Invasive plant removal strategies and native plant community recovery in Ontario, Canada

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Abstract

The introduction and spread of invasive species are of major conservation concern. Invasive plant species are hypothesized to impact the population dynamics of native flora, including species at risk (SAR), and may disrupt the functioning of the plant communities which they invade. Some native plant populations may be more vulnerable due to pre-existing factors such as fragmented habitat, poor competitive nature, and/or limited geographical ranges. Because of this, the presence of one or more invasive species is frequently cited as a leading cause of at-risk species decline. However, the actual evidence for this link is weak and the mechanisms are unclear. In this study, I aimed to (1) determine the effect of invasive management schemes on the recovery of native plant communities and to (2) examine the role of factors such as method of removal and duration of invasive removal at two conservation areas in southern Ontario. After 12 candidate study areas were surveyed, two were chosen for the study (for logistical reasons). Specifically, pairs of 'control' and 'invasive' removal sites were established at St. Williams Conservation Reserve, near Turkey Point Provincial Park, ON (*N* = 10) and Bruce Peninsula National Park, ON (*N* = 8) through May - August 2018. Plots were surveyed for native and invasive plant species richness and abundance using transect methods. I found a significant difference in the abundance of native and invasive plants between control and treatment plots at St. Williams Conservation Reserve and Bruce Peninsula National Park, although the trends were in the opposite direction. Neither site had a significant difference in plant diversity between treatment types. I discuss my findings in light of the differences in land use history and

management at the two areas and their implications for invasive removal schemes to manage for native plant conservation.

Résumé

L'introduction et la propagation d'espèces envahissantes sont un problème majeur pour la conservation. Les espèces végétales envahissantes peuvent modifier la dynamique des populations de la flore indigène, y compris des espèces en péril (EEP), et peuvent perturber le fonctionnement des communautés végétales qu'elles envahissent. Certaines populations de plantes indigènes affectées par ces altérations peuvent être particulièrement vulnérables en raison de facteurs préexistants tels que la fragmentation des habitats, l'infériorité concurrentielle et / ou des aires de répartition géographique limitées. Pour cette raison, la présence d'une ou de plusieurs espèces envahissantes est fréquemment citée comme l'une des principales causes du déclin des espèces en péril. Cependant, les preuves réelles de ce lien sont faibles et les mécanismes peu clairs. Dans cette étude, je visais à (1) déterminer l'effet des schémas de gestion des espèces invasives sur le rétablissement des communautés végétales indigènes et à (2) examiner le rôle de facteurs tels que la méthode d'élimination et la durée de l'élimination des espèces invasives dans deux zones de conservation du sud Ontario. Après avoir étudié 12 zones d'étude potentielles, deux zones ont été choisies pour l'étude. Plus précisément, des paires de sites de contrôle et d'élimination des espèces envahissantes ont été établies dans la Réserve de conservation de St. Williams, près du parc provincial de Turkey Point, ON (N = 10) et du Parc national de la péninsule Bruce (N = 8) de mai à août 2018, et la richesse en espèces végétales ainsi que leur abondance ont été estimées à l'aide de transects. J'ai trouvé une différence significative dans l'abondance des plantes indigènes et envahissantes entre les parcelles de contrôle et de traitement dans la Réserve de conservation de St. Williams

et le Parc national de la Péninsule-Bruce, bien que les tendances étaient dans la direction opposée. Aucun des deux sites ne présentait de différence significative dans la diversité végétale entre les types de traitement. Je discute de mes résultats à la lumière des différences dans l'historique de l'utilisation des terres et de la gestion entre les deux zones et leurs implications pour les programmes de suppression des espèces envahissantes pour la conservation des plantes indigènes.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Chapter 1: General Introduction

The introduction and spread of invasive species are of global conservation concern due to their ability to modify aquatic and terrestrial ecosystems (Gurevitch & Padilla 2004). The total number of new invasive species continues to increase in ecosystems across North America, despite increased awareness and conservation (Ruiz *et al.* 2000), with vascular plants being among the most common invaders (Vitousek *et al.* 1997). The literature on biological invasions is immense and growing, leading to increased awareness among scientists, the general public and policy makers (Lowry *et al.* 2013). The suite of impacts that are often associated with exotic plant invasions is widely accepted, however, the specific ecological drivers of their effects remain poorly understood and controversial (Stinson *et al.* 2006). There is scant evidence that the control and eradication of invasives can lead to an increase in native species richness, vegetative cover, recruitment and diversity, although removing and managing invasive species is a common goal at all levels of government (Zavaleta *et al.* 2001). Yet, even how we define and refer to invasive species is unclear, with biologists typically using the term 'invasive' for instances when a species spreads rapidly and persists extensively outside of its range (Simberloff 2013), and others reserving 'invasive' for references to introduced species that cause negative economic, ecological or health impacts (Colautti *et al.* 2006). Other commonly used terms include alien, exotic, non-indigenous, non-native, noxious, nuisance, pest, and weed (Colautti *et al.* 2006; Simberloff 2013).

Invasives are frequently suspected to impose detrimental effects to species-at-risk (SAR), including vascular plants (Hobbs & Huenneke 1992; Rand *et al.* 2015). In fact, invasives are recognized by the International Union for Conservation of Nature (IUCN) as one of the primary threats to SAR (IUCN/SSC 2000). This is true in Canada as well, with invasives frequently listed alongside habitat loss and degradation, pollution, and overexploitation as major threats to native plant communities (Hayward 2009).

