6387969	RD	1
1044B	2013	8/26/2013	489298	6387900	MD	1
1047A	2013	7/17/2013	476269	6378107	PX	1
1047B	2013	7/17/2013	476170	6378284	MX	1
1053A	2013	07/05/2013	471967	6374273	MX	1
1053B	2013	07/05/2013	471762	6374244	MX	2
1055A	2014	7/23/2014	474846	6375917	MX	1
1055B	2014	7/23/2014	474422	6375954	PX	1
1066A	2014	7/16/2014	484962	6376037	PX	1
1066B	2014	7/16/2014	484758	6376038	MX	1
107A	2012	8/20/2012	497475	6171839	MD	1
107B	2012	8/20/2012	497411	6171956	MG	1
1082A	2014	7/17/2014	483966	6384499	MX	1
1082B	2014	7/17/2014	484079	6384526	PX	1
1084A	2013	8/21/2013	485538	6385558	MX	1
1084B	2013	8/21/2013	485499	6385705	MX	1
1086A	2014	7/27/2014	480771	6377888	PX	1
1086B	2014	7/27/2014	480787	6377715	PX	1

1088A	2013	07/06/2013	475800	6374587	PM	1
1088B	2013	07/06/2013	475918	6374412	MG	1
1092A	2014	7/21/2014	488459	6378089	RD	2
1092B	2014	7/21/2014	488636	6377965	PX	2
1096A	2013	7/19/2013	489942	6377910	RD	1
1096B	2013	7/19/2013	490037	6377902	PX	1
110A	2012	7/28/2012	517499	6147299	MD	1
110B	2012	7/28/2012	517448	6147242	MD	1
111A	2012	7/20/2012	496620	6169215	RD	2
111B	2012	7/20/2012	496553	6169205	RD	2
1124A	2013	07/01/2013	530840	6271382	RD	1
1124B	2013	07/01/2013	530837	6271469	RD	1
1129A	2013	07/02/2013	533113	6266173	PM	1
1129B	2013	07/02/2013	533180	6266261	PM	1
1131A	2013	07/02/2013	485338	6230080	MD	1
1131B	2013	07/02/2013	485114	6229973	MD	1
1134A	2013	07/02/2013	483408	6228575	MD	1
1134B	2013	07/02/2013	483553	6228631	MD	1
1135A	2013	07/01/2013	484343	6227842	RD	1
1135B	2013	07/01/2013	484303	6227948	PD	1
1137A	2013	07/01/2013	478675	6226546	MD	1
1137B	2013	07/01/2013	478619	6226410	PM	1
1140A	2013	07/02/2013	485336	6234314	MD	1
1140B	2013	07/02/2013	485260	6234316	MD	1
1144A	2013	07/01/2013	479834	6224830	PM	1
1144B	2013	07/01/2013	480063	6224800	RD	1
1146A	2013	07/01/2013	487553	6225683	PM	1
1146B	2013	07/01/2013	487567	6225588	MD	1
1147A	2014	6/24/2014	437248	6076985	PM	1
1147B	2014	6/24/2014	437188	6077053	MM	1
1148A	2013	08/01/2013	436460	6076644	PD	1
1148B	2013	08/01/2013	436336	6076652	MG	1
1150A	2014	6/23/2014	435301	6092633	MD	1
1150B	2014	6/23/2014	435390	6092704	PX	1
1151A	2014	6/23/2014	433975	6094435	PX	1
1151B	2014	6/23/2014	433762	6094487	MD	1
1152A	2013	7/28/2013	437886	6097362	RG	1
1152B	2013	7/28/2013	437691	6097038	PX	1
1153A	2013	7/29/2013	465116	6078865	RD	1
1153B	2013	7/29/2013	465164	6078764	MX	1
1155A	2014	6/23/2014	471312	6078812	MM	1

1155B	2014	6/23/2014	471440	6079010	RG	1
1156A	2014	6/24/2014	435409	6092671	MD	1
1156B	2014	6/24/2014	466605	6055991	MM	1
1157A	2013	7/27/2013	466283	6055162	RD	1
1157B	2013	7/27/2013	466515	6055197	RD	1
1159A	2014	6/24/2014	461188	6079512	RD	1
1159B	2014	6/24/2014	461238	6079362	MD	1
115A	2013	8/14/2013	494033	6178128	MD	1
115B	2013	8/14/2013	494080	6178325	MD	1
1161A	2013	7/31/2013	400348	6057224	PX	1
1161B	2013	7/31/2013	400319	6057335	PM	1
1163A	2013	7/30/2013	410638	6078985	MD	1
1163B	2013	7/30/2013	410706	6079183	MG	1
1165A	2013	08/12/2013	500931	6055769	RG	1
1165B	2013	08/12/2013	500902	6055842	MM	1
125A	2012	7/23/2012	474061	6161372	PM	1
125B	2012	7/23/2012	474004	6161310	PM	1
128A	2012	7/18/2012	523700	6186803	RD	1
128B	2012	7/18/2012	523643	6186747	RD	1
135A	2012	8/25/2012	513991	6137505	PM	1
135B	2012	8/25/2012	513901	6137585	PD	1
137A	2012	8/28/2012	517120	6133407	RD	2
137B	2012	8/28/2012	517216	6133428	PM	2
139A	2012	7/17/2012	480153	6199387	PM	1
139B	2012	7/17/2012	480144	6199333	PM	1
13A	2012	07/11/2012	516484	6066379	RD	1
13B	2012	07/11/2012	516537	6066333	MD	1
142A	2012	7/17/2012	480548	6195570	MM	1
142B	2012	7/17/2012	494789	6157699	PM	1
143A	2012	7/24/2012	494729	6157662	MM	1
143B	2012	7/24/2012	494739	6157699	MM	1
149A	2012	8/26/2012	487630	6135578	MG	1
149B	2012	8/26/2012	487662	6135672	RG	1
157A	2012	8/19/2012	526155	6188228	MM	2
157B	2012	8/19/2012	526262	6188180	MM	2
159A	2013	8/13/2013	541708	6194580	MG	1
159B	2013	8/13/2013	541916	6194406	RD	1
15A	2012	08/08/2012	535551	6052395	RD	2
15B	2012	08/08/2012	535305	6052649	MM	2
160A	2012	7/19/2012	510167	6185996	PD	1
160B	2012	7/19/2012	510108	6185943	PD	1

161A	2012	7/19/2012	492500	6168816	PM	1
161B	2012	7/19/2012	492533	6168875	PD	1
166A	2012	7/27/2012	492861	6146498	PM	2
166B	2012	7/27/2012	492808	6146450	PM	2
169A	2013	7/16/2013	482928	6246622	MD	1
169B	2013	7/16/2013	482922	6246708	PM	1
171A	2013	8/26/2013	443299	6316878	RD	1
171B	2013	8/26/2013	443245	6316744	MM	1
172A	2012	8/26/2012	473151	6234411	MD	1
172B	2012	8/26/2012	473085	6234368	PM	1
173A	2012	7/18/2012	472628	6236329	MD	1
173B	2012	7/18/2012	472708	6236232	PM	1
185A	2012	8/18/2012	511919	6243793	PD	2
185B	2012	8/18/2012	511767	6244044	PD	2
186A	2012	7/17/2012	506728	6232584	RD	1
186B	2012	7/17/2012	506965	6232634	PM	1
187A	2012	8/16/2012	508157	6238884	RD	1
187B	2012	8/16/2012	508049	6239086	MM	1
189A	2012	7/18/2012	472226	6236148	RD	1
189B	2012	7/18/2012	472301	6236223	MM	1
195A	2014	7/29/2014	483494	6246278	MD	1
195B	2014	7/29/2014	483299	6246298	RD	1
197A	2012	8/17/2012	475000	6234922	RD	1
197B	2012	8/17/2012	474786	6234858	PD	1
198A	2012	8/17/2012	474801	6235384	RD	1
198B	2012	8/17/2012	474902	6235236	PM	1
19A	2012	08/07/2012	525301	6060732	RD	1
19B	2012	08/07/2012	525335	6060549	MM	1
1A	2012	07/09/2012	530293	6055967	RD	1
1B	2012	07/09/2012	530228	6056015	MM	1
2004A	2014	8/13/2014	504656	6434503	PX	1
2004B	2014	8/13/2014	504781	6434453	PX	1
2016A	2014	8/13/2014	504467	6434687	PX	1
2016B	2014	8/13/2014	504390	6434604	PX	1
201A	2012	8/25/2012	522215	6228950	RD	1
201B	2012	8/25/2012	522075	6229013	PM	1
202A	2012	7/21/2012	456687	6229125	MM	1
202B	2012	7/21/2012	456702	6229177	PM	1
2043A	2014	8/15/2014	497267	6427858	MD	1
2043B	2014	8/15/2014	497209	6427674	MD	1
2059A	2014	8/16/2014	497028	6427015	PX	1

2059B	2014	8/16/2014	497064	6427178	PX	1
2065A	2014	8/14/2014	503394	6434109	RD	1
2065B	2014	8/14/2014	503409	6434182	PX	1
2071A	2014	07/06/2014	425260	6180218	MG	1
2071B	2014	07/06/2014	425610	6180157	RD	1
2082A	2014	07/03/2014	468698	6184648	MX	1
2082B	2014	07/03/2014	496855	6184654	MD	1
2086A	2014	07/04/2014	471718	6183363	PM	1
2086B	2014	07/04/2014	471430	6183508	RD	1
2087A	2014	07/05/2014	469997	6183061	RD	1
2087B	2014	07/05/2014	469857	6183108	PX	1
2101A	2014	7/31/2014	498792	6240945	PM	1
2101B	2014	7/31/2014	498814	6240828	NT	1
2107A	2014	07/08/2014	510994	6160516	PM	1
2107B	2014	07/08/2014	510863	6160212	MD	1
2113A	2014	08/12/2014	494396	6164031	MG	1
2113B	2014	08/12/2014	494510	6164123	RD	1
211A	2012	7/16/2012	497001	6250544	PD	1
211B	2012	7/16/2012	497048	6250389	PM	1
2120A	2014	07/01/2014	551887	6054912	RD	1
2120A2	2014	8/15/2014	551887	6054912	RD	1
2120B	2014	07/01/2014	551890	6055019	MX	1
2120B2	2014	8/15/2014	551890	6055019	MX	1
2121A	2014	07/04/2014	552391	6057531	MM	1
2121B	2014	07/04/2014	552548	6057563	MM	1
2127A	2014	7/30/2014	519027	6063713	MD	1
2127B	2014	7/30/2014	519283	6063397	RD	1
213A	2012	8/26/2012	460384	6235690	MD	1
213B	2012	8/26/2012	460296	6235590	MD	1
2147A	2014	07/07/2014	508298	6158580	PD	1
2147B	2014	07/07/2014	507827	6158639	RD	1
2148A	2014	8/14/2014	505608	6156189	PM	1
2148B	2014	8/14/2014	505762	6156104	NT	1
2151A	2014	8/15/2014	505135	6154756	RD	1
2151B	2014	8/15/2014	505136	6154939	MG	1
2152A	2014	8/16/2014	507430	6153024	PM	1
2152B	2014	8/16/2014	507703	6152966	PM	1
2153A	2014	8/17/2014	504733	6156194	RD	1
2153B	2014	8/17/2014	504667	6156106	PM	1
2154A	2014	8/18/2014	506065	6155253	RD	1
2154B	2014	8/18/2014	506026	6155341	MD	1

2156A	2014	08/01/2014	503782	6240818	MD	3
2156B	2014	08/01/2014	503763	6240580	MM	2
2157A	2014	08/04/2014	504167	6240555	PD	3
2157B	2014	08/04/2014	504119	6240442	NT	3
216A	2012	8/29/2012	485526	6263381	MD	2
216B	2012	8/29/2012	485596	6263266	SD	2
219A	2012	8/19/2012	487060	6264744	RD	1
219B	2012	8/19/2012	486932	6264796	MD	1
224A	2012	7/20/2012	443451	6314794	RD	1
224B	2012	7/20/2012	443596	6314828	MM	1
229A	2014	08/05/2014	507207	6245631	PM	1
229B	2014	08/05/2014	507098	6245879	MG	2
230A	2012	8/27/2012	454441	6296590	PM	1
230B	2012	8/27/2012	454500	6296735	MD	1
233A	2012	7/22/2012	474352	6294859	MM	2
233B	2012	7/22/2012	474273	6294901	MG	2
237A	2014	08/02/2014	506381	6240768	MM	3
237B	2014	08/02/2014	506297	6240603	MM	2
241A	2012	8/15/2012	513713	6243139	MM	1
241B	2012	8/15/2012	513873	6243351	MM	1
243A	2012	8/14/2012	506897	6229019	MM	1
243B	2012	8/14/2012	506734	6228975	RG	1
245A	2012	7/16/2012	517158	6227666	MM	1
245B	2012	7/16/2012	517156	6227589	MM	1
246A	2013	08/11/2013	513741	6236162	MM	1
246B	2013	08/11/2013	513647	6235847	RG	1
248A	2012	7/20/2012	443282	6317368	MG	1
248B	2012	7/20/2012	443239	6317419	MG	1
250A	2012	7/21/2012	466129	6234871	PM	1
250B	2012	7/21/2012	466175	6234964	MG	1
251A	2014	7/19/2014	510216	6229121	PM	1
251B	2014	7/19/2014	510262	6228998	MD	1
252A	2012	8/14/2012	506347	6229574	PM	1
252B	2012	8/14/2012	506215	6229468	RD	1
256A	2012	7/19/2012	446404	6313845	PM	2
256B	2012	7/19/2012	446359	6313804	MM	2
257A	2012	8/28/2012	509875	6217116	PM	1
257B	2012	8/28/2012	509790	6217002	PM	1
265A	2012	07/08/2012	462900	6365090	RD	2
265B	2012	07/08/2012	462834	6365096	RD	2
266A	2012	8/16/2012	482022	6375262	MD	1

266B	2012	8/16/2012	481906	6375255	MD	1
271A	2013	7/18/2013	488733	6374924	RD	1
271B	2013	7/18/2013	488957	6375069	PX	1
272A	2014	7/19/2014	488490	6374828	MD	2
272B	2014	7/19/2014	488203	6374832	MM	2
276A	2012	8/16/2012	481949	6375479	MD	1
276B	2012	8/16/2012	481771	6375443	MD	1
286A	2012	8/17/2012	489376	6375986	SD	1
286B	2012	8/17/2012	489445	6376133	PX	1
296A	2013	07/07/2013	479269	6374601	RD	1
297A	2013	07/07/2013	479212	6374618	MD	1
298A	2012	07/10/2012	463038	6365278	RD	1
298B	2012	07/10/2012	463042	6365213	RD	1
2A	2012	08/07/2012	539411	6055510	RG	1
2B	2012	08/07/2012	539528	6055298	PM	1
3003A	2015	7/29/2015	502277	6229554	MG	2
3003B	2015	7/29/2015	502221	6229464	PM	2
3018A	2015	7/16/2015	413382	6176905	PD	1
3018B	2015	7/16/2015	413395	6177261	PM	1
3021A	2015	7/28/2015	501526	6233592	RD	1
3021B	2015	7/28/2015	501563	6233831	MX	1
3023A	2015	7/14/2015	506161	6232739	SD	1
3023B	2015	7/14/2015	506170	6232830	SD	1
3024A	2015	08/11/2015	479603	6259951	RD	2
3024B	2015	08/11/2015	479521	6260220	PD	2
3029A	2015	7/13/2015	430987	6186275	SD	1
3029B	2015	7/13/2015	430992	6186200	PM	1
3033A	2015	7/31/2015	457690	6241720	PD	1
3033B	2015	7/31/2015	457581	6241799	MM	1
3036A	2015	7/31/2015	457927	6241352	MD	1
3036B	2015	7/31/2015	457788	6241306	MD	1
3045A	2015	08/12/2015	411388	6175440	PD	1
3045B	2015	08/12/2015	411296	6175474	PD	1
3048A	2015	07/12/2015	501117	6234741	PD	1
3048B	2015	07/12/2015	501026	6234764	PD	1
3049A	2015	08/10/2015	483674	6257939	RD	1
3049B	2015	08/10/2015	483364	6257772	RG	1
3052A	2015	8/14/2015	475128	6275614	MD	1
3052B	2015	8/14/2015	475089	6275738	RD	1
3055A	2015	8/13/2015	421247	6179504	RG	1
3055B	2015	8/13/2015	421297	6179457	RG	1

3057A	2015	7/13/2015	430133	6186282	MM	1
3057B	2015	7/13/2015	430068	6186302	PM	1
3063A	2015	08/01/2015	416132	6157325	PD	1
3063B	2015	08/01/2015	415879	6157245	RD	1
3064A	2015	07/11/2015	418617	6155022	MG	1
3064B	2015	07/11/2015	418672	6154887	MG	1
3067A	2015	7/30/2015	483852	6375005	PX	1
3067B	2015	7/30/2015	483986	6375022	PX	1
3068A	2015	7/15/2015	479886	6381282	PX	1
3068B	2015	7/15/2015	479800	6381331	PX	1
3069A	2015	7/15/2015	483482	6378952	PX	1
3069B	2015	7/15/2015	483453	6379061	PX	1
306A	2013	7/16/2013	481350	6375910	MD	1
306B	2013	7/16/2013	481478	6375897	PM	1
3070A	2015	07/03/2015	474364	6083953	MD	1
3070B	2015	07/03/2015	474491	6084026	PM	1
3075A	2015	6/29/2015	455154	6069012	MG	1
3075B	2015	6/29/2015	455071	6069087	MX	1
3082A	2015	6/28/2015	449753	6074229	NT	1
3082B	2015	6/28/2015	449741	6074137	MG	1
3083A	2015	07/01/2015	487573	6046083	SD	2
3083B	2015	07/01/2015	487646	6046154	MG	2
3084A	2015	6/23/2015	437478	6094199	SD	2
3084B	2015	6/23/2015	437377	6094208	RG	2
3085A	2015	07/02/2015	440240	6095088	RD	1
3085B	2015	07/02/2015	440397	6095044	PX	1
3087A	2015	7/17/2015	430885	6100090	RD	1
3087B	2015	7/17/2015	430792	6100255	PD	1
3093A	2015	8/18/2015	459701	6058276	RD	1
3093B	2015	8/18/2015	459775	6088418	PM	1
3094A	2015	7/26/2015	479335	6046373	RD	1
3094B	2015	7/26/2015	479528	6046494	PD	1
3095A	2015	7/25/2015	482055	6053120	RD	1
3095B	2015	7/25/2015	482223	6053174	PM	1
3097A	2015	7/18/2015	435739	6096285	MD	1
3097B	2015	7/18/2015	435877	6096367	PX	1
309A	2012	07/11/2012	466347	6368776	MM	1
309B	2012	07/11/2012	466282	6368776	PM	1
3100A	2015	07/10/2015	463268	6056297	RD	2
3100B	2015	07/10/2015	463236	6056157	MM	2
3101A	2015	8/15/2015	483345	6053247	RD	1

3101B	2015	8/15/2015	483321	6053319	RD	1
3103A	2015	6/30/2015	481034	6044033	RD	1
3103B	2015	6/30/2015	481333	6044139	MM	1
3107A	2015	6/24/2015	436480	6106757	PX	1
3107B	2015	6/24/2015	436348	6106739	MM	1
3108A	2015	8/19/2015	452814	6078085	MD	1
3108B	2015	8/19/2015	452930	6078133	RD	1
3110A	2015	6/25/2015	483435	6047353	SD	1
3110B	2015	6/25/2015	483502	6047387	PM	1
3115A	2015	7/26/2015	479637	6046028	PD	1
3115B	2015	7/26/2015	479943	6045935	MM	1
3116A	2015	7/24/2015	483966	6043190	RD	1
3116B	2015	7/24/2015	484155	6043214	PM	1
3118A	2015	8/16/2015	468795	6081408	RD	1
3118B	2015	8/16/2015	468758	6081537	RD	1
3125A	2015	8/16/2015	468485	6081140	PM	1
3125B	2015	8/16/2015	468591	6080960	MM	1
3131A	2015	7/27/2015	476760	6085927	MM	1
3131B	2015	7/27/2015	476910	6086105	MM	1
3140A	2015	8/17/2015	460339	6056394	RG	1
3140B	2015	8/17/2015	460420	6056440	RG	1
3146A	2015	7/19/2015	436361	6105536	PX	1
3146B	2015	7/19/2015	436497	6105413	MM	1
3148A	2015	7/18/2015	435704	6096524	PX	1
3148B	2015	7/18/2015	435695	6096401	PD	1
3149A	2015	07/02/2015	439544	6095188	PX	1
3149B	2015	07/02/2015	439561	6094970	MD	1
314A	2012	07/07/2012	474607	6379084	MM	1
314B	2012	07/07/2012	474584	6378981	PM	1
317A	2012	07/12/2012	464592	6365728	MM	1
317B	2012	07/12/2012	464658	6365753	MX	1
318A	2012	8/15/2012	478640	6374525	MM	1
318B	2012	8/15/2012	478510	6374512	MX	1
319A	2013	8/23/2013	486782	6377930	MM	1
319B	2013	8/23/2013	486860	6377874	PX	1
320A	2012	07/11/2012	466267	6369726	MM	1
320B	2012	07/11/2012	466282	6368776	MX	1
321A	2012	07/09/2012	463736	6364255	MM	2
321B	2012	07/09/2012	463674	6364193	MM	2
337A	2014	7/18/2014	481353	6382081	PX	1
337B	2014	7/18/2014	481275	6381847	PX	1

339A	2012	07/07/2012	475581	6379789	MX	1
339B	2012	07/07/2012	475565	6379717	MX	1
340A	2013	7/29/2013	491511	6042941	VD	1
340B	2013	7/29/2013	491664	6042994	MM	1
341A	2014	07/02/2014	527062	6043839	RD	2
341A2	2014	8/16/2014	527062	6043839	RD	1
341B	2014	07/02/2014	527207	6043884	PM	2
341B2	2014	8/16/2014	527207	6043884	PM	1
344A	2013	8/13/2013	526965	6012307	RD	1
344B	2013	8/13/2013	526892	6012352	VD	1
349A	2014	08/04/2014	514735	6058654	MX	1
349B	2014	08/04/2014	480813	6035799	MD	1
34A	2012	08/05/2012	529376	6045299	RG	1
34B	2012	08/05/2012	529422	6045436	MG	1
356A	2014	07/06/2014	558481	6022050	RD	1
356A2	2014	8/14/2014	558481	6022050	RD	1
356B	2014	07/06/2014	558369	6022214	RD	1
356B2	2014	8/14/2014	558369	6022214	RD	1
35A	2012	07/08/2012	558558	6066315	PD	1
35B	2012	07/08/2012	558555	6066268	PD	1
369A	2013	08/11/2013	552534	6051431	MM	1
369B	2013	08/11/2013	552568	6051275	MM	1
384A	2013	8/25/2013	496193	6422499	PD	1
384B	2013	8/25/2013	496340	6422430	PX	1
38A	2012	07/08/2012	558231	6062818	MD	1
38B	2012	07/08/2012	558350	6062757	PM	1
390A	2014	08/01/2014	521777	6061215	MD	1
390B	2014	08/01/2014	521751	6061057	PD	1
396A	2013	8/24/2013	504665	6434947	MD	1
396B	2013	8/24/2013	504606	6435045	PX	1
397A	2013	08/10/2013	505875	6016090	RD	1
397B	2013	08/10/2013	505964	6016003	PX	1
398A	2013	6/24/2013	485365	6045318	RD	1
398B	2013	6/24/2013	485466	6045310	MX	1
405A	2014	08/02/2014	517734	6058910	RD	1
405B	2014	08/02/2014	517626	6058955	PM	1
407A	2013	7/26/2013	485675	6034810	MD	1
407B	2013	7/26/2013	485500	6034915	RG	1
417A	2014	07/03/2014	538290	6033310	RD	1
417B	2014	07/03/2014	538370	6033582	NT	1
419A	2013	6/23/2013	483950	6046285	RD	1

419B	2013	6/23/2013	483857	6046365	PM	1
424A	2013	08/08/2013	481132	6032615	RD	1
424B	2013	08/08/2013	481198	6032684	PM	1
425A	2014	7/31/2014	520884	6058238	RD	1
425B	2014	7/31/2014	520816	6058096	MM	1
428A	2013	6/24/2013	533612	6041836	RD	1
428B	2013	6/24/2013	533674	6041846	RD	1
435A	2013	6/23/2013	535010	6041959	MD	1
435B	2013	6/23/2013	534951	6041909	PM	1
436A	2014	07/05/2014	542425	6041905	RD	1
436A2	2014	8/17/2014	542425	6041905	RD	1
436B	2014	07/05/2014	542444	6041689	RD	1
436B2	2014	8/17/2014	542444	6041689	RD	1
439A	2014	7/29/2014	518684	6061417	PM	1
439B	2014	7/29/2014	518641	6061766	NT	1
445A	2013	6/22/2013	532798	6031616	PM	1
445B	2013	6/22/2013	532946	6031569	MM	1
446A	2014	07/07/2014	524987	6041276	MX	2
446B	2014	07/07/2014	524879	6041126	PX	2
459A	2013	7/30/2013	485718	6035409	PM	1
459B	2013	7/30/2013	485842	6035484	MD	1
45A	2012	07/09/2012	529884	6061935	RD	1
45B	2012	07/09/2012	529804	6061889	MX	1
46A	2012	08/05/2012	500591	6020887	MD	1
46B	2012	08/05/2012	500569	6021051	MM	1
478A	2014	07/08/2014	554908	6055356	MX	1
478B	2014	07/08/2014	555016	6055425	RG	1
485A	2013	7/27/2013	560623	6027606	RG	1
485B	2013	7/27/2013	560472	6027741	RG	1
486A	2013	08/09/2013	526678	6039391	MM	1
486B	2013	08/09/2013	526643	6039468	MM	1
502A	2014	8/18/2014	483451	6047745	PD	1
502B	2014	8/18/2014	483676	6047652	MM	1
520A	2013	7/29/2013	488312	6034453	MX	1
520B	2013	7/29/2013	488403	6034651	MX	1
523A	2013	08/07/2013	494664	6050450	MX	1
523B	2013	08/07/2013	494710	6050535	MG	1
527A	2013	6/22/2013	484891	6045606	PM	2
527B	2013	6/22/2013	485117	6045751	RD	2
529A	2013	8/14/2013	484921	6043712	MX	1
529B	2013	8/14/2013	484878	6043787	MM	1

52A	2012	08/08/2012	526062	6053817	MM	1
52B	2012	08/08/2012	526196	6053785	RD	1
535A	2013	7/25/2013	507293	6145315	RD	1
535B	2013	7/25/2013	507239	6145194	RD	1
541A	2013	7/18/2013	507389	6170646	RD	1
541B	2013	7/18/2013	507394	6170574	PM	1
54A	2012	07/07/2012	558613	6056417	MM	2
54B	2012	07/07/2012	558626	6056336	MM	2
556A	2014	08/06/2014	494093	6168086	PM	1
556B	2014	08/06/2014	494259	6168304	PM	1
560A	2013	7/27/2013	487682	6171323	MD	1
560B	2013	7/27/2013	487595	6171201	RD	1
577A	2014	08/09/2014	482431	6170710	MD	1
577B	2014	08/09/2014	482513	6170815	RD	1
585A	2014	08/07/2014	451023	6135525	PX	1
585B	2014	08/07/2014	451175	6135567	MM	1
586A	2014	07/01/2014	495298	6167014	MD	1
586B	2014	07/01/2014	495356	6166815	PM	1
589A	2013	7/16/2013	494911	6165888	MD	1
589B	2013	7/16/2013	511191	6200456	PX	1
58A	2012	08/08/2012	523429	6052864	PD	1
58B	2012	08/08/2012	523523	6052683	RG	1
59A	2012	07/10/2012	510555	6062639	MM	1
59B	2012	07/10/2012	538009	6054776	MG	1
601A	2013	7/19/2013	507620	6207515	PM	1
601B	2013	7/19/2013	507547	6207510	MM	1
602A	2013	08/08/2013	538918	6193422	MD	1
602B	2013	08/08/2013	539138	6193335	RD	1
604A	2014	08/08/2014	502252	6155753	MD	2
604B	2014	08/08/2014	502162	6155922	MG	2
621A	2013	7/28/2013	511833	6188847	PD	1
621B	2013	7/28/2013	511915	6188921	PD	1
623A	2014	07/06/2014	509448	6159396	RD	1
623B	2014	07/06/2014	509570	6159338	RD	1
630A	2014	8/13/2014	504891	6155233	RD	1
630B	2014	8/13/2014	505000	6155268	PM	1
635A	2013	08/11/2013	477777	6205285	RD	1
635B	2013	08/11/2013	477910	6205426	RD	1
637A	2013	7/20/2013	497472	6175241	MD	1
637B	2013	7/20/2013	497373	6175269	PM	1
644A	2013	7/17/2013	516422	6145209	PM	1