In the Canadian context, the largest proportion of invasive plants are found in areas with high land use transformation, with southern Ontario and southern British Columbia being the most susceptible, where introduced plant species frequently invade fragmented natural habitats (White *et al.* 1993). The province of Ontario has 4143 vascular plant species, of which 1279 or roughly 31% are considered invasive (NHIC 2020). A large proportion of these are garden weeds and horticultural escapees, and many arguably pose a minimal threat to native communities because they are usually restricted to agricultural fields, urban landscapes, and other highly disturbed areas (Henson *et al.* 2005). However, some of these invasives have expanded their range to natural areas, including *Taraxacum officinale* (common dandelion) and *Epipactis helleborine* (broad- leaved helleborine), but currently occur in small numbers and /or do not negatively affect natives (White *et al.* 1993). There are, of course, invasives that spread and thrive outside of their range and that disrupt native plant communities, two classic examples include *Rhamnus cathartica* (European Buckthorn) and *Alliaria petiolata* (Garlic Mustard) (White *et al.* 1993; Henson *et al.* 2005). The habitats most likely to be negatively affected by invasions are those that are already under ecological stress from disturbances such as fragmentation, land use change, and pollution (Vitousek *et al.* 1997).

Various control measures, such as removals, implemented for invasive plants are arguably the most common type of restoration efforts for native flora (D'Antonio, August-Schmidt & Fernandez- Going 2016). Removing invasives ideally results in a recovery of native plant richness and biomass (Flory & Clay 2009). There are five main classical control methods for invasive species: 1) mechanical removal, 2) chemical herbicide/ pesticide, 3) prescribed burns, 4) integrated pest management, and 5) biological control. Ideally, the strategy would be determined after considering the ecological impact, human impact, and cost in both the short and long term (White *et al.* 1993). Depending on need and response to communities, classic removal methods should be coupled with seed additive treatments of natives.

Despite a myriad of different removal methods, the impacts of different removal techniques on native communities is not well studied (Zavaleta *et al.* 2001). The few studies that have addressed this question have demonstrated that native plant community response is often contingent on removal methods and target species (Biggerstaff & Beck 2007; Mason & French 2007; Flory & Clay 2009). This is because different invasive species facilitate different changes to native plant communities, and because of this, the unique impact(s) of each invasive may need to be identified to implement the most appropriate removal technique.

Considering that invasives are so often cited as a threat to native plants, studies that examine the efficacy of removal methods and/ or restoration efforts are essential for developing effective community restoration efforts (Hulme & Bremner 2006). For example, Hulme (2006) articulates that 'much research to date is primarily concerned with quantifying the scale of the problem rather than delivering robust solutions and has not adequately addressed all stages of the invasion process, and only a few studies embrace the ecosystem approach'. Lacking research on the efficacy of invasive management, it is difficult to create effective management plans (Kettenring & Adams 2011). An additional issue is that restoration efforts themselves are prone to invasion due to disturbance, which can be an obstacle to the restoration process (D'Antonio and Meyerson 2002).

Given this, the goals of my study were 1) to establish a database of invasive management schemes in Ontario and western Quebec and 2) to examine the effects of invasive removal on the plant native community in a set of conservation areas. Here, I describe the outcome of this endeavour and discuss the next steps for improving the design and implantation of invasive plant management schemes.

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Chapter 2: The effect of invasive plant removal strategies on native plant community recovery in Canada

2.1: Introduction

Native plant abundance and distribution are determined by abiotic, but also biotic factors, such as competition from neighbouring plants (Gurevitch & Padilla 2004). Indeed, the presence of one or more invasive species is frequently cited as a leading cause of extinction threat for natives (Wilcove *et al.* 1998). Invasives are cited as the second largest driving force for species endangerment behind habitat loss and alteration (Wilcove *et al.* 1998), including among reports contracted by the Ontario and Canadian governments for assessing species at risk of extinction (Appendix 1). Some native plant populations may be especially vulnerable due to pre-existing factors such as fragmented habitat, poor competitive nature, and/or limited geographical ranges (Walck *et al.* 1999). However, as reviewed by Gurevitch and Padilla (2004), evidence for a mechanistic link between plant invasions and native species decline is weak, and the factors that drive the association are not always clear (Levine *et al.* 2003). Hypothesized causes of species loss and threats are largely speculative, and currently lack sufficient experimental field support (Gurevitch & Padilla 2004, Kettenring & Adams, 2011, Vilà *et al.* 2011).

Only a small number of studies have attempted to quantify both the degree and extent to which invasive plant species impact rare and endemic plants (Huenneke & Thomson 1995; Lesica & Shelly 1996; Walck *et al.* 1999; Thomson 2005; Combs *et al.* 2011; Rojas-Sandoval & Meléndez-Ackerman 2012; Grewell *et al.* 2013). Levine *et al.* (2003) reported that only 5% of studies looking at the impacts of invasions on plant diversity had actually tested the specific mechanism of the impact (e.g., via competition, allelopathy). In fact, there is good reason to suspect that the correlation could be spurious in many cases, since the presence of invasives frequently co-occurs independently with other risk factors for endangerment, such as habitat disturbance (Gurevitch & Padilla 2004; Didham *et al.* 2007). This is concerning because the active management of invasive species is one of the primary management strategies currently applied to plant conservation (Rand *et al.* 2015). Yet, the most efficient eradication methods cannot be assessed without the proper information regarding the mechanisms that cause native species declines via dominant invasives (Rand *et al.* 2015). This begs the question as to whether current management strategies are effectively operating to improve native plant diversity and/or reduce presence of invasives (Rand *et al.* 2015).