644B	2013	7/17/2013	516508	6145203	MD	1
64A	2012	08/06/2012	505039	6026787	MM	2
64B	2012	08/06/2012	505006	6026532	MG	2
668A	2013	7/29/2013	493304	6151522	PD	1
668B	2013	7/29/2013	493297	6151410	MD	1
669A	2013	08/09/2013	537291	6191223	RG	1
669B	2013	08/09/2013	537395	6190974	RD	1
682A	2013	08/12/2013	494518	6169756	MM	1
682B	2013	08/12/2013	494560	6169648	RD	1
691A	2014	07/02/2014	476601	6168202	MM	1
691B	2014	07/02/2014	476893	6168218	MX	1
693A	2013	7/26/2013	514916	6185362	MM	1
693B	2013	7/26/2013	515006	6185387	MM	1
698A	2013	7/15/2013	511189	6200460	MM	2
698B	2013	7/15/2013	511265	6200465	PM	2
703A	2013	08/07/2013	494303	6161745	PM	1
703B	2013	08/07/2013	494434	6161554	RG	1
704A	2013	7/24/2013	512864	6149105	MG	1
704B	2013	7/24/2013	512772	6149199	MD	1
70A	2012	08/06/2012	492563	6048028	PX	1
70B	2012	08/06/2012	492744	6048091	RD	1
717A	2013	7/21/2013	487771	6168018	PX	1
717B	2013	7/21/2013	487709	6168082	PX	1
72A	2012	08/06/2012	492965	6048442	PM	1
72B	2012	08/06/2012	492826	6048470	MD	1
73A	2012	07/06/2012	484676	6042796	PX	1
73B	2012	07/06/2012	484687	6042879	PM	1
741A	2014	7/21/2014	454457	6220612	MD	1
741B	2014	7/21/2014	454406	6220452	PM	1
744A	2013	6/23/2013	459897	6233238	RD	1
744B	2013	6/23/2013	459860	6233321	PX	1
751A	2014	7/30/2014	479440	6273392	MM	2
751B	2014	7/30/2014	479427	6273318	RD	1
753A	2014	7/20/2014	449744	6221035	MG	1
753B	2014	7/20/2014	449849	6221012	NT	1
761A	2013	08/09/2013	497791	6254744	RD	1
761B	2013	08/09/2013	497542	6254537	PM	1
767A	2013	7/19/2013	483804	6246040	MD	1
767B	2013	7/19/2013	483843	6245990	PM	1
77A	2012	07/12/2012	483509	6050881	PX	2
77B	2012	07/12/2012	483405	6050931	MM	2

785A	2014	7/22/2014	451011	6222967	PM	1
785B	2014	7/22/2014	450897	6222925	MD	1
787A	2014	07/04/2014	487821	6256174	MM	1
787B	2014	07/04/2014	487757	6256182	RD	1
789A	2013	07/04/2013	470215	6234873	MD	1
789B	2013	07/04/2013	470287	6234875	MM	1
790A	2014	07/02/2014	487080	6254179	RD	1
790B	2014	07/02/2014	487146	6254256	MM	1
794A	2013	08/12/2013	519422	6236929	MD	1
794B	2013	08/12/2013	519383	6236838	RD	1
798A	2014	08/03/2014	502265	6242334	MD	1
798B	2014	08/03/2014	502052	6242329	RD	1
804A	2014	7/18/2014	508668	6230970	MD	1
804B	2014	7/18/2014	508471	6230716	MD	1
80A	2012	7/25/2012	482062	6132135	RD	1
80B	2012	7/25/2012	482118	6132163	RD	1
816A	2013	07/07/2013	463769	6248580	PD	1
816B	2013	07/07/2013	463687	6248564	PD	1
817A	2013	7/20/2013	482260	6248270	MD	1
817B	2013	7/20/2013	482169	6248391	RD	1
825A	2013	7/17/2013	444433	6314228	RD	1
825B	2013	7/17/2013	444491	6314286	RG	1
835A	2013	08/08/2013	511481	6226073	MG	1
835B	2013	08/08/2013	511437	6225983	PM	1
837A	2013	6/24/2013	511835	6227797	RD	1
837B	2013	6/24/2013	511760	6227741	PM	1
848A	2014	07/05/2014	453640	6292723	PM	1
848B	2014	07/05/2014	453734	6292790	RD	1
850A	2013	7/15/2013	473933	6252874	RG	1
850B	2013	7/15/2013	473871	6252846	MM	1
853A	2013	8/25/2013	519433	6228178	PM	1
853B	2013	8/25/2013	519427	6228006	PM	1
854A	2013	8/14/2013	499321	6254238	MM	1
854B	2013	8/14/2013	499393	6254019	PM	1
85A	2012	7/16/2012	541326	6193050	RD	1
85B	2012	7/16/2012	541317	6193117	MD	1
861A	2013	07/05/2013	453332	6294549	MM	1
861B	2013	07/05/2013	453344	6294647	PM	1
868A	2013	8/22/2013	458874	6290016	PM	1
868B	2013	8/22/2013	458757	6289884	MD	1
870A	2013	Not	466158	6236588	MM	1

		Collected				
870B	2013	Not Collected	466127	6236611	RD	1
872A	2013	7/18/2013	469572	6234546	PM	1
872B	2013	7/18/2013	469557	6234670	PM	1
879A	2013	07/03/2013	497894	6255934	MM	1
879B	2013	07/03/2013	467460	6289555	MM	1
87A	2012	7/29/2012	518607	6182546	PD	1
87B	2012	7/29/2012	518751	6182552	PD	1
886A	2013	8/21/2013	507230	6240612	MM	1
886B	2013	8/21/2013	507254	6240516	MM	1
892A	2013	08/07/2013	465162	6246255	MM	1
892B	2013	08/07/2013	465238	6246144	PD	1
894A	2013	8/23/2013	503605	6219771	MM	1
894B	2013	8/23/2013	503511	6219842	MG	1
897A	2014	7/16/2014	469229	6288835	MM	1
897B	2014	7/16/2014	469371	6288714	RG	1
90A	2012	7/22/2012	462056	6146124	RD	1
90B	2012	7/22/2012	462058	6146057	RD	1
910A	2013	07/06/2013	447626	6313377	RD	1
910B	2013	07/06/2013	447477	6313448	MD	1
920A	2014	07/03/2014	461194	6234424	MX	1
920B	2014	07/03/2014	461170	6234345	MM	1
921A	2014	7/17/2014	509298	6230884	MX	1
921B	2014	7/17/2014	509337	6230780	RD	1
922A	2013	6/22/2013	478333	6253483	PM	2
922B	2013	6/22/2013	478347	6253021	MG	2
926A	2013	8/24/2013	466766	6245786	MD	1
926B	2013	8/24/2013	466660	6245723	PM	1
928A	2014	7/15/2014	475260	6253912	MD	2
928B	2014	7/15/2014	475414	6253553	MM	2
929A	2013	08/10/2013	486072	6247931	PM	1
929B	2013	08/10/2013	485984	6248090	RG	1
934A	2013	8/22/2013	487749	6389435	RD	1
934B	2013	8/22/2013	487828	6389468	MD	1
936A	2014	7/26/2014	488638	6388234	MX	1
936B	2014	7/26/2014	488617	6388071	PD	1
947A	2013	7/15/2013	468145	6365682	RD	1
947B	2013	7/15/2013	467955	6365592	MX	1
962A	2014	7/22/2014	488283	6376151	RD	1
962B	2014	7/22/2014	488103	6376256	MM	1

965A	2013	7/16/2013	481421	6376133	MD	1
965B	2013	7/16/2013	481662	6376168	RD	1
975A	2014	7/20/2014	490080	6390702	PX	1
975B	2014	7/20/2014	490113	6390527	MM	2
978A	2013	7/20/2013	489063	6374470	RD	1
978B	2013	7/20/2013	489206	6374510	PX	1

APPENDIX 1.3: Complete list of vascular plant species detected at the Rarity and Diversity plots in the Lower Athabasca Region between 2012 and 2015.

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Abies balsamea	S5	S5	64	8	PM, PD, MX, MM, MG, MD, RG, RD
Achillea alpina	S5	S5	24	9	NT, PM, MX, MM, MG, MD, RG, RD, SD
Achillea millefolium	S5	S5	254	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Actaea rubra	S5	S5	121	9	NT, PM, MX, MM, MG, MD, RG, RD, SD
Adoxa moschatellina	S5	S4	22	7	PM, MM, MG, MD, RG, RD, SD
Agastache foeniculum	S4	S4	4	3	NT, MM, MG
Agoseris glauca	S5	S5	1	1	PM
Agrimonia striata	S4	S4	6	5	NT, MX, MG, RG, RD
Agrostis scabra	S5	S5	148	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Agrostis stolonifera	SNA	SNA	3	3	PM, MM, RD
Alisma triviale	S4	S5	2	2	RG, RD
Allium cernuum	S5	S5	3	2	MM, MG
Alnus incana	S5	S5	95	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Alnus viridis	S5	S5	172	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Alopecurus aequalis	S5	S5	10	7	NT, PM, MM, MG, RG, RD, SD
Amelanchier alnifolia	S5	S5	204	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Andromeda polifolia	S5	S5	114	7	PM, PD, MM, MG, MD, RG, RD
Anemone canadensis	S5	S5	14	5	MX, MM, MG, RD, SD
Anemone cylindrica	S5	S5	2	2	MM, MG
Anemone multifida	S5	S5	37	6	NT, PX, PM, MX, MM, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Anemone parviflora	S5	S5	1	1	RD
Anemone patens	S5	S5	37	5	PX, PM, MX, MM, RD
Anemone virginiana var. cylindroidea	SNR	S3	2	2	MX, MM
Antennaria microphylla	SNR	S5	5	3	NT, PX, RD
Antennaria neglecta	S5	S5	23	8	NT, PX, PM, PD, MX, MM, RD, SD
Antennaria parvifolia	S5	S5	4	2	PD, MM
Antennaria rosea	S5	S5	2	1	PM
Anthoxanthum hirtum	SNR	S5	3	3	MX, MM, SD
Apocynum androsaemifolium	S5	S5	46	6	NT, PX, PM, MX, MM, MG
Aquilegia brevistyla	S5	S5	9	5	PX, PM, MX, MM, MD
Arabidopsis lyrata	S4	S4	5	2	PX, PM
Arabis pycnocarpa	S5	S5	1	1	NT
Aralia nudicaulis	S5	S5	192	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Arceuthobium americanum	S4	S4	5	3	PX, PM, MM
Arctostaphylos uva-ursi	S5	S5	197	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Arctous rubra	S5	S5	13	4	PM, MM, MD, RD
Arnica chamissonis	S5	S5	4	4	PM, MG, MD, RD
Artemisia absinthium	SNA	SNA	1	1	PM
Artemisia biennis	S5	S5	2	2	PM, MG
Artemisia campestris	S5	S5	18	6	PX, PM, MX, MM, MG, SD
Artemisia dracunculus	S4	S4	1	1	NT
Artemisia frigida	S5	S5	1	1	NT
Artemisia ludoviciana	S5	S5	1	1	NT
Asclepias ovalifolia	S3	S3	1	1	NT
Astragalus alpinus	S5	S5	1	1	MG
Astragalus americanus	S5	S5	28	8	NT, PX, PM, MX, MM, MG, RG, RD
Astragalus	S4	S4	1	1	MM

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
canadensis					
Astragalus cicer	SNA	SNA	2	1	PM
Astragalus laxmannii	SNR	S5	1	1	NT
Astragalus robbinsii	S3	S3	1	1	MG
Athyrium filix-femina	S5	S4	1	1	MG
Beckmannia syzigachne	S5	S5	9	6	PM, MG, MD, RG, RD, SD
Betula glandulosa	S5	S5	46	7	NT, PM, MM, MD, RG, RD, SD
Betula neoalaskana	S5	S5	298	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Betula occidentalis	S4	S4	9	5	PM, PD, MM, MD, RD
Betula papyrifera	S4	S5	44	9	PX, PM, PD, MM, MG, MD, RG, RD, SD
Betula pumila	S5	S5	238	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Betula x sargentii	SNA	SNA	1	1	MD
Betula x winteri	SNA	SNA	1	1	RD
Bidens cernua	S5	S5	14	8	NT, PM, PD, MG, MD, RG, RD, SD
Boechera grahamii	SNR	S5	2	2	NT, PX
Botrychium multifidum	S3	S4	2	2	PX, RD
Botrychium simplex	S2	S2	1	1	SD
Botrychium virginianum	S4S5	S5	15	6	PM, MM, MG, MD, RG, RD
Bromus ciliatus	S5	S5	70	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Bromus inermis	SNA	SNA	16	7	NT, PM, PD, MX, MM, MG, RD
Calamagrostis canadensis	S5	S5	401	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Calamagrostis purpurascens	S3	S4	3	3	PX, PM, MX
Calamagrostis	S5	S5	52	10	PX, PM, PD, MX,

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
stricta					MM, MG, MD, RG, RD, VD
Calamovilfa longifolia	S4	S5	1	1	NT
Calla palustris	S4	S4S5	10	4	PM, MM, MG, RD
Callitriche hermaphroditica	S4	S4	1	1	SD
Callitriche palustris	S5	S5	3	1	RD
Caltha natans	S5	S5	4	4	MG, RG, RD, SD
Caltha palustris	S5	S5	145	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Calypso bulbosa	S5	S5	3	2	PM, MM
Campanula rotundifolia	S5	S5	160	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Canadanthus modestus	S5	S5	3	3	MG, MD, RD
Capnoides sempervirens	S5	S5	13	7	NT, PX, PM, MX, MM, MD, RD
Capsella bursa-pastoris	SNA	SNA	2	2	MG, RG
Cardamine dentata	S3	S2	3	1	RD
Cardamine pensylvanica	S5	S5	15	6	PM, MM, MG, RG, RD, SD
Carex adusta	S1	S3	7	3	NT, PX, MX
Carex aquatilis	S5	S5	280	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Carex atherodes	S5	S5	28	8	PM, MM, MG, MD, RG, RD, SD, VD
Carex atratiformis	S4	S4	1	1	RD
Carex aurea	S5	S5	28	8	NT, PM, MM, MG, MD, RG, RD, SD
Carex backii	S3	S3	1	1	MM
Carex bebbii	S4	S5	29	9	NT, PX, PM, MM, MG, MD, RG, RD, SD
Carex brunnescens	S4	S4	106	10	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD
Carex canescens	S5	S5	117	11	NT, PX, PM, PD, MX, MM, MG,

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
					MD, RG, RD, SD
Carex capillaris	S5	S5	25	7	NT, PM, MG, MD, RG, RD, SD
Carex capitata	S3	S4	2	2	PM, RD
Carex chordorrhiza	S5	S5	63	7	NT, PX, PM, MG, MD, RG, RD
Carex concinna	S5	S5	25	7	PM, MX, MM, MG, MD, RG, RD
Carex crawfordii	S5	S4	4	3	PM, MM, RD
Carex deflexa	S3	S3	36	8	NT, PX, PM, MX, MM, MG, MD, RG
Carex deweyana	S4	S4	40	9	PX, PM, MX, MM, MG, MD, RG, RD, SD
Carex diandra	S5	S5	99	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Carex disperma	S5	S5	235	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Carex duriuscula	S5	S5	1	1	NT
Carex foenea	S4	S4	42	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Carex gynocrates	S5	S5	138	9	PM, PD, MX, MM, MG, MD, RG, RD, SD
Carex heleonastes	S2	S3	8	2	MD, RD
Carex houghtoniana	S3S4	S3	6	3	NT, PX, MM
Carex hystericina	S1	S2	1	1	RD
Carex interior	S3	S4	43	6	PM, PD, MG, MD, RG, RD
Carex lacustris	S2	S4	2	1	RD
Carex lasiocarpa	S4	S4	41	4	MG, MD, RG, RD
Carex leptalea	S5	S5	72	7	PM, PD, MG, MD, RG, RD, SD
Carex limosa	S4	S4	71	6	PM, PD, MM, MD, RG, RD
Carex livida	S3	S3	3	2	MD, RD
Carex loliacea	S3	S3	2	2	MM, RD
Carex magellanica	S4	S5	131	9	NT, PM, PD, MX, MM, MG, MD, RG, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Carex media	S5	S5	27	7	PM, MX, MM, MG, MD, RG, RD
Carex microptera	S4	S4	1	1	RG
Carex oligosperma	S3	S3	11	3	PM, MD, RD
Carex parryana var. parryana	S3	S3	16	6	PM, PD, MG, MD, RD, SD
Carex pauciflora	S3	S4	24	6	PM, PD, MM, MD, RG, RD
Carex peckii	S4	S4	9	4	PM, MM, MG, RD
Carex pellita	S5	S5	4	3	PX, MD, RD
Carex praegracilis	S5	S5	1	1	RD
Carex prairea	S3	S5	44	7	PM, PD, MX, MG, MD, RG, RD
Carex praticola	S5	S5	4	4	PX, MM, RG, RD
Carex pseudocyperus	S3	S3	3	3	MG, MD, RD
Carex retrorsa	S3	S4	2	2	MG, RG
Carex richardsonii	S3	S4	11	5	PX, PM, MX, RD, SD
Carex rossii	S4	S4	2	2	PX, MM
Carex rostrata	S3	S4	11	4	PD, MD, RD, VD
Carex sartwellii	S4	S4	30	5	PM, MX, MD, RD, SD
Carex scirpoidea	S5	S5	1	1	RD
Carex siccata	S5	S5	161	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Carex sprengelii	S4	S4	1	1	MG
Carex tenera	S3	S3	16	5	PM, PD, MM, MD, RD
Carex tenuiflora	S3S4	S4	90	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Carex tonsa	S3	S3	43	5	PX, PM, MX, MM, MD
Carex trisperma	S3	S3	37	7	PM, PD, MM, MG, MD, RG, RD
Carex umbellata	S2	S4	2	2	PM, MD
Carex utriculata	S5	S5	111	11	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Carex vaginata	S5	S5	109	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Carex viridula	S3S4	S4	1	1	SD
Carex xerantica	S3	S4	1	1	NT
Castilleja miniata	S5	S5	1	1	MG
Cerastium arvense	S5	S5	1	1	RD
Cerastium fontanum ssp. vulgare	SNA	SNA	1	1	RD
Cerastium nutans	S4	S4	4	4	PM, MG, MD, SD
Ceratophyllum demersum	S3	S4	4	2	MG, RD
Chamaedaphne calyculata	S4	S4S5	114	7	PX, PM, PD, MM, MG, MD, RD
Chamerion angustifolium	S5	S5	384	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Chenopodium album	SNA	SNA	4	3	NT, PX, RD
Chenopodium leptophyllum	SNR	S3	2	2	PX, MX
Chenopodium simplex	S3	S4	1	1	MG
Chrysosplenium iowense	S3	S4	17	5	PM, MG, MD, RG, RD
Chrysosplenium tetrandrum	S3S4	S3S4	6	4	NT, MG, RG, RD
Cicuta bulbifera	S4	S4	52	7	PD, MX, MG, MD, RG, RD, SD
Cicuta maculata	S5	S5	24	7	PM, MM, MG, MD, RG, RD, SD
Cicuta virosa	S3	S3	12	3	MD, RD, SD
Cinna latifolia	S4	S4	43	8	NT, PM, MM, MG, MD, RG, RD, SD
Circaea alpina	S4	S4	31	7	PM, MM, MG, MD, RG, RD, SD
Cirsium arvense	SNA	SNA	21	7	NT, MM, MG, MD, RG, RD, VD
Cirsium drummondii	S5	S5	1	1	RD
Cirsium vulgare	SNA	SNA	1	1	RD
Collomia linearis	S5	S5	1	1	NT
Comandra umbellata	S5	S5	58	9	NT, PX, PM, PD, MX, MM, MG, MD, RD
Comarum palustre	S5	S5	157	10	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Conyza canadensis	S5	S4	25	6	NT, PX, PM, MX, MM, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Coptidium lapponicum	S4	S4	50	8	PX, PM, PD, MX, MG, MD, RG, RD
Coptis trifolia	S3	S3	33	8	PX, PM, MM, MG, MD, RG, RD, SD
Corallorhiza maculata	S3	S4	14	5	MX, MM, MG, RG, RD
Corallorhiza striata	S3	S3	10	4	MX, MM, RG, RD
Corallorhiza trifida	S5	S5	57	8	PX, PM, MX, MM, MG, MD, RG, RD
Cornus canadensis	S5	S5	376	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Cornus sericea	S5	S5	92	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Corydalis aurea	S5	S5	3	3	PM, MM, RD
Corylus cornuta	S5	S5	32	6	PM, MX, MM, MG, RG, RD
Crepis runcinata	S5	S5	2	2	NT, RD
Crepis tectorum	SNA	SNA	63	9	NT, PX, PM, MX, MM, MG, MD, RD, SD
Cypripedium acaule	S3	S3	2	1	PX
Cypripedium parviflorum	S3	S5	3	2	MD, RD
Cypripedium passerinum	S4	S5	2	2	MD, RD
Dactylorhiza viridis	S5	S5	5	3	NT, PM, MM
Danthonia intermedia	S4S5	S5	3	3	PX, PM, MX
Dasiphora fruticosa	S5	S5	1	1	PM
Delphinium glaucum	S5	S5	12	4	MM, MG, RG, SD
Deschampsia cespitosa	S5	S5	31	10	NT, PM, MX, MM, MG, MD, RG, RD, SD, VD
Descurainia sophia	SNA	SNA	2	2	NT, MG
Dichanthelium acuminatum	SU	S2	5	2	PX, MD
Diphasiastrum complanatum	S5	S5	99	8	PX, PM, MX, MM, MG, MD, RG, RD
Diphasiastrum sitchense	S2	S3	5	2	PM, MD
Dracocephalum parviflorum	S5	S4	9	6	PX, PM, MX, MM, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Drosera anglica	S3	S4	10	3	MD, RG, RD
Drosera linearis	S3	S4	4	2	RG, RD
Drosera rotundifolia	S5	S5	133	10	NT, PX, PM, PD, MM, MG, MD, RG, RD, SD
Drymocallis arguta	S5	S4	1	1	NT
Dryopteris carthusiana	S4	S5	37	6	PM, PD, MM, MG, RG, RD
Dryopteris expansa	S3	S4	8	6	PM, MM, MG, MD, RG, SD
Echinochloa crusgalli	SNA	SNA	1	1	RD
Eleocharis acicularis	S5	S5	3	3	PM, MM, RG
Eleocharis palustris	S5	S5	16	5	MM, MD, RG, RD, VD
Eleocharis quinqueflora	S3	S3	4	2	RG, RD
Elymus canadensis	S4	S4	4	2	MX, MM
Elymus glaucus	S3	S4	2	2	PX, MM
Elymus repens	SNA	SNA	12	5	NT, PM, MM, MG, RD
Elymus trachycaulus	S5	S5	50	9	NT, PX, PM, MX, MM, MG, MD, RG, RD
Empetrum nigrum	S5	S5	14	6	PM, PD, MG, MD, RG, RD
Epilobium ciliatum	S5	S5	79	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Epilobium leptophyllum	S3	S3	76	8	NT, PM, PD, MG, MD, RG, RD, SD
Epilobium palustre	S3	S4	102	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Equisetum arvense	S5	S5	270	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Equisetum fluviatile	S5	S5	105	10	PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Equisetum hyemale	S5	S5	28	8	PX, PM, MX, MM, MG, MD, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Equisetum palustre	S5	S5	17	6	PM, MM, MG, MD, RD, SD
Equisetum pratense	S5	S5	86	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Equisetum scirpoides	S5	S5	142	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Equisetum sylvaticum	S5	S5	291	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Equisetum variegatum	S5	S5	7	3	PM, MM, RD
Erigeron acris	S5	S5	8	5	PM, MM, MD, RD, SD
Erigeron elatus	S4	S4	3	3	PM, MD, RD
Erigeron glabellus	S5	S5	8	6	NT, PX, MX, MM, MG, VD
Erigeron lonchophyllus	S5	S5	1	1	PM
Erigeron philadelphicus	S5	S5	7	6	PM, MX, MM, RG, RD, SD
Eriophorum angustifolium	S4	S5	43	8	PX, PM, PD, MM, MG, MD, RG, RD
Eriophorum brachyantherum	S3	S4	10	7	NT, PM, PD, MM, MD, RG, RD
Eriophorum gracile	S3	S4	37	5	PX, PD, MD, RG, RD
Eriophorum russeolum	S3	S4	31	5	PM, PD, MM, MD, RD
Eriophorum scheuchzeri	S3	S3	3	3	PD, MG, RG
Eriophorum vaginatum	S5	S5	110	6	NT, PM, PD, MM, MD, RD
Eriophorum viridicarinatum	S4	S4	21	4	PD, MD, RG, RD
Erysimum cheiranthoides	S5	S5	6	4	PD, MG, RD, SD
Euphrasia nemorosa	SNA	SNA	5	3	PM, PD, RD
Euphrasia subarctica	SNR	S3	2	1	PM
Eurybia conspicua	S5	S5	46	8	NT, PM, MX, MM, MG, MD, RG, RD
Euthamia graminifolia	S5	S4	2	2	PM, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Festuca rubra	S4	S5	9	7	NT, PX, PM, MM, MG, MD, SD
Festuca saximontana	S5	S5	21	5	PX, PM, MX, MM, MG
Fragaria vesca	S4	S4	67	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Fragaria virginiana	S5	S5	244	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Galearis rotundifolia	S5	S5	30	6	PM, PD, MM, MG, MD, RD
Galeopsis tetrahit	SNA	SNA	15	7	NT, PM, MM, MG, MD, RG, RD
Galium boreale	S5	S5	226	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Galium labradoricum	S3	S4	92	10	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Galium trifidum	S5	S5	90	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Galium triflorum	S5	S5	123	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Gaultheria hispidula	S3	S4	13	6	PM, PD, MG, MD, RG, RD
Gentianella amarella	S5	S5	31	9	PX, PM, PD, MX, MM, MG, MD, RG, RD
Geocaulon lividum	S5	S5	176	9	PX, PM, PD, MX, MM, MG, MD, RG, RD
Geranium bicknellii	S5	S5	46	10	NT, PX, PM, PD, MX, MM, MD, RG, RD, SD
Geum aleppicum	S5	S5	61	11	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Geum macrophyllum	S5	S5	33	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Geum rivale	S5	S5	18	8	NT, PM, PD, MM, MG, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Glyceria borealis	S4	S4	2	2	MD, RD
Glyceria grandis	S5	S5	10	3	MG, MD, RD
Glyceria pulchella	S3	S4	11	4	MG, RG, RD, SD
Glyceria striata	S4	S5	39	7	PM, MX, MG, MD, RG, RD, SD
Gnaphalium uliginosum	SNA	SNA	1	1	RG
Goodyera repens	S5	S5	76	9	PX, PM, PD, MX, MM, MG, MD, RG, RD
Gymnocarpium dryopteris	S5	S5	23	8	PM, MX, MM, MG, MD, RG, RD, SD
Halenia deflexa	S4	S4	21	7	NT, PM, MX, MM, MG, RG, RD
Hedysarum alpinum	S5	S5	9	6	PM, MX, MM, MG, RD, SD
Helianthus pauciflorus	S4	S3	2	2	NT, PM
Heracleum maximum	S5	S5	12	5	MX, MM, MG, RG, SD
Hesperostipa curtiseta	S5	S5	1	1	NT
Heuchera richardsonii	S5	S5	5	4	NT, PM, MM, SD
Hieracium umbellatum	S5	S5	155	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Hippuris vulgaris	S5	S5	16	5	PM, MG, RD, SD, VD
Hordeum jubatum	S5	S5	13	9	NT, PM, MM, MG, MD, RG, RD, SD, VD
Hudsonia tomentosa	S3	S3	19	3	PX, MX, MD
Hypericum majus	S2	S3	1	1	SD
Impatiens capensis	S4	S4	15	4	MM, MG, RG, RD
Impatiens noli-tangere	S3	S4	3	2	MM, RD
Juncus alpinoarticulatus	S5	S5	7	4	PM, MM, RD, SD
Juncus balticus	S5	S5	41	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Juncus brevicaudatus	S2	S3	5	4	NT, PM, PD, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Juncus bufonius	S5	S5	6	6	NT, PM, PD, MD, RG, RD
Juncus filiformis	S3	S4	2	2	PM, MD
Juncus nodosus	S5	S5	6	4	PM, RG, RD, VD
Juncus stygius	S2	S3	6	2	MD, RD
Juncus tenuis	S5	S5	12	7	NT, PX, PM, MM, MD, RG, RD
Juncus vaseyi	S3	S4	12	7	NT, PX, PM, PD, MM, RD, SD
Kalmia polifolia	S3	S4	66	6	PX, PM, PD, MM, MD, RD
Koeleria macrantha	S5	S5	15	5	NT, PX, MX, MM, MG
Lactuca biennis	S2	S3	2	2	MG, RG
Larix laricina	S5	S5	247	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Lathyrus ochroleucus	S5	S5	188	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Lathyrus venosus	S3	S4	3	2	MM, RG
Lechea intermedia var. depauperata	S1	S1	1	1	PX
Lemna trisulca	S4	S5	1	1	RD
Lemna turionifera	SNR	S5	28	6	PM, MM, MG, RD, SD, VD
Lepidium densiflorum	S5	S5	2	1	PX
Leucophysalis grandiflora	SU	S1	18	3	PX, MX, RD
Leymus innovatus	S5	S5	222	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Lilium philadelphicum	S5	S5	48	9	NT, PX, PM, MX, MM, MG, MD, RG, RD
Linnaea borealis	S5	S5	351	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Lolium arundinaceum	SNA	SNA	2	2	PX, PM
Lonicera dioica	S5	S5	169	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Lonicera involucrata	S5	S5	149	11	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Lonicera villosa	S3	S3	186	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Luzula multiflora	S3	S4	6	3	NT, PM, MM
Luzula parviflora	S5	S5	26	8	PM, MX, MM, MG, MD, RG, RD, SD
Lycopodium annotinum	S5	S5	130	9	PX, PM, PD, MX, MM, MG, MD, RG, RD
Lycopodium dendroideum	S4	S4	79	6	PX, PM, MX, MM, RG, RD
Lycopodium lagopus	S3	S4	40	8	PX, PM, MX, MM, MG, RG, RD, SD
Lycopus asper	S3	S3	4	3	MG, RD, SD
Lycopus uniflorus	S3	S3	8	5	PM, PD, MG, RG, RD
Lysimachia ciliata	S4	S4	3	3	NT, MM, RD
Lysimachia maritima	S4	S4	1	1	RD
Lysimachia thyrsiflora	S3	S4	61	9	PX, PD, MX, MM, MG, MD, RG, RD, SD
Maianthemum canadense	S5	S5	307	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Maianthemum racemosum	S5	S5	1	1	RD
Maianthemum stellatum	S5	S5	22	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Maianthemum trifolium	S5	S5	285	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Malaxis monophyllos	S3	S3	12	6	MX, MM, MG, MD, RG, RD
Malaxis paludosa	S1	S2S3	9	4	PM, MD, RG, RD
Matricaria discoidea	SNA	SNA	2	2	NT, RG
Matteuccia struthiopteris	S3	S4	2	2	MG, RG
Medicago lupulina	SNA	SNA	2	2	MM, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Medicago sativa	SNA	SNA	6	3	PM, MM, RD
Melampyrum lineare	S3	S4	102	9	NT, PX, PM, PD, MX, MM, MG, MD, RD
Melilotus alba	SNA	SNA	11	5	NT, PM, MM, MD, RD
Melilotus officinalis	SNA	SNA	5	4	NT, PM, MX, MM
Mentha arvensis	S5	S5	35	10	NT, PX, PM, MM, MG, MD, RG, RD, SD, VD
Menyanthes trifoliata	S5	S5	60	5	MG, MD, RG, RD, SD
Mertensia paniculata	S5	S5	173	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Mitella nuda	S5	S5	243	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Moehringia lateriflora	S5	S5	46	8	NT, PM, MM, MG, MD, RG, RD, SD
Moneses uniflora	S5	S5	45	6	PM, MM, MG, MD, RG, RD
Monotropa uniflora	S3	S3	7	4	PM, MX, MM, RD
Muhlenbergia cuspidata	S4	S4	1	1	MM
Muhlenbergia glomerata	S4	S4	7	3	MD, RG, RD
Mulgedium pulchellum	S5	S5	1	1	NT
Myrica gale	S3S4	S3	10	4	PX, PD, MD, RD
Myriophyllum sibiricum	S5	S5	5	1	RD
Nassella viridula	S5	S5	1	1	NT
Nasturtium officinale	SNA	SNA	1	1	MG
Neottia borealis	S4	S4	4	2	MD, RD
Neottia cordata	S4	S4	35	7	PM, PD, MM, MG, MD, RG, RD
Nuphar variegata	S4	S5	2	2	RD, VD
Orthilia secunda	S5	S5	306	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Oryzopsis asperifolia	S4	S5	99	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Osmorhiza depauperata	S5	S5	16	4	MM, MG, MD, RG
Oxytropis deflexa	S5	S5	1	1	RD
Oxytropis splendens	S5	S5	2	2	PX, MX
Packera paupercula	S5	S5	49	10	NT, PX, PM, PD, MX, MM, MD, RG, RD, SD
Parnassia palustris	S5	S5	80	11	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Pascopyrum smithii	S4	S5	1	1	PM
Pedicularis groenlandica	S5	S5	1	1	RD
Pedicularis labradorica	S5	S5	52	8	NT, PX, PM, PD, MX, MM, MD, RD
Pedicularis parviflora	S3	S3	20	4	PD, MD, RG, RD
Penstemon gracilis	S3	S4	1	1	NT
Persicaria amphibia	S5	S5	46	9	PX, PM, MM, MG, MD, RG, RD, SD, VD
Persicaria lapathifolia	S5	S5	2	2	MG, SD
Persicaria maculosa	SNA	SNA	2	1	RD
Petasites frigidus	S5	S5	24	8	PM, PD, MX, MM, MG, MD, RG, RD
Petasites frigidus var. frigidus	S5	S5	5	5	PM, MM, MG, MD, RD
Petasites frigidus var. palmatus	S5	S5	280	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Petasites frigidus var. sagittatus	S5	S5	104	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Petasites frigidus var. vitifolius	S5	S5	24	8	PM, PD, MM, MG, MD, RG, RD, SD
Phacelia franklinii	S4	S4	4	2	PX, MX
Phalaris arundinacea	S5	S5	7	3	RD, SD, VD
Phalaris canariensis	SNA	SNA	1	1	RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Phleum pratense	SNA	SNA	21	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Phragmites australis	S3	S4	1	1	RD
Picea glauca	S5	S5	267	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Picea mariana	S5	S5	389	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Pilosella aurantiaca	SNA	SNA	3	2	MM, RD
Pilosella caespitosa	SNA	SNA	1	1	MX
Pinguicula vulgaris	S3	S4	1	1	RD
Pinus banksiana	S5	S5	231	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Pinus contorta	S5	S5	1	1	PM
Piptatherum pungens	S4	S4	149	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Plantago major	SNA	SNA	23	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Platanthera dilatata	S3	S3	5	2	MD, RD
Platanthera huronensis	S5	S5	116	8	NT, PM, PD, MX, MG, MD, RG, RD
Platanthera obtusata	S5	S5	29	8	PM, PD, MX, MM, MG, MD, RG, RD
Platanthera orbiculata	S3	S4	64	8	PX, PM, MX, MM, MG, MD, RG, RD
Poa interior	S5	S5	1	1	PM
Poa palustris	S5	S5	72	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Poa pratensis	S5	S5	99	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Polemonium acutiflorum	S4	S4	5	3	MG, MD, RD
Polygala senega	S3	S4	3	2	PM, RD
Polygonum aviculare	SNA	SNA	1	1	NT