There are two main models to explain the association between the presence of invasives and the decline of native species abundance and diversity. The first is the 'driver' or 'highly interactive' model, which predicts that invasive species are superior competitors causing native species to be limited in resources, and therefore decline in number (Tilman 1988). On the other hand, the 'passenger' or 'weakly interactive' model, predicts that declines experienced by natives are explained by co-occurring non- interactive factors, such as habitat disturbance, along with reproductive barriers (e.g., low recruitment, many years to maturity) that prevent natives from tolerating environmental stressors (Seabloom *et al.* 2003). These two models have very different implications for the management of invasives species. If the driver model is the predominant pathway by which invasives impact native ecosystems, then eradication efforts should be the most suitable approach for native recovery. On the other hand, if invasions and native species decline are both associated with a third driver (e.g., habitat disturbance or loss), this calls for a different approach, such as habitat restoration in the form of seedling planting. For example, *Betula lenta L.* (Cherry Birch), *Castilleja levisecta* (Golden Paintbrush), and *Cirsium hillii* (Hill's Thistle) are three example of Canadian SAR that are grown in-lab via micropropagation that have been later transplanted into the field as seedlings, which has been deemed a successful regeneration strategy for these species (Sheikholeslami *et al.* 2020).

In a highly cited study, MacDougall and Turkington (2005) tested whether two dominant invasive grasses played a role in reducing the abundance of rare/endangered plants in an oak-savannah habitat in coastal British Columbia. Using an experimental approach, they demonstrated that the growth, abundance and reproduction of only some native oak savannah species were positively influenced by the removal of the invasive grasses. Interestingly, competition with invasives alone was not able to explain the rarity of 36/79 species, contradicting the driver model of invasive dominance. The results of this study indicate that rare plants in this invaded ecosystem are more likely to be restricted by non-interactive processes (passenger model), such as dispersal limitation, rather than via competition with invaders alone (Germain *et al.* 2017) or, that they are simply unable to respond demographically to invasive removal as a result of demographic constraints that are common characteristics of endangered plants, such as low seed set, elongated dormant stages, or slow development (MacDougall & Turkington 2005),

Removal of invasive plants is a common technique to manage native plant communities in protected areas (PAs) (e.g., national and provincial parks, conservation areas, recreation areas), which are defined as being an area legally designated to conserve the ecosystem characteristic of the region (Sy *et al.* 2009). This is because invasive species are considered to be one of the highest threats posed to PA ecosystem integrity (De Poorter *et al.* 2007; Parks Canada Agency 2008). While the methods of removal vary, they are most often a combination of mechanical (i.e., hand pulling), chemical (i.e., pesticide spray) or burning (Table 2a, b).

A more comprehensive understanding is necessary to better answer the following questions pertaining to the biology of invasive plants: 1) What impact do removal efforts have? 2) Do these impacts vary by region and/ or ecosystem type? 3) Does length of removal effort (e.g., number of years) matter?

For my research, I chose PAs in two regions of southern Ontario from a wider list of potential study sites (Table 1). I studied plant communities in St. Williams Conservation Reserve (SWCR) and Bruce Peninsula National Park (BPNP) located in Simcoe, Ontario and Northern Bruce Peninsula, Ontario, respectively. These two areas were distinct in terms of ecosystem type, understory herb species, and dominant tree/ shrub species, and analyzed independently. For example, SWCR lies within the Carolinian forest (Oldham 2017), while BPNP is characterized by large amounts of *Thuja occidentalis* (northern white- cedar) and the Great Lakes and St. Lawrence lowlands (Parks Canada Agency 2016). Both areas have a high presence of vascular plant species at risk (SAR) and a considerable amount invasive species management, especially with respect to conserving species at risk. In both areas, invasive species removals have been going on for between 2-10 years (Table 2a/2b).

The goal of my thesis was to assess existing invasive species management programs in these two protected areas to determine their effectiveness at controlling invasive species and native plant species restoration. I hypothesized that, if invasive species impact native communities via the driver model, historical removal plots (i.e., those with > 2 years of removal activity), would exhibit higher plant richness and abundance, compared to control plots. I predicted that there would be fewer invasive species in removal plots than control plots since removal plots were chosen to be similar except for removal management.

A second goal was to review the degree to which experts view invasives to be a driving force behind at-risk species decline, relative to other risks such as habitat loss. All species listed under the Species at Risk Act (SARA) as extirpated, endangered or threatened must receive a recovery strategy which describes critical habitat, clearly outlines population and distribution goals for recovery, and lists the major threats to the species, as determined by experts on the species. The reports are important to evaluate because in order to recommend effective management strategies for land managers for practise we need a greater understanding of the threat descriptions (McCune *et al.* 2013).

These recovery strategies are required to clearly describe threats and recovery strategies for each respective species they aim to protect. In a review of 78 finalized reports, I assessed how many explicitly mentioned that invasives are a threat to the SAR in question and, if specified, which invasives were cited as being responsible for decline (Appendix 1).

2.2.1 Methodology

2.2.1.1 Overview

In Canada, 37% of all species at risk fall into the vascular plant category, making it the largest group of species listed under SARA (McCune and Morrison 2020). There are 241 vascular plant species listed for protection as at-risk, of which 87 (44%) are found in Ontario. To examine the impacts of invasive species, I performed a literature review of the SARA (*N* = 67) and Committee on the Status of Endangered Wildlife in Canada (when SARA not available) (COSEWIC) (*N* = 11) recovery strategies for all vascular plants listed in Ontario.