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Populus balsamifera	S5	S5	203	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Populus tremuloides	S5	S5	343	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Potamogeton alpinus	S3S4	S4S5	6	1	RD
Potamogeton friesii	S4	S4	1	1	RD
Potamogeton gramineus	S4	S4	4	2	MD, RD
Potamogeton pusillus	S5	S5	3	1	RD
Potamogeton richardsonii	S5	S5	1	1	RD
Potentilla anserina	S5	S5	2	2	NT, RD
Potentilla gracilis	S5	S5	1	1	RD
Potentilla norvegica	S5	S5	73	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Potentilla pensylvanica	S5	S5	1	1	NT
Potentilla rivalis	S3	S4	3	3	PD, MG, SD
Primula incana	S5	S4	5	3	PM, MM, RD
Prosartes trachycarpa	S5	S5	39	5	PM, MX, MM, MG, RG
Prunus pensylvanica	S5	S5	88	9	NT, PX, PM, MX, MM, MG, MD, RG, RD
Prunus virginiana	S5	S5	35	8	NT, PX, PM, MX, MM, MG, RG, RD
Pyrola asarifolia	S5	S5	251	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Pyrola chlorantha	S5	S5	94	9	PX, PM, PD, MX, MM, MG, MD, RG, RD
Pyrola elliptica	S3	S4	8	6	PX, MM, MD, RG, RD, SD
Pyrola minor	S4	S4	7	4	PM, MM, MD, RD
Ranunculus abortivus	S5	S4	6	3	MG, MD, RD
Ranunculus aquatilis	S5	S5	4	2	RD, SD
Ranunculus cymbalaria	S5	S5	2	2	PM, RD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Ranunculus gmelinii	S5	S5	36	8	PM, MX, MM, MG, MD, RG, RD, SD
Ranunculus macounii	S5	S5	11	6	NT, PM, MM, MG, RD, SD
Ranunculus pensylvanicus	S3	S3	2	2	MG, SD
Ranunculus sceleratus	S5	S5	15	7	PM, MM, MG, MD, RG, RD, SD
Rhamnus alnifolia	S3	S3	73	9	PM, PD, MX, MM, MG, MD, RG, RD, SD
Rhinanthus minor	S4	S4	16	7	NT, PM, PD, MM, MD, RG, RD
Rhododendron groenlandicum	S5	S5	450	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Ribes americanum	S4	S4	4	4	PD, MM, RG, RD
Ribes glandulosum	S5	S5	82	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Ribes hirtellum	S4	S4	23	7	PM, MM, MG, MD, RG, RD, SD
Ribes hudsonianum	S5	S5	130	10	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Ribes lacustre	S5	S5	101	9	PX, PM, MX, MM, MG, MD, RG, RD, SD
Ribes oxyacanthoides	S5	S5	160	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Ribes triste	S5	S5	188	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Rorippa palustris	S5	S5	10	4	MG, RG, RD, SD
Rosa acicularis	S5	S5	365	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Rosa woodsii	S5	S5	64	8	PX, PM, MX, MM, MG, RG, RD, SD
Rubus arcticus	S5	S5	171	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Rubus chamaemorus	S5	S5	172	11	NT, PX, PM, PD,

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
					MX, MM, MG, MD, RG, RD, SD
Rubus idaeus	S5	S5	235	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Rubus pubescens	S5	S5	240	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Rumex britannica	S3	S3	4	1	RD
Rumex crispus	SNA	SNA	9	4	MG, MD, RG, RD
Rumex fueginus	S5	S5	3	3	MG, RG, SD
Rumex occidentalis	S5	S5	91	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Rumex triangulivalvis	S5	S5	1	1	RD
Salix arbusculoides	S4	S4	44	9	NT, PM, PD, MM, MG, MD, RG, RD, SD
Salix athabascensis	S3	S4	32	6	NT, PX, PM, PD, MD, RD
Salix bebbiana	S5	S5	348	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Salix boothii	S3	S3	2	2	PM, RD
Salix candida	S4	S4	63	8	PM, PD, MX, MG, MD, RG, RD, SD
Salix discolor	S5	S5	53	8	PM, PD, MM, MG, MD, RG, RD, SD
Salix famelica	S5	S4	1	1	RD
Salix glauca	S4	S5	11	5	NT, PD, MD, RD, SD
Salix lasiandra	S5	S5	6	5	NT, PM, RD, SD, VD
Salix maccalliana	S5	S4	101	10	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD
Salix myrtillifolia	S5	S5	146	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Salix pedicellaris	S4	S5	121	8	PX, PM, PD, MM, MG, MD, RG, RD
Salix petiolaris	S5	S5	42	8	PX, PM, PD, MM, MG, MD, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Salix planifolia	S5	S5	215	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Salix prolixa	S3	S3	2	2	RG, RD
Salix pseudomonticola	S4	S4	46	11	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Salix pseudomyrsinites	SNR	S5	39	9	PM, PD, MX, MM, MG, MD, RG, RD, SD
Salix pyrifolia	S4	S5	138	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Salix scouleriana	S4	S5	62	10	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD
Salix serissima	S4	S4	60	9	PM, PD, MX, MM, MD, RG, RD, SD, VD
Sanicula marilandica	S4	S4S5	12	4	NT, MX, MM, MG
Sarracenia purpurea	S3	S3	12	2	MD, RD
Scheuchzeria palustris	S3	S4	22	4	MM, MD, RG, RD
Schizachne purpurascens	S5	S5	101	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Schoenoplectus acutus	S4	S5	5	2	RD, VD
Schoenoplectus tabernaemontani	S5	S5	5	4	PM, MG, RD, VD
Scirpus atrocinctus	SNR	S4	17	7	NT, PM, PD, MG, MD, RD, SD
Scirpus microcarpus	S5	S5	15	5	PM, MG, RG, RD, SD
Scolochloa festucacea	S4	S4	3	2	RD, VD
Scutellaria galericulata	S5	S5	77	11	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Senecio eremophilus	S5	S5	6	3	PD, RD, VD
Senecio fremontii	S3	S3	3	2	PM, RD
Senecio vulgaris	SNA	SNA	1	1	PD
Shepherdia canadensis	S5	S5	138	11	NT, PX, PM, PD, MX, MM, MG,