Southern Ontario is the most densely populated region in Canada (Lovett-Doust & Kuntz 2001) creating a serious conservation challenge for species endemic to the area (Ontario Ministry of Natural Resources 2009). The region, geographically, contains less than 1% of Canada's landmass, yet this is where 25% of the population resides (Government of Ontario 2000). My study includes sites in two areas of Ontario, St. William's Conservation Reserve near Simcoe, ON, and Bruce Peninsula National Park, ON. Southern Ontario hosts several unique ecosystems, making it a biodiversity hotspot (Kerr & Deguise 2004). Ecosystem types unique to Southern Ontario include the Carolinian forest, tall grass prairie, oak savannah, Great Lake coastal wetlands, and sand dunes (Oldham 2017). Southern Ontario includes critical habitat for over 40% of Canada's plant species, 85.7% of which are designated Species at Risk (SAR). Species at Risk here is defined as per the formal recognition by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and/ or the Species At Risk Act (SARA) occur in the Carolinian zone (Oldham 2017).

2.2.1.2 Study areas and sites

A set of potential study areas (i.e., locations where long-term invasive plant removal is occurring to preserve or restore SAR) was established by first contacting land managers and biologists of private and public land holdings across Ontario and West Québec (*N* = 12; Table 1). Once contact was made, I requested information from land managers on the history of invasive species removal in the area, including the number of removal sites, the species removed, the removal method, the number of years the removal effort was performed, as well as geographical information (i.e., GPS polygon data in the form of .kml or .kmz files). In addition, I gathered information on whether removals were performed specifically for SAR recovery. Once I had obtained a database of removal projects around the two provinces, I assessed potential study areas according to the size and duration of the removal efforts. These areas included lands owned and maintained by the Nature Conservancy of Canada (NCC), Parks Canada, Long Point Basin Land Trust (LPBLT), and the St. Williams Conservation Reserve (STCR). The candidate areas region ranged as far south as Pelee Island (41°57’46.28” N, 82°31’06.36” W) and as far north as Bruce Peninsula National Park (45°15’25.53” N, 81°39’26.06” W). Ultimately, only two study areas contained a feasible number of adequately sized replicates (defined as at least ten potential removal plots that have been treated for invasives for a minimum of two years). Other areas were also rejected for a variety of reasons such as: removal area size limitations, concern for increased foot ‘traffic’ near SAR, transportation complications, and the inability to support adequate paired control sites.

2.2.1.3 Plant surveys

During the summer of 2018, I surveyed sites at St. Williams Conservation Reserve and Bruce Peninsula National Park. For both areas, I obtained required research and collection permits. Each of these sites has several vascular plant SAR occurrences as well as extensive invasive species removals conducted across the properties. Using management records obtained from the area's administrators, I selected ten previously established invasive species removal 'sites' from each area, determined based on the similarity of the removal site's 'polygon size', which is a measure of the size of the removal perimeter. Sites also needed to have a minimum of two years of removal history, and proximity to SAR (where possible), to be included in the study.

Once the 10 removal sites per area were determined, I then chose a 'control' site to pair with each established 'removal' site, for a total of 20 study sites (10 pairs of one removal and one control) per area. At Bruce Peninsula National Park, two out of ten pairs were eventually dropped for reasons of unsuitability (e.g., size or ability to find a comparable control site).

Control sites were selected in an ecologically similar area nearby (i.e., similar dominant tree and understory herb species) where invasive removal had not been performed. This allowed me to compare the plant communities at removal and control sites. Each control site was placed at least 100 m from the removal, however in a few cases (N = 5) it needed to be closer (50 m), due to lack of availability of a suitable control at that distance.

The plant community at each of the 18 pairs (10 at St. Williams; 8 at BPNP) was thoroughly surveyed once during the summer of 2018 between May and August. Surveys were performed by establishing 2 x 100 m transect lines along which quadrat surveys were performed. At each site, transect lines were strategically placed within a removal polygon, trying to stay away from the edge where possible, in order to avoid edge effects. I marked the transect line start and end points with flags, used GPS to record their position, and then laid down a 100 m transect line using survey tape. At 10 m intervals along the transect a flag was placed so that every 10 m we could easily move along the line and place our 1 m x 1 m survey quadrat. Quadrats alternated between the left and right sides of the line every ten meters. Then, two field technicians and I identified and counted every plant encountered inside the quadrats to obtain a measure of diversity and abundance. Seedlings that were only at the cotyledon stage were not counted due to the difficulty of identifying them to genus or species.

Plant species identification was, to the best of our ability, made in the field using field guides (Newcomb & Morrison 1977). Unknown specimens were carefully photographed, noted for key identifying features, sometimes pressed, and given a code for later identification in the lab. A small proportion of taxa were only identified to the genus level because of insufficient photo detail and extreme difficulty identifying to species when not in flower (e.g., *Viola* spp., *Rubus* spp., *Solidago* spp.). A multitude of resources were used in the identification process. These included *Michigan flora* (Voss & Reznicek 2012), *Shrubs of Ontario* (Soper & Heimburger 1982), and www.gobotany.com's online keys. Additionally, unknown species that could not be identified were sent to expert Dr. Jenny McCune (University of Lethbridge) or Mike Oldham (Ontario Ministry for Natural Resources) for identification.

2.2.1.4. Survey sites

2.2.1.4.1 St. Williams Conservation Reserve

St. Williams Conservation Reserve (SWCR) is 1035 hectares of restored crown land located in Norfolk, ON. The property has a long list of varying past land uses. The area of my study was completely logged in the late 1800s. The land received protected status in 1908 as a conservation area; the first restoration project of its kind in Canada (Ontario Ministry of Natural Resources 2009). The reserve was officially made into a conservation reserve under the *Provincial Parks and Conservation Reserves Act, 2006* in June of 2008. Norfolk County as a whole contains 28% natural forest cover, which is the largest intact remaining area of Carolinian forest in Canada (Oldham 2017). In addition, this site harbors the highest proportion of rare species in Ontario (Henson *et al.* 2005) with several threatened vegetation communities (Ontario Ministry of Natural Resources 2009). Some of the key threatened species at the reserve include: *Castanea dentata* (American Chestnut)*, Chimaphila maculata* (Spotted Wintergreen)*, Cornus florida* (Eastern Flowering Dogwood)*, Juglans cinerea* (Butternut) *Tephrosia virginiana* (Virginia Goat's- Rue), and *Viola pedata* (Bird's- Foot Violet).

The SWCR property is composed of two separate sections, the Zavitz- Nursery Tract (ZNT) and Turkey Point Tract (WTPT) which are separated by 11 km. These two areas are further subdivided into management blocks assigned by the SWCR. The removal and control sites were somewhat unevenly distributed among the two properties; four of my sites were at ZNT and six were at WTPT. The reasons for the uneven distribution included my ability to find sufficient suitable removal sites, avoiding other ongoing scientific projects, as well as the active pine plantation of *Pinus strobus* (Eastern White Pine) and *Pinus reinosa* (Red Pine) at ZNT and WTPT blocks.

In terms of invasive species management, the SWCR has been performing a variety of removal techniques for several different species since 2009. The techniques applied fall into the following categories: mechanical, chemical, mechanical/ chemical, and prescribed burning. Removal of invasives has been extensive in this area with over 40 invasive species being managed across the property (Table 2a).

2.2.1.4.2 Bruce Peninsula National Park

Bruce Peninsula National Park (BPNP) is located at the northern edge of the 90 km long Bruce Peninsula, encompassing the northern tip of the Niagara Escarpment's talus slopes (Parks Canada Agency 2016). The park's tree canopy is largely dominated by coniferous species, such as *Thuja occidentalis* (Northern White Cedar) (Johnson 2016). The park also contains several globally- rare ecosystems such as alvars and cliff edges, as well as the Great Lakes & St. Lawrence lowlands. Bruce Peninsula was given federal park status in 1987 (Parks Canada Agency 2016). These features make it a botanically significant region of Ontario. Bruce Peninsula National Park is home to six species of SAR plants: *Platanthera leucophaea* (Eastern Prairie Fringed Orchid), *Tetraneuris herbacea* (Lakeside Daisy), *Cirsium hillii* (Hill's Thistle), *Iris lacustris* (Dwarf Lake Iris), *Potamogeton hillii* (Hill's Pondweed), and *Arnoglossum plantagineum* (Tuberous Indian-Plantain) (Parks Canada Agency 2016). Invasives are actively managed throughout the park as a strategy to conserve SAR (Table 2b). The region is home to 1380 plant species, of which 457 (33.1%) are considered non-native (Johnson 2016).

2.2.1.4.3 Invasive/exotic and native status

The classification of a species' national and/or sub-national native (S rank) and sub- national exotic status (SE rank) was determined using a data set obtained from the Ontario Ministry of Natural Resources and Forestry (OMNRF) Natural Heritage Information Centre (NHIC) (NHIC 2020). This report includes the various sub-national and global ranks rankings for each vascular plant in the province of Ontario (NatureServe 2009). The ranking system is based on the species status assessment calculator described by NatureServe (2009). More specifically, the NHIC defines exotic status as follows: where a species is known to occur as a non-native, alien, or introduced in Ontario, the exotic status value assigned to the species is 'SE'. In some cases, species appear as 'SE?', which indicates that there is uncertainty about whether the species is exotic or native.

Numeric ranks of 1 through 5 to the exotic status indicate the species' abundance in Ontario, with 1 being the least abundant and 5 being the most. A species may be exotic in one part of Ontario and native in another part, in which case it is ranked according to its native status at the location (Martina Furrer, Ontario Ministry of Natural Resources and Forestry, *per*s. *comm.*). Exotic ranks do not necessarily indicate the severity of a species' invasiveness at a particular site. However, this classification system was determined to be the best metric currently available to categorize species based on whether or not they are native or exotic in the province of Ontario.

2.2.1.4.4 Statistical Analyses

Each species' abundance was calculated by summing individual plants across plots; plot species richness is the total number of species encountered at each plot. I used the R package vegan (Oksanen *et al.* 2019) to calculate Shannon's diversity (Chao *et al.* 2014) for each of my sites, using the function 'diversity'. These values were later converted into Hill numbers (Chao *et al.* 2014) by taking the exponent of the Shannon values. Hill numbers are preferred over the Shannon values because they provide the effective number of a species and are considered easier to interpret and compare than other indices (Chao *et al.* 2014). Generalized linear mixed models (GLMM) were run to test for a significant effect of treatment (i.e., invasive species removal) on species abundance and diversity. Because pairing was ultimately not possible across all sites, the unit of replication was the individual site; treatment was included as a fixed effect. Site was included as a random effect in all models to avoid pseudoreplication. Models were run separately for the two areas. In the end, I tested three different GLMMs with 1) species richness, 2) abundance, and 3) exotic abundance as the response variables and treatment as the predictor. All GLMM's were run with a log link function (Poisson distribution). I also included the number of years of active management as a fixed effect, however, its inclusion was non- significant in every model, and was therefore dropped from the final models.

All analyses were performed using the *glmer* function of the lme4 (Bates *et al.* 2019) package in R, version 3.6.1 (R Core Team 2017). All models also include a sub- plot ID as a random factor to account for overdispersion (Bates *et al.* 2015) which all models were initially tested for and found to have. Once the sub-plot ID was added into the model, overdispersion was re-tested for and found to no longer be a statistical issue.