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
					MD, RG, RD, SD
Sibbaldiopsis tridentata	S3	S3	99	9	PX, PM, PD, MX, MM, MG, MD, RD, SD
Silene latifolia	SNA	SNA	2	2	NT, RD
Sisyrinchium montanum	S5	S5	8	4	NT, PM, MM, RD
Sium suave	S5	S5	18	6	MM, MG, RG, RD, SD, VD
Solidago gigantea	S5	S5	1	1	RG
Solidago missouriensis	S5	S5	20	7	NT, PX, PM, MX, MM, MD, RD
Solidago multiradiata	S5	S5	21	6	PM, MX, MM, MD, RG, RD
Solidago nemoralis	S4	S4	9	3	PX, MX, MM
Solidago simplex	S5	S5	71	9	NT, PX, PM, PD, MX, MM, MG, MD, RD
Sonchus arvensis	SNA	SNA	39	11	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD, VD
Sonchus oleraceus	SNA	SNA	1	1	MD
Sorbus scopulina	S4	S5	8	3	MM, MG, RG
Sparganium angustifolium	S5	S4	7	2	MD, RD
Sparganium eurycarpum	S4	S4	1	1	MG
Sparganium natans	S3	S4	5	2	MD, RD
Sphenopholis intermedia	S3	S4	1	1	RD
Spiraea lucida	S5	S5	1	1	MM
Spiranthes lacera	S1	S2	3	3	NT, PX, MM
Spiranthes romanzoffiana	S5	S5	76	6	PM, PD, MM, MD, RG, RD
Spirodela polyrhiza	S4	S3	3	3	PM, MG, SD
Stachys palustris	S5	S5	21	8	NT, PX, PM, MM, MG, MD, RD, SD
Stellaria calycantha	S5	S4	13	5	PM, MM, MD, RG, RD
Stellaria crassifolia	S5	S5	4	3	NT, MG, RD
Stellaria longifolia	S5	S5	178	12	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Stellaria longipes	S5	S5	24	8	PX, PM, PD, MM, MG, MD, RD, SD
Stellaria media	SNA	SNA	4	3	PM, MG, MD
Streptopus amplexifolius	S5	S5	3	3	MM, MG, RG
Symphoricarpos albus	S5	S5	107	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, SD
Symphoricarpos occidentalis	S5	S5	8	6	NT, PM, MG, RG, RD, SD
Symphyotrichum boreale	S5	S5	21	6	PM, PD, MG, MD, RG, RD
Symphyotrichum ciliolatum	S5	S5	227	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Symphyotrichum ericoides	S4	S5	1	1	RD
Symphyotrichum falcatum	S5	S5	3	3	NT, MM, SD
Symphyotrichum laeve	S5	S5	69	10	NT, PX, PM, MX, MM, MG, MD, RG, RD, VD
Symphyotrichum lanceolatum	S5	S5	11	7	NT, PX, PM, MD, RG, RD, VD
Symphyotrichum puniceum	S4	S4	83	11	NT, PM, PD, MX, MM, MG, MD, RG, RD, SD, VD
Tanacetum vulgare	SNA	SNA	1	1	PD
Taraxacum officinale	SNA	SNA	123	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Tephroseris palustris	S5	S5	3	2	PX, RD
Thalictrum venulosum	S5	S5	47	9	NT, PX, PM, MX, MM, MG, RG, RD, SD
Triantha glutinosa	S5	S5	10	3	MD, RG, RD
Trichophorum alpinum	S4	S3	1	1	MD
Trichophorum cespitosum	S4	S4	2	2	MD, RD
Trientalis borealis	S4	S4	288	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Trientalis europaea	S3	S3	4	3	PX, MD, RG
Trifolium hybridum	SNA	SNA	39	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Trifolium pratense	SNA	SNA	34	9	NT, PM, MX, MM, MG, MD, RG, RD, SD
Trifolium repens	SNA	SNA	19	8	NT, PM, MX, MM, MG, MD, RG, RD
Triglochin maritima	S5	S5	64	8	PX, PM, PD, MM, MD, RG, RD, VD
Triglochin palustris	S5	S5	8	4	MD, RG, RD, VD
Typha latifolia	S5	S5	52	10	NT, PM, PD, MM, MG, MD, RG, RD, SD, VD
Urtica dioica	S5	S5	63	10	NT, PX, PM, MM, MG, MD, RG, RD, SD, VD
Utricularia cornuta	S1	S1	1	1	VD
Utricularia intermedia	S4	S4	33	4	PM, MD, RG, RD
Utricularia minor	S4	S3	22	5	PX, MD, RG, RD, VD
Utricularia vulgaris	S5	S5	19	6	PM, MG, RG, RD, SD, VD
Vaccinium caespitosum	S5	S5	67	8	PM, PD, MX, MM, MG, MD, RG, RD
Vaccinium myrtilloides	S5	S5	379	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Vaccinium oxycoccos	S5	S5	263	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Vaccinium uliginosum	S3	S3	1	1	RD
Vaccinium vitis-idaea	S5	S5	474	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Veronica americana	S5	S5	4	4	MM, MD, RD, SD
Viburnum edule	S5	S5	202	10	PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Vicia americana	S5	S5	165	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD

Scientific Name	Conservation Status Rank (2014)	Conservation Status Rank (2015)	Number of Records	Number of Ecosites	Ecosites
Viola adunca	S5	S5	76	10	NT, PX, PM, PD, MX, MM, MG, MD, RD, SD
Viola canadensis	S5	S5	48	8	NT, PM, MX, MM, MG, RG, RD, SD
Viola nephrophylla	S4	S4	32	9	PM, PD, MX, MM, MG, MD, RG, RD, SD
Viola palustris	S4	S4	18	5	PM, MM, MG, RG, RD
Viola renifolia	S5	S5	188	11	NT, PX, PM, PD, MX, MM, MG, MD, RG, RD, SD
Viola selkirkii	S3	S3	1	1	MG
Zigadenus elegans	S5	S5	1	1	RD
Zizia aptera	S5	S5	4	4	PM, MX, MM, RD

APPENDIX 4.1: Individual growth form models for pseudoturnover and the number of species missed.

Models for pseudoturnover per growth form

Table A4.1. Summary of linear models examining relationships between pseudoturnover for forbs and total richness, forb richness, and ecosite category for the repeat survey dataset. Log_{10} transformations were applied to all continuous variables.

	Model Variable	Beta Coefficient	S.E.	*p*
Forb	Relationship with species richness (all growth forms): $R^2 = 0.024$			
	Intercept	0.743	0.251	0.004
	Richness	0.245	0.145	0.095
	Relationship with forb richness: $R^2 = 0.004$			
	Intercept	0.984	0.163	<0.001
	Forb richness	0.129	0.115	0.265
	Relationship with ecosite: $R^2 = 0.061$			
	Intercept	1.063	0.055	<0.001
	NT	0.362	0.159	0.026
	PX	0.157	0.159	0.329
	PM	0.104	0.103	0.313
	PD	-0.091	0.119	0.447
	MX	0.165	0.159	0.305
	MG	0.158	0.112	0.164
	MD	0.284	0.112	0.014
	RG	0.280	0.265	0.294
	RD	0.102	0.096	0.289
	SD	0.204	0.159	0.206

Table A4.2. Summary of linear models examining relationships between pseudoturnover for graminoids and total richness, graminoid richness, and ecosite category for the repeat survey dataset. Log_{10} transformations were applied to all continuous variables.

	Model Variable	Beta Coefficient	S.E.	*p*
Graminoid	Relationship with species richness (all growth forms): $R^2 = 0.187$			
	Intercept	-0.664	0.432	0.128
	Richness	1.057	0.249	<0.001
	Relationship with graminoid richness: $R^2 = 0.297$			
	Intercept	0.372	0.146	0.0132
	Graminoid richness	0.884	0.156	<0.001
	Relationship with ecosite: $R^2 = 0.048$			
	Intercept	1.123	0.105	<0.001
	NT	0.061	0.302	0.839
	PX	0.352	0.302	0.248
	PM	0.099	0.194	0.611
	PD	-0.436	0.226	0.058
	MX	-0.221	0.302	0.466
	MG	0.277	0.213	0.198
	MD	-0.223	0.213	0.299
	RG	0.474	0.502	0.349
	RD	0.199	0.181	0.275
	SD	0.165	0.302	0.588

Table A4.3. Summary of linear models examining relationships between pseudoturnover for shrubs and total richness, shrub richness, and ecosite category for the repeat survey dataset. Log_{10} transformations were applied to all continuous variables.

	Model Variable	Beta Coefficient	S.E.	*p*
Shrub	Relationship with species richness (all growth forms): $R^2 = 0.036$			
	Intercept	0.506	0.288	0.083
	Richness	0.321	0.166	0.057
	Relationship with shrub richness: $R^2 = 0.026$			
	Intercept	0.693	0.214	0.00184
	Shrub richness	0.333	0.192	0.087
	Relationship with ecosite: $R^2 = 0.028$			
	Intercept	1.061	0.065	<0.001
	NT	0.263	0.187	0.164
	PX	0.020	0.187	0.913
	PM	0.013	0.120	0.912
	PD	-0.205	0.140	0.148
	MX	-0.405	0.187	0.034
	MG	0.115	0.132	0.387
	MD	-0.024	0.132	0.857
	RG	0.101	0.310	0.746
	RD	0.018	0.112	0.876
	SD	0.133	0.187	0.479

Table A4.4. Summary of linear models examining relationships between pseudoturnover for trees and total richness, tree richness, and ecosite category for the repeat survey dataset. Log_{10} transformations were applied to all continuous variables.

	Model Variable	Beta Coefficient	S.E.	*p*
Tree	Relationship with species richness (all growth forms): $R^2 = 0.169$			
	Intercept	-1.424	0.571	0.015
	Richness	1.317	0.329	<0.001
	Relationship with tree richness: $R^2 = 0.277$			
	Intercept	-0.173	0.198	0.387
	Tree richness	1.414	0.261	<0.001
	Relationship with ecosite: $R^2 = 0.052$			
	Intercept	0.736	0.137	<0.001
	NT	0.570	0.394	0.153
	PX	0.194	0.394	0.624
	PM	0.431	0.253	0.094
	PD	-0.287	0.295	0.334
	MX	0.371	0.394	0.350
	MG	0.300	0.278	0.285
	MD	-0.278	0.278	0.321
	RG	0.735	0.655	0.266
	RD	-0.034	0.237	0.886
	SD	0.637	0.394	0.111

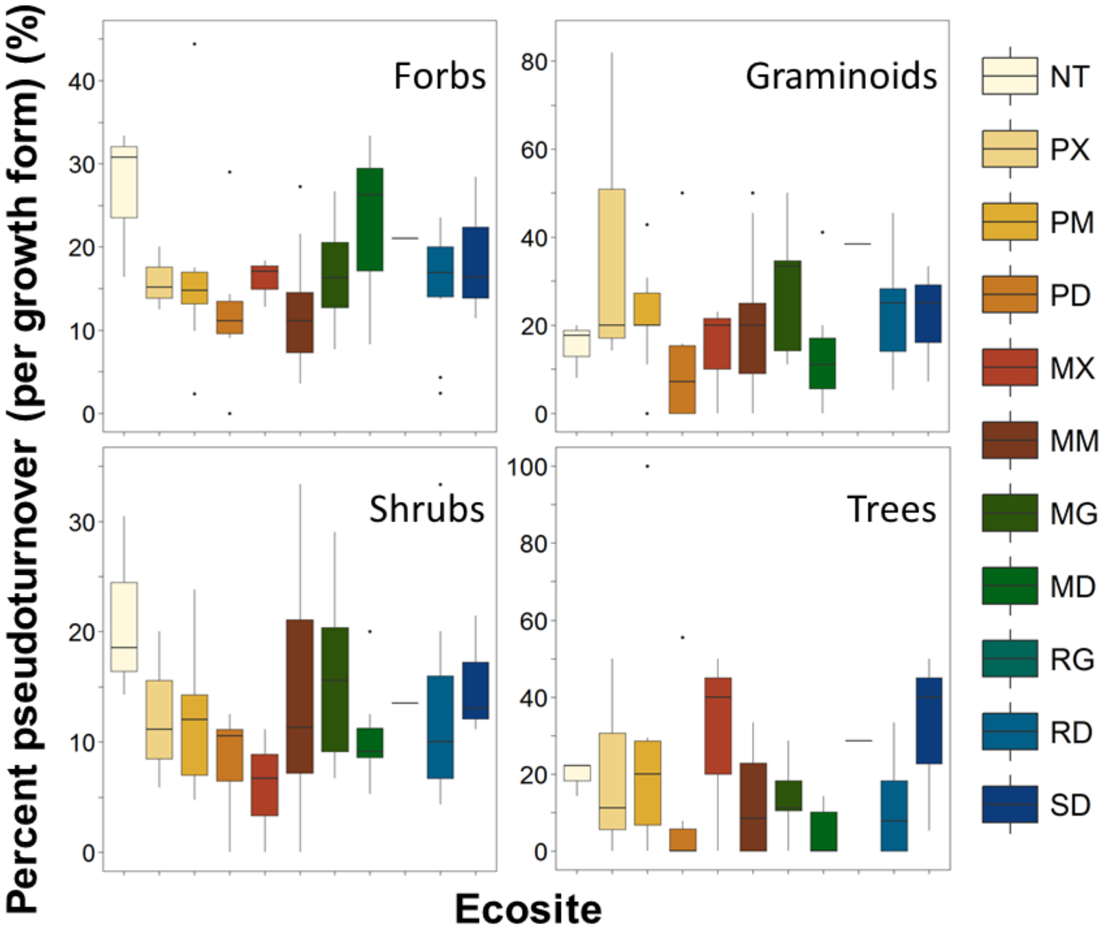

Figure A4.1. Variation in pseudoturnover per growth form across the 11 ecosite categories included in the repeat survey dataset.

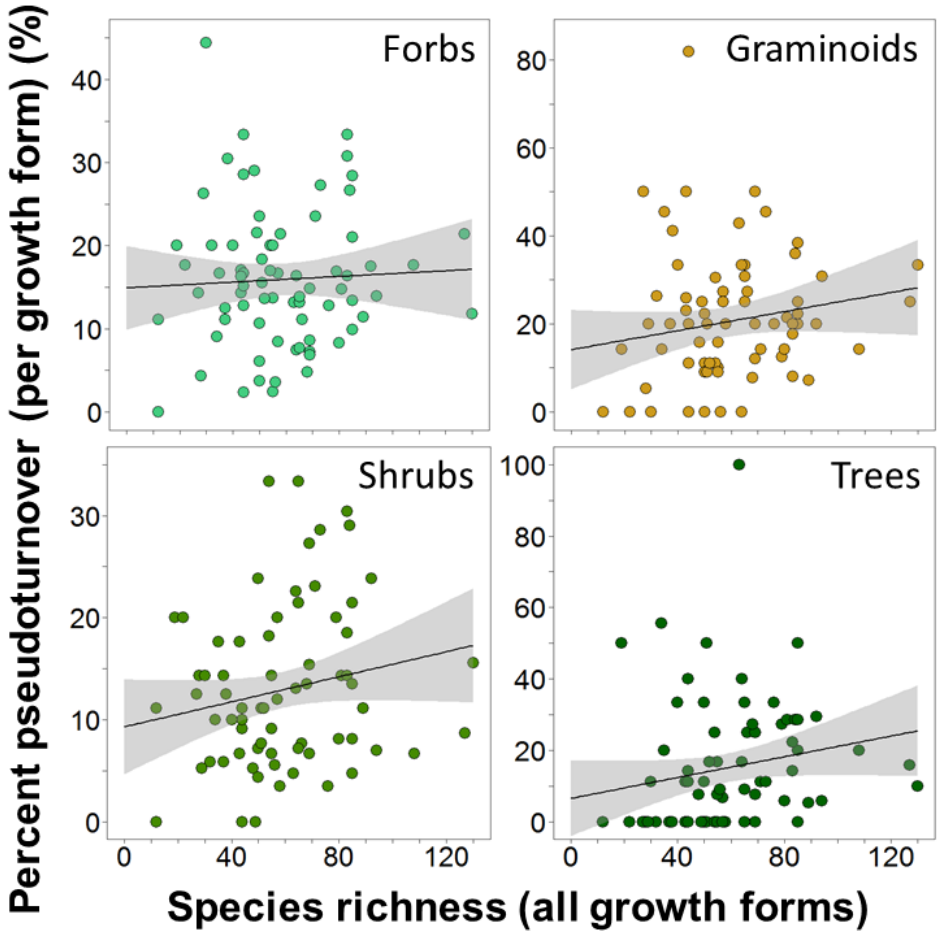

Figure A4.2. Relationships between pseudoturnover per growth form and total richness for the repeat survey dataset. Axes were not $\log_{10}$-transformed for legibility purposes; however, some variables were transformed in the linear models.