2.2.2 Survey of Committee on the Status of Endangered Wildlife in Canada assessment and status report (COSEWIC) and Species at Risk Act recovery strategies (SARA)

As part of the preliminary work for my thesis, I systematically surveyed the publicly available finalized recovery strategies for 79 at-risk vascular plant species in Ontario from the Species at Risk Public Registry (Environment Canada 2017). I did this by using Microsoft Word's search function to seek specific mentions of 'invasive species', in the context of risk factors for recovery (see below for details). Additionally, *Solidago speciosa* (Showy Goldenrod) currently has multiple status reports on two at- risk populations, which I treated as two different species, since they have different SARA designations.

2.2.2.1 Data extracted

To determine the reported impacts of invasive species for each vascular plant SAR, where possible, I used the finalized SARA report. Where there was no existing SARA recovery strategy report then the COSEWIC assessment and status report were used instead. In either case, the source was noted in the dataset (Appendix 1). From each report, I collected data on the year of the latest review, whether invasives were listed as a threat, the level of threat, the specific invasive species specified (if any), the total number of invasive species listed, the species' COSEWIC status, SARA status, and schedule. In Canada, there exists Schedule 1, 2 and 3 (Appendix 2). If a species is Schedule 1 it is part of the official SARA wildlife species at risk in Canada and its protection and recovery are being implemented. While species on Schedule 2 and 3 are those that have been assessed by COSEWIC but need to be further assessed before they are moved to Schedule 1 and officially protested under SARA.

Next, I used the shortcut ‘CTRL+F’ in Word and searched for the words ‘invasive’, ‘exotic’, ‘alien’, and ‘non-native’ in the documents to ensure no mentions were inadvertently omitted. In instances where the search yielded no results, I thoroughly read the ‘threats to species’ sub- headings to confirm that invasive species were not referred to by some other term. In some cases, an invasive species name alone was referred to as the risk for endangerment, this more thorough search captured these cases as well. Some recovery strategies explicitly ranked the level of threat, while others did not. When mentioned, the level of threat was noted for being ‘low’, ‘medium’, ‘high’, ‘unknown’, or ‘none’ (Appendix 1).

2.2.2.2 Analyses

Once I had completed the data collection, I calculated the percentage of recovery strategies that listed invasives as a threat. I then separated the threats into the four categories (high, medium, low, and unknown) (Appendix 1) described above, similar to McCune et al. (2013).

3. Results

3.1 Field study

3.1.2 St. Williams Conservation Reserve

I identified 187 species across 123 genera at the ten control and ten removal sites located at SWCR (Appendix 3). Of these, 166 are native to Ontario, and 21 are considered exotic by NHIC (2020). The species most frequently seen at St. William’s were *Maianthemum canadense*

(Canada Mayflower)*, Acer rubrum* (Red Maple)*, Mitchella repens* (Partridgeberry)*, Trientalis borealis* (Starflower)*, Rubus spp.* (Raspberry)*,* and *Toxicodendron radicans* (Poison Ivy). All are considered native to Ontario and are common understory herbs. I also encountered a single plant species recognized as at risk under the Species-At-Risk Act (SARA) in my SWCR plots: at removal site 4 (Table 3), two *Chimaphila maculata* (Spotted Wintergreen) individuals were observed. This species is protected as a Schedule 1, S1-critically imperiled species-at-risk under SARA (Ursi et al., 2010).

Species richness

Control sites at SWCR had a similar mean number of species compared to removal sites (mean +/- SE = 34.1 +/- 2.41 and 33.5 +/- 3.56, respectively). A *GLMM* found no significant difference in species richness between the two site types (Figure 1, $\chi2 = 0.054$, df = 1, p = 0.812).

Abundance

On average, control sites at SWCR had a higher mean abundance of individual plants (mean +/- SE, 1956.8 +/- 190.5) compared to removal sites (mean +/- SE 1361.2 +/- 249.9). A *GLMM* found that this difference was significant (Figure 3, $\chi2 = 4.65$, df = 1, p = 0.031).

Exotic/ invasive species

I identified 21 invasive species recognized by the National Heritage Information Centre's (NHIC) most recent vascular plant database (NHIC 2020) across the 20 survey sites at SWCR. Many of these invasives were trees (e.g., *Pinus sylvestris, Rosa multiflora, and Acer platanoides*). The most abundant invasive species were *Allaria petiolata* (Garlic Mustard)*, Rosa multiflora* (Multiflora Rose) *and Acer platanoides* (Norway Maple). On average, control sites had a mean (+/- SE) of 6 +/- 3.204 invasive species present and removal sites had a mean (+/- SE) of 5.6 +/- 1.39 invasive species. There was no significant difference in the number of invasive species between control and removal sites ($\chi 2$ = 0.9754, df = 1, p = 0.323).

3.1.3 Bruce Peninsula National Park

I identified 195 species across 133 genera in the eight control and eight removal sites at BPNP, respectively (Appendix 4). The most common species encountered were: *Poa* spp. (Poaceae), *Solidago* spp. (Goldenrod), *Fragaria* spp. (Wild Strawberry), *Plantago lanceolata* (English Plantain), *Leucanthemum vulgare* (Ox-eye Daisy), *and Lotus corniculatus* (Bird's-foot Trefoil). No species at risk were observed in any plot, although there are several found and actively managed in the park (e.g., *Iris lacustris*) (Parks Canada Agency 2016).

Species richness

Control plots had a mean (+/- SE) of 40.2 +/- 3.94 species while removal plots had an average of 40.3 +/- 2.45, this difference was not significant (Figure 2, $\chi 2$ = 2.60, df = 1, p = 0.107).

Abundance

On average, control sites had a mean (+/- SE) abundance of 1932.3 +/- 339.3 individuals, while removal sites had an average of 2170.6 +/- 197.9 individuals. There was no statistically significant difference in plant abundance between the two site types ($\chi 2$ = 1.157, df= 1, p = 0.282).

Exotic/Invasives

Plots at BPNP had a total of 49 invasive species of various sub-national exotic ranks (SE rank) (NHIC 2019). The most common include: *Plantago lanceolata, Leucanthemum vulgare and*

Lotus corniculatus. However, none of these are targeted for removal by BPNP. The most commonly encountered invasive species actively managed and removed by BPNP was *Centaurea nigrescens* (Short-fringed Knapweed), closely followed by *Centaurea stoebe* (Spotted Knapweed).

On average, control sites at BPNP had an abundance of 43 invasive individuals per site, while removal sites had 77 invasive individuals per site. A *GLMM* test of the difference found a significant difference (Figure 4, $\chi2$= 8.00, df = 1, p = 0.005).

3.2 Results of SARA and COSEWIC reports

There are 78 vascular plant species listed in Ontario as being at risk of extinction (Environment Canada 2017). Of these 78-ranked species, 80% have invasive species listed as being a threat in their respective SARA or COSEWIC reports. Of this 80%, 33.33% of reports that list invasives as a threat do not know to what extent, if any, invasives pose to the plants ability to persist. This statistic is noticeably higher than found in McCune *et al.* (2013), however, that study looked at several taxa, not just vascular plants.

4. Discussion

In my examination of the effect of invasive species removal on species at risk in two separate areas managed for plant conservation in Ontario, I was unable to address whether invasive removals are positively impacting SAR recovery. In large part, this was due to the fact that SAR are exceedingly rare, and therefore enormous sampling effort, far beyond the scope of my MSc, are required to test the impacts of management strategies on their recovery. My thesis highlights a crucial need for more detailed records and follow- up sampling on invasive removal efforts over time. For example, sampling prior to the start of invasive removal efforts would be extremely useful to establish their impacts on plant diversity and abundance.

At both St. Williams Conservation Reserve (SWCR) and Bruce Peninsula National Park (BPNP), I found no significant difference of treatment (removal) on the total species richness of a site. At BPNP, I also found no significant difference in the overall abundance of plants between treatments, while at SWCR, removal sites exhibited a higher plant abundance than control sites. When I looked at the abundance of only invasive species, I found no significant difference at SWCR, while at BPNP a significant difference was observed between treatment types.

Mean species richness of the two site types differed by less than one species in both study regions (Figure 1, Figure 2; Table 5). This finding is inconsistent with my hypothesis that removal plots with > 2 years of removal activity would exhibit higher plant richness and abundance, compared to similarly invaded control plots. This result has two possible interpretations. The first is that removals are not impacting plot species richness in the way that they are expected to. I do note that an important alternative explanation is that the control sites were not as heavily invaded as the removal sites to begin with (Wilcove *et al.* 1998; Gurevitch & Padilla 2004). However, it was my intention to find control plots as similar to the removal pair as possible, which included presence of invasives. This finding also contradicts results found by other studies of invasive removal, which found that plot species richness increased following invasive removal (e.g., MacDougall & Turkington 2005; Hulme & Bremner 2006). Although I note that the increase in richness observed by MacDougall and Turkington

(2005) was mostly by ruderal invasive/exotic species, so although richness increased it was not because of native species recovery.

With respect to overall plant abundance at BPNP, there was no significant difference between treatment and control plots. At SWCR, however, I found a significant difference in abundance between control and removal plots, with control plots having a higher overall abundance of all plants (native and invasive) (Figure 3). I think this unexpected result can at least partly be explained by the complicated land use history of SWCR, and how heavily invaded it is. For example, McCune *et al.* (2017) found that past landscape history was a significant predictor of present-day plant diversity. In addition, many invasive species found at SWCR are capable of forming dense thickets (e.g., *B. thunbergii, R. multiflora, V. rossicum*). Thus, removal sites at SWRC may have a much longer timeline for recovery than those in other areas. Additionally, despite the fact that SWRC has been performing removals for up to seven years at these sites, detailed, standardized records on tracking and changes in species composition over time have not been kept, making it difficult to pinpoint explanations for this pattern.

When I compared the total abundance of only invasive species between control and removal plots, there was no difference between site types at SWCR. This suggests that either the removals were having no effect on invasives or that the control sites were a poor representation of site community composition prior to removal. This is in contrast to what I found at BPNP, where there was a significant difference between control and removal plots, with removal plots having more exotic species present on average (Figure 4). None of the most abundant invasives at these sites were species that were actually targeted for removal, explaining their presence in the removal sites. This result has several possible explanations. First, all of my sites at BPNP were on newly acquired land with a history of recent human disturbance (e.g., historic airport landing strips, old fields) or were travelled heavily by tourists (e.g., Singing Sands beach). Most of BPNP's unique ecosystems and forests remain largely naïve to widespread encroachment of invasive species (Tyler Miller, Parks Canada, *pers. comm.*).