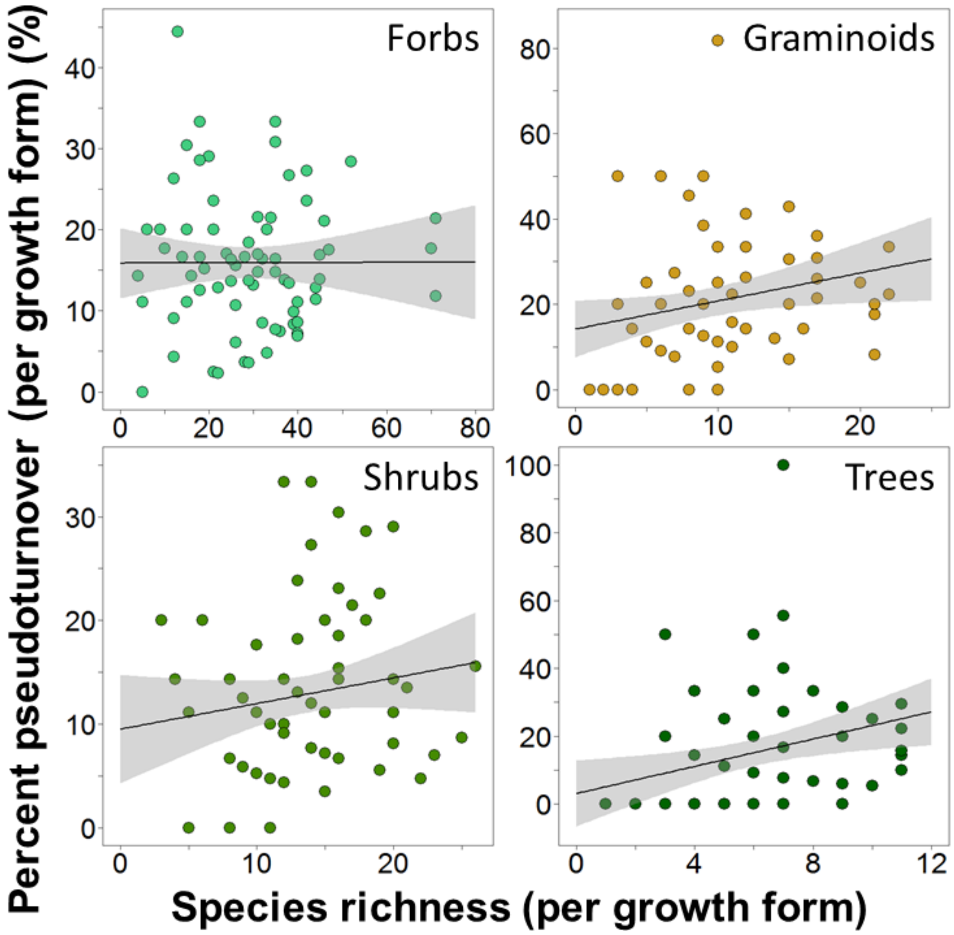

Figure A4.3. Relationships between pseudoturnover per growth form and individual growth form richness for the repeat survey dataset. Axes were not log_{10}-transformed for legibility purposes; however, some variables were transformed in the linear models.

Models for the number of species missed per growth form

Table A4.5. Summary of linear models examining relationships between the number of forb species missed and total richness, forb richness, and ecosite category for the repeat survey dataset. Log_{10} transformations were applied to all continuous variables.

	Model Variable	Beta Coefficient	S.E.	*p*
Forb	Relationship with species richness (all growth forms): $R^2 = 0.411$			
	Intercept	-0.800	0.118	<0.001
	Richness	0.807	0.069	<0.001
	Relationship with forb richness: $R^2 = 0.394$			
	Intercept	-0.332	0.081	<0.001
	Forb richness	0.659	0.058	<0.001
	Relationship with ecosite: $R^2 = 0.296$			
	Intercept	0.573	0.035	<0.001
	NT	0.235	0.071	0.001
	PX	-0.147	0.112	0.193
	PM	0.084	0.071	0.238
	PD	-0.402	0.064	<0.001
	MX	0.054	0.112	0.632
	MG	0.195	0.078	0.013
	MD	-0.023	0.062	0.710
	RG	0.334	0.188	0.078
	RD	-0.032	0.066	0.624
	SD	0.257	0.112	0.023

Table A4.6. Summary of linear models examining relationships between the number of graminoid species missed and total richness, graminoid richness, and ecosite category for the repeat survey dataset. A log_{10} transformation was applied only to the number of species missed.

	Model Variable	Beta Coefficient	S.E.	*p*
Graminoid	Relationship with species richness (all growth forms): $R^2 = 0.26$			
	Intercept	0.011	0.041	0.782
	Richness	0.006	0.001	<0.001
	Relationship with graminoid richness: $R^2 = 0.422$			
	Intercept	0.052	0.027	0.052
	Graminoid richness	0.029	0.002	<0.001
	Relationship with ecosite: $R^2 = 0.204$			
	Intercept	0.275	0.032	<0.001
	NT	0.260	0.065	<0.001
	PX	0.117	0.102	0.255
	PM	0.136	0.065	0.037
	PD	-0.181	0.058	0.002
	MX	-0.066	0.102	0.523
	MG	0.194	0.071	0.007
	MD	-0.044	0.057	0.435
	RG	0.225	0.172	0.191
	RD	0.183	0.060	0.003
	SD	0.083	0.102	0.419

Table A4.7. Summary of linear models examining relationships between the number of shrub species missed and total richness, shrub richness, and ecosite category for the repeat survey dataset. No $\log_{10}$ transformations were applied to any variables.

	Model Variable	**Beta Coefficient**	**S.E.**	***p***
Shrub	Relationship with species richness (all growth forms): $R^2 = 0.180$			
	Intercept	0.003	0.246	0.989
	Richness	0.027	0.004	<0.001
	Relationship with shrub richness: $R^2 = 0.185$			
	Intercept	-0.318	0.288	0.270
	Shrub richness	0.137	0.020	<0.001
	Relationship with ecosite: $R^2 = 0.136$			
	Intercept	1.750	0.191	<0.001
	NT	0.917	0.387	0.019
	PX	-0.917	0.614	0.137
	PM	-0.250	0.387	0.519
	PD	-1.292	0.349	<0.001
	MX	-1.250	0.614	0.043
	MG	0.536	0.427	0.211
	MD	-0.789	0.339	0.021
	RG	0.750	1.028	0.467
	RD	-0.341	0.360	0.344
	SD	0.417	0.614	0.498

Table A4.8. Summary of linear models examining relationships between the number of tree species missed and total richness, tree richness, and ecosite category for the repeat survey dataset. A $\log_{10}$ transformation was applied only to the number of species missed.

	Model Variable	Beta Coefficient	S.E.	*p*
Tree	Relationship with species richness (all growth forms): $R^2 = 0.166$			
	Intercept	-0.041	0.037	0.264
	Richness	0.004	0.001	<0.001
	Relationship with tree richness: $R^2 = 0.220$			
	Intercept	-0.044	0.032	0.169
	Tree richness	0.036	0.005	<0.001
	Relationship with ecosite: $R^2 = 0.135$			
	Intercept	0.138	0.028	<0.001
	NT	0.195	0.057	0.001
	PX	-0.008	0.090	0.927
	PM	0.162	0.057	0.005
	PD	-0.093	0.051	0.071
	MX	0.172	0.090	0.059
	MG	0.081	0.063	0.200
	MD	-0.057	0.050	0.255
	RG	0.212	0.151	0.164
	RD	0.009	0.053	0.862
	SD	0.188	0.090	0.039

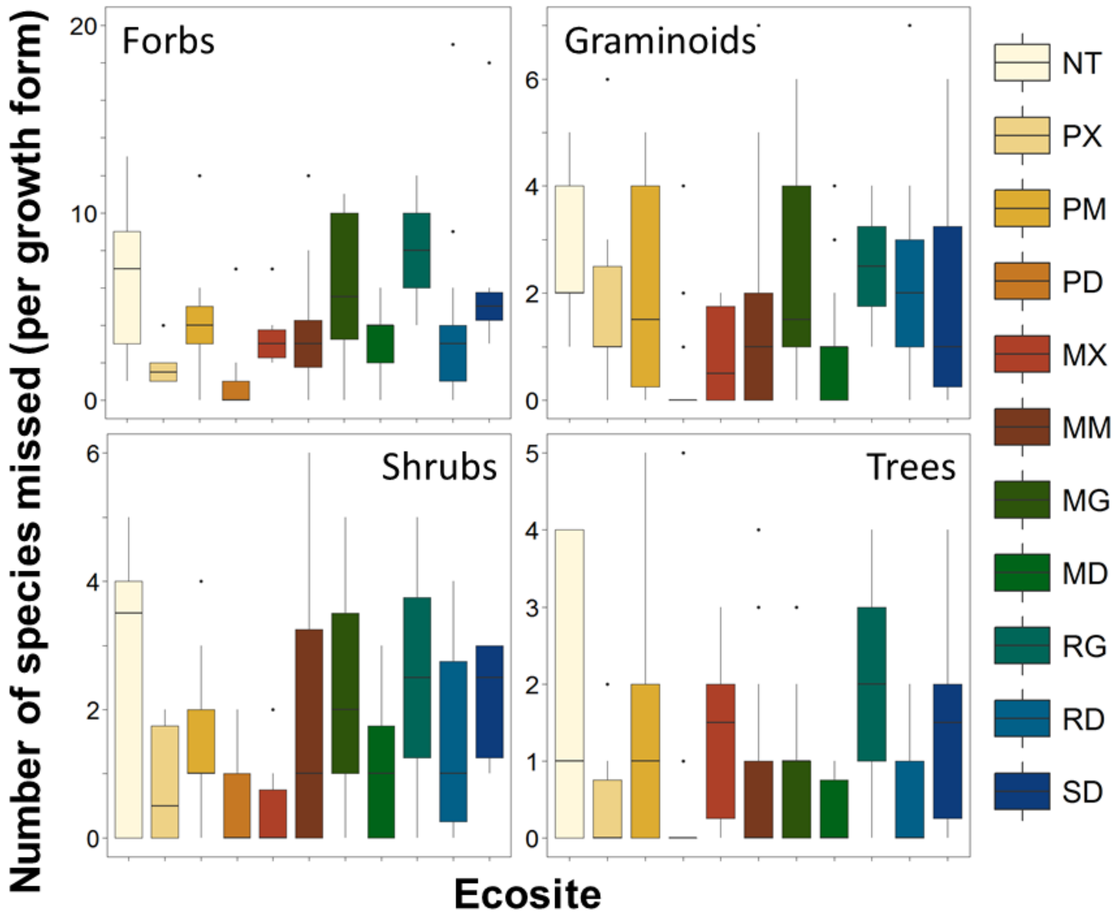

Figure A4.4. Variation in the number of species missed per growth form across the 11 ecosite categories included in the repeat survey dataset.

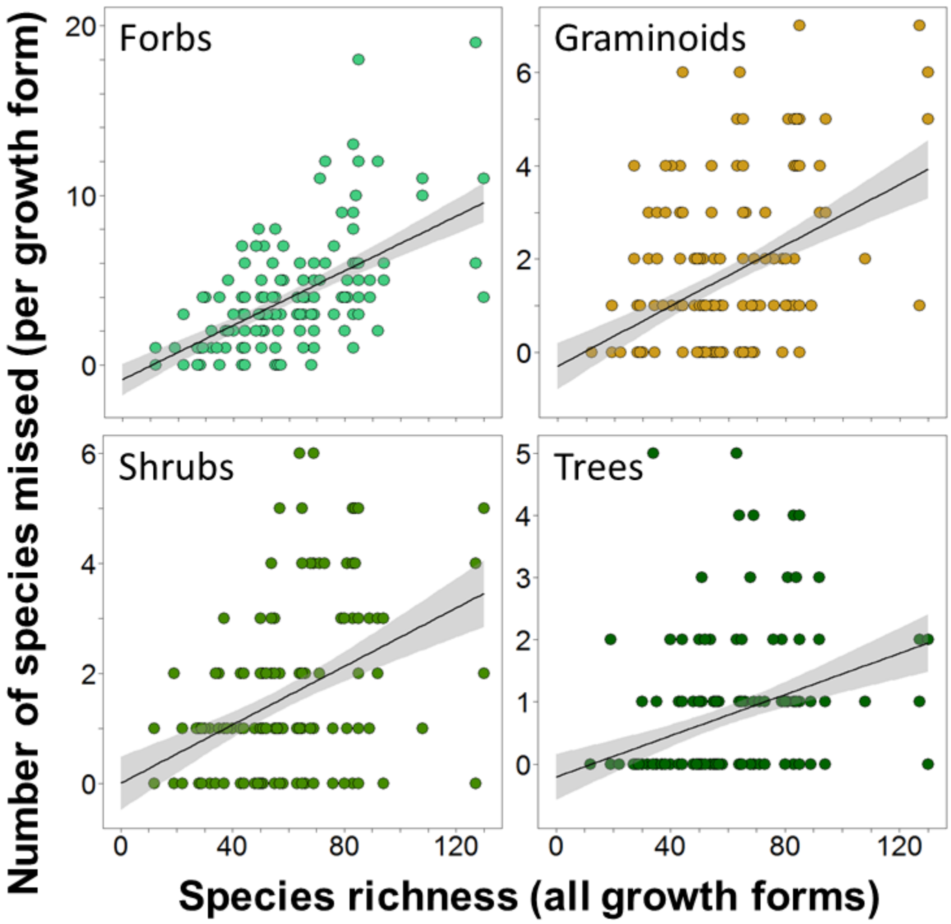

Figure A4.5. Relationships between the number of species missed per growth form and total richness for the repeat survey dataset. Axes were not log_{10}-transformed for legibility purposes; however, some variables were transformed in the linear models.