Though invasive plant species intervention remains a top priority in rare and endemic plant conservation, there is a lack of studies that quantify the degree to which invasive plants threaten at-risk plants (Hobbs & Huenneke 1992; Huenneke & Thomson 1995; Lesica & Shelly 1996; Walck *et al.* 1999; Combs *et al.* 2011; Rojas-Sandoval & Meléndez-Ackerman 2012; Grewell *et al.* 2013; Rand *et al.* 2015). Biotic interactions (e.g., competition, facilitation), coupled with abiotic factors, are the major predictors of the abundance and distribution of plant species in a community (Gurevitch & Padilla 2004). However, pinpointing the role of any particular factor is often difficult, at least partly due to the interactions among them (e.g., resource availability can influence the strength of competition among plant species) (Lesica & Shelly 1996). Moreover, different life stages can experience/impose impacts of different magnitudes and directions, making predictions about the impacts of plant to plant interactions even more difficult (Leger & Espeland 2010). For example, an eleven-year study, carried out by Rand et al. (2015), found that the effects of invasive species *Centaurea stoebe* on the rare native species *Cirsium pitcheri* varied significantly across life stage as well as habitat type. The probability of *C. pitcheri* juvenile seedling establishment and survivorship was heavily influenced by the presence of *C. stoebe* as a neighbouring plant, with the presence of an invasive having a negative effect on the probability that seeds planted survived to adulthood (Rand *et al.* 2015). These results are mirrored in other studies (Lesica & Shelly 1996; Thomson 2005), illustrating that the presence of invasive species alone often cannot explain changes subjected to plant communities following invasion (MacDougall & Turkington 2005). One of the challenges of interpreting my findings is that there were no assessments of site diversity/invasive load during the pre-management period in either area. This makes assessing whether removal efforts have been effective over time much more difficult. Overall, my thesis highlights the fact invasive removals need to be tracked much more intensively. Short-term reductions of invasive species are typically the main measure of success gathered by land managers (Lindenmayer *et al.* 2015). Progress is rarely assessed with broader goals in mind, such as, whether invasive removal reverses the negative impacts of invasion, its long-term effects, or what disturbance is caused by the management practises themselves (Lindenmayer *et al.* 2015). For example, Mason & French (2007) found that although herbicide treatments increased native plant diversity more than mechanical hand- weeding, it also caused an increase in the number of invasive plants found in the plots. This finding accentuates that where feasible and/ or in areas of high conservation value, such as those with species at-risk, mechanical hand- weeding should be performed over herbicide application (Mason & French 2007). In another removal study, removal treatments were performed once with no follow-maintenance to replicate doable management practises (Thomson 2005).

One of the results of my study, that invasive removal has little to no impact on native community richness, points towards the passenger model being the best at explaining invasive plant dominance. Other studies have shown that the removal of invasives cannot be used alone to explain native plant decline, including those at risk for endangerment (MacDougall & Turkington 2005; Rand *et al.* 2015). There is a critical need for future studies to focus more intensely on other non-interactive factors that exist in invaded plant communities (Rand *et al.* 2015). For example, seed dispersal capabilities strongly influence recruitment and low dispersal can result in a community supporting almost less than half as many species as it is capable of (Germain *et al.* 2017). Because of this, it is suggested that invasive removals and re-establishment of natives (i.e., planting, micropropagation, seed additive) be performed together in order to have the best chance to successfully restore natives (Díaz *et al.* 2003; Hulme & Bremner 2006).

The growing popularity of the field of invasion biology has created a multitude of studies, and yet, there is little consensus regarding the effects that invasive plant species have on native plant communities. This difference can in part be attributed to a disconnect between varying invasive study outcome expectations and goals. For example, land managers want management plants that are reasonable and practical given time and funding constraints, while academic researchers can be blinded by publication goals (Hallet *et al.* 2017). Additionally, management recommendations typically flow from academics to practitioners in a unidirectional manner. The only way we can achieve better management plans is to incorporate knowledge and ideas from both sides of invasive control teams (Funk *et al.* 2020).

Despite the fact that 80% of Ontario SARA vascular plant species reports list invasives as a threat to at- risk plant populations, in very few, if any cases, has the role of invasives been formally assessed. In addition, there is little evidence pointing towards invasive species being the lead culprit behind continued endangerment of SAR. Habitat disturbance is cited nearly as often as invasives as a driver of native species loss (Gurevitch & Padilla 2004). On the other hand, it has been shown in some studies that disturbance is an important driving force in facilitating the encroachment of invasives (Buckley *et al.* 2004). Future studies should focus on long term, experimental approaches to detangling the complex drivers of native species decline, while working more intimately with land managers.

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Chapter 3: Future directions and general conclusions

3.1 Overview

The effects of species invasions on natural and managed native plant communities is complex, and difficult to measure. Although their potential to cause detrimental effects is frequently observed, the mechanisms at play and their overall effect on native communities remains unclear (Vitousek *et al.* 1997; Flory & Clay 2009).

Additionally, invasive removal studies typically only look at one removal method rather than comparing several to see the efficacy of each. This is crucial because removal methods have been shown to elicit various restoration responses to native communities (Flory & Clay 2009). Ideally, I would have liked to include removal type as a predictor in my study design, but both BPNP and SWCR sites performed a combination of different mechanical and chemical methods in an effort to combat invasive species, making it difficult to compare.

Disentangling the drivers of native species decline is difficult, and the effects of invasives are not always clear. Nevertheless, invasive species are estimated to cost us $7.5 billion Canadian dollars (CAD)/ year from removal efforts (Dawson 2002). More regionally, the Invasive Ontario municipalities and conservation authorities spend nearly $51 million dollars on invasive species management (Vyn 2019). It is thus important to clarify whether such operations are having their intended effects. Dedicated, long term studies involving a range of invasives (and native plant species) with adequate are necessary to make additional progress on this question (MacDougall and Turkington 2005).

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List of tables

Table 1: Summary of potential study sites in Ontario for surveying of which 2 were suitable, information on invasives removed at each site are located in Table 2

	Property Name	Land Ownership/ Managers	Province	Invasive Removals?	SAR present?	SAR present
1	Bruce Peninsula National Park	Parks Canada	Ontario	Yes	Yes