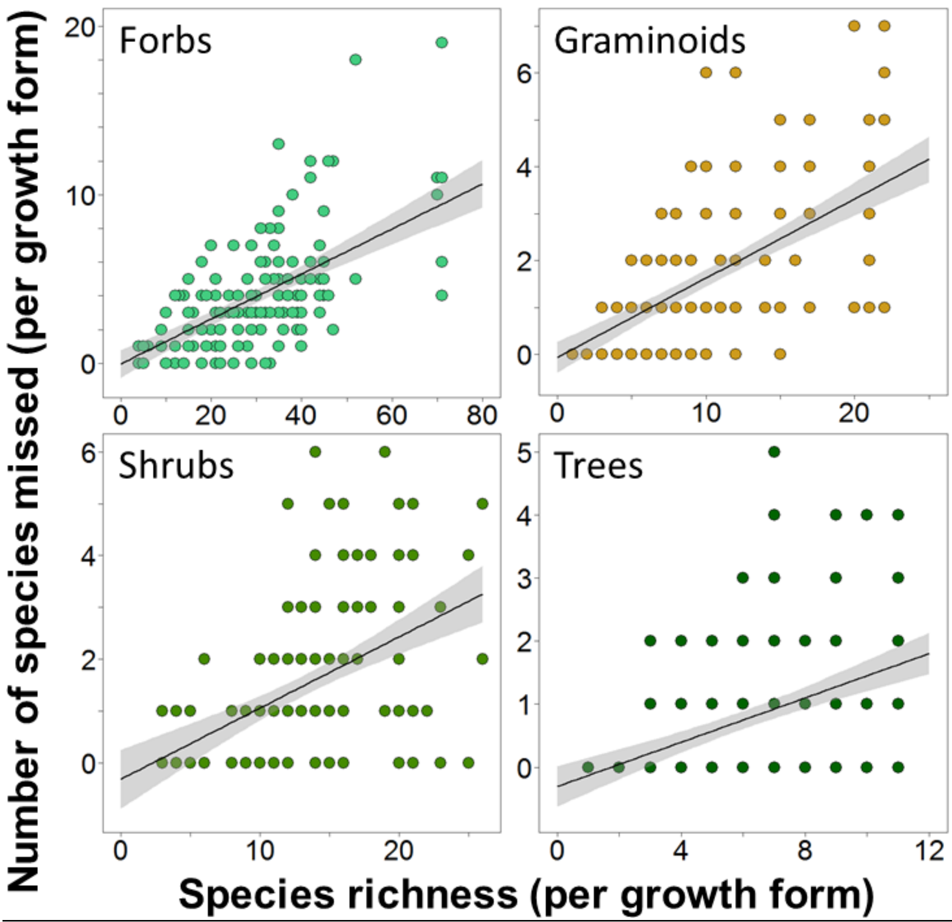

Figure A4.6. Relationships between the number of species missed per growth form and individual growth form richness for the repeat survey dataset. Axes were not $\log_{10}$-transformed for legibility purposes; however, some variables were transformed in the linear models.

APPENDIX 5.1 Single species models (*Allium cernuum*).

Table A5.1.1. Results of AIC model comparison of candidate models relating the success of detecting *Allium cernuum* (*n* = 53) to explanatory survey variables. Abundance was log transformed in all models. Survey order refers to the order in which plots were completed by a given observer.

Model	K	AIC	ΔAIC
success ~ abundance + survey order + (1 | plot) + (1 | observer)	4	69.4	0
success ~ abundance + arrangement + survey order + (1 | plot) + (1 | observer)	5	69.6	0.2
success ~ abundance + arrangement + (1 | plot) + (1 | observer)	4	71	1.6
success ~ abundance * arrangement + (1 | plot) + (1 | observer)	5	71.2	1.8
success ~ (1 | plot) + (1 | observer)	2	74.9	5.5
success ~ survey order + (1 | plot) + (1 | observer)	3	75.2	5.8

Table A5.1.2. Parameters of the best-fitting model of *Allium cernuum* detection success (*n* = 53) as determined by AIC model evaluation (Table A5.1.1). Abundance was log transformed in all models.

Parameter (units)	Standardized coefficient	Standardized standard error	p-value
Intercept	0.00	0.00	*0.00*
Abundance	2.30	0.93	*0.01*
Survey order	1.32	0.71	*0.06*

APPENDIX 7.1 Location of 40 historic rare plant populations visited in the field in 2016 to determine persistence.

Table A7.1.1. Field locations surveyed in 2016 (*n* = 40). EO_ID is the element occurrence ID assigned by ACIMS to recorded populations, we used these ID's for field visits.

EO_ID	Target species	S-Rank	Latitude	Longitude	Habitat Class	Date of survey(s)
7307	*Lactuca biennis*	S3	54.586400	-110.453260	Upland	7/11/2016
9346	*Nymphaea leibergii*	S2	57.432360	-111.613460	Aquatic	8/21/2016
9347	*Nymphaea leibergii*	S2	57.419750	-111.559520	Aquatic	8/25/2016
9348	*Nymphaea leibergii*	S2	57.419210	-111.554990	Aquatic	8/25/2016
9349	*Nymphaea leibergii*	S2	57.418220	-111.548700	Aquatic	8/25/2016
9568	*Polygaloides paucifolia*	S2	54.550777	-111.218050	Upland	6/25/2016
10145	*Potentilla bimundorum*	S2	57.374374	-111.634628	Disturbed	7/25/2016
12310	*Carex vulpinoidea*	S3	54.599339	-110.493175	Disturbed	8, 13/07/2016
12313	*Carex vulpinoidea*	S3	54.605110	-110.503670	Disturbed	7/7/2016
12919	*Cypripedium acaule*	S3	57.173872	-111.601275	Upland	8/20/2016
12921	*Cypripedium acaule*	S3	57.148680	-111.600020	Upland	6/26/2016
13052	*Spiranthes lacera*	S2	56.759783	-111.536999	Upland	7/20/2016
14087	*Isoetes echinospora*	S2	56.368259	-111.282659	Aquatic	8/14/2016
15698	*Sceptridium oneidense*	S1	57.065161	-111.876823	Upland	23, 24, 25, 26/07/2016
15894	*Lactuca biennis*	S3	54.577226	-110.488344	Upland	7, 11/07/2016
16009	*Carex oligosperma*	S3	57.524580	-111.300949	Aquatic	8/22/2016
16392	*Cypripedium acaule*	S3	57.524660	-111.468760	Upland	8/26/2016
16996	*Cypripedium acaule*	S3	57.539200	-111.070270	Upland	8/26/2016
16998	*Cypripedium acaule*	S3	57.549896	-111.058412	Upland	8/26/2016
17304	*Cypripedium acaule*	S3	57.060493	-111.886521	Upland	7/22/2016
17613	*Lathyrus palustris*	S1	57.539190	-111.076370	Aquatic	8/26/2016
18593	*Isoetes echinospora*	S2	55.946318	-112.028961	Aquatic	8/13/2016
18899	*Najas flexilis*	S3	54.529111	-110.334627	Aquatic	6,13/07/2016
*18901	*Najas flexilis*	S4	54.529110	-110.334615	Aquatic	6,13/07/2016
*18903	*Najas flexilis*	S5	54.525685	-110.344503	Aquatic	6,13/07/2016
*19177	*Najas flexilis*	S6	54.524403	-110.332506	Aquatic	6,13/07/2016
*19178	*Najas flexilis*	S7	54.523628	-110.343452	Aquatic	6,13/07/2016
21514	*Dryopteris cristata*	S8	56.282640	-110.963770	Upland	7/27/2016
21515	*Dryopteris cristata*	S3	56.443755	-110.989417	Upland	7/27/2016
21588	*Spiranthes lacera*	S2	56.878380	-111.469850	Upland	6/26/2016
21595	*Cypripedium acaule*	S3	56.879900	-111.470420	Disturbed	6/26/2016
21808	*Dryopteris cristata*	S3	56.451766	-111.317433	Upland	8/25/2016
21809	*Dryopteris cristata*	S3	56.434471	-111.344241	Upland	8/24/2016

21810	*Phegopteris connectilis*	S3	56.429970	-111.331278	Upland	6/25/2016
22025	*Dryopteris cristata*	S3	54.731225	-110.331360	Upland	7/17/2016
22324	*Liparis loeselii*	S2	54.721840	-112.386980	Aquatic	6/29/2016
22327	*Nymphaea tetragona*	S2	56.899321	-111.433066	Aquatic	6/25/2016
22585	*Sceptridium oneidense*	S1	57.041188	-111.873259	Disturbed	7/22/2016
24360	*Gratiola neglecta*	S3	53.742860	-110.715750	Disturbed	7/14/2016
24362	*Gratiola neglecta*	S3	53.660144	-110.760607	Disturbed	8/6/2016
24369	*Botrychium crenulatum*	S3	54.018090	-110.592985	Upland	10,12/07/2016
24414	*Houstonia longifolia*	S3	53.784130	-110.683980	Upland	8/6/2016
24440	*Lactuca biennis*	S3	56.436440	-111.297900	Upland	8/20/2016
24443	*Lactuca biennis*	S3	56.484033	-111.301773	Disturbed	8/28/2016

***** Five *Najas flexilis* sites included in the ACIMS database occur around the shores of Ethel Lake, outside of Cold Lake, Alberta with no physical boundaries between sites (i.e. effectively one population). We report their locations here but have treated them as one population in all analyses.

APPENDIX 7.2 Analysis of survey time and target species abundance in rare plant population revisitation surveys.

Imperfect detection of organisms during surveys, particularly rare species, has gained significant attention in recent years (MacKenzie *et al.* 2005; Chen *et al.* 2009; Alexander *et al.* 2012; McCarthy *et al.* 2013). Population size, a factor shown to influence detectability (Alexander *et al.* 2012; McCarthy *et al.* 2013), varied widely among sites and target species at the 37 field sites discussed in Chapter 7. To better understand potential advantages to surveying large populations and the difference in effort expended to detect small vs. large populations in the field, we compared survey effort (time) and the population size of detected target species using linear regression. Both variables were log transformed prior to analysis to normalize variables.

Surveyors searched the target area exhaustively using time unlimited surveys at all 37 field sites. A maximum of 21 person hours occurred at one site, although in many cases (n = 13) the target species were detected shortly after starting surveys ('detection upon arrival'). Median total search time when species were encountered was 0 minutes (range: 0-120, $\bar{x}$ = 26), when species were absent median search time was 360 minutes (range: 10-1260, $\bar{x}$ = 401). Where population sizes were small (< 30 individuals), total search effort required to detect species was at maximum 2 person hours, however up to 10.5 person hours were expended at non-detection sites to achieve reasonable confidence of absence. All populations > 30 individuals were detected upon arrival. Supporting our expectation, survey effort (time) was significantly negatively related to population size (r^2 = 0.62, p = < 0.001).

Our findings have practical application for future revisitation surveys. Logistically, surveys to confirm absence may require multiple days and target species which occur at low abundance require significant search time (e.g. 2 hours for a 50-m radius circle). Surveys reporting extirpations of small populations (as determined by the reported initial population size) must be accompanied by a metric of search effort to ensure confidence in findings. These data are now requested by ACIMS with public submissions; however, we suggest this be adopted as a standard by industry, consultants, and researchers.

APPENDIX 7.3. Visually classified amounts of human footprint (footprint severity) for 188 provincial rare plant records.

Table A7.3.1. Amount of footprint potentially impacting historic rare plant populations based on visual examination using Google Earth imagery within the oil sands area, Alberta (*n* = 119).

Amount of human footprint	Number (%)	Species
High	6 (5%)	*Cardamine parviflora*
		Gratiola neglecta
		Polygaloides paucifolia
		Potentilla bimundorum
Moderate	15 (13%)	*Blysmopsis rufa*
		Botrychium hesperium
		Campanula aparinoides
		Cardamine dentata
		Carex vulpinoidea
		Cypripedium acaule
		Houstonia longifolia
		Lactuca biennis
		Malaxis paludosa
		Plantago maritima
		Potentilla bimundorum
		Spiranthes lacera
Low	90 (76%)	*Arctagrostis latifolia ssp. arundinacea*
		Arethusa bulbosa
		Astragalus bodinii
		Botrychium crenulatum
		Botrychium matricariifolium
		Botrychium michiganense
		Carex oligosperma
		Carex vulpinoidea
		Cypripedium acaule
		Dryopteris cristata
		Elodea canadensis
		Eutrema salsugineum
		Gymnocarpium jessoense
		Houstonia longifolia
		Isoetes echinospora
		Lactuca biennis
		Leucophysalis grandiflora

		Malaxis paludosa *Najas flexilis* *Nymphaea tetragona* *Pellaea glabella ssp. simplex* *Phegopteris connectilis* *Piptatherum canadense* *Polygaloides paucifolia* *Salix sitchensis* *Scirpus pallidus* *Spiranthes lacera* *Utricularia cornuta* *Utricularia ochroleuca*
ND	8 (1%)	*Astragalus bodinii* *Cardamine parviflora* *Cypripedium acaule* *Houstonia longifolia* *Polygaloides paucifolia* *Potamogeton amplifolius* *Spartina pectinata*

Table A7.3.2 Amount of footprint potentially impacting historic rare plant populations based on visual examination using Google Earth imagery within the surface mineable area, Alberta (*n* = 69).

Amount of human footprint	Number (%)	Species
High	6 (9%)	*Campanula aparinoides* *Cypripedium acaule* *Malaxis paludosa* *Nymphaea tetragona* *Potentilla bimundorum* *Sceptridium oneidense*
Moderate	9 (13%)	*Cypripedium acaule* *Leucophysalis grandiflora* *Sceptridium oneidense*
Low	53 (77%)	*Campanula aparinoides* *Carex oligosperma* *Cypripedium acaule* *Cystopteris montana* *Dryopteris cristata* *Elodea canadensis*

		Epilobium halleanum *Gentianopsis detonsa ssp. raupii* *Lathyrus palustris* *Liparis loeselii* *Malaxis paludosa* *Nymphaea leibergii* *Nymphaea tetragona* *Plantago maritima* *Sparganium glomeratum* *Spartina pectinata* *Spiranthes lacera*
ND	1 (1%)	*Polygaloides paucifolia*

APPENDIX 7.4 Presumed misidentification of three ACIMS recorded populations in the oil sands area.

Three of our 40 surveyed populations (7%) are strongly suspected to be misidentifications in the original records (false positives). These populations were recorded and submitted as *Dryopteris cristata* (S3, *n* = 2) and *Spiranthes lacera* (S2, *n* = 1). In the case of the two *D. cristata* records, a similar common species, *Dryopteris carthusiana*, was found in abundance at both survey locations. Both locations were searched for 6 person hours by our observers. *Dryopteris cristata* is distinguished from its congeners by being mostly bipinnate, rather than bipinnate to tripinnate, and mostly lacking spinulose tips to the pinnules, key characters which can be challenging to recognize. We suspect that young individuals of *D. carthusiana* could have been mistaken for *D. cristata*. In the case of *S. lacera*, an orchid identified by its singular row of spirally arranged white flowers, site conditions did not match those associated with this species. *Spiranthes lacera* is almost exclusively found in dry, sandy, Jack pine-dominated forests in our region; site conditions at this location were moist mixedwood, dominated by *Picea glauca* and *Populus balsamifera*, with a mossy substrate. Four meters from the original record centroid we encountered a single *Goodyera repens*, a superficially similar species which, despite key differences, shares a white, loosely spiralled floral arrangement with *S. lacera*. We consider this to have been a misidentification based on the superficial similarity of this species, the location of the individual relative to the record centroid, and the habitat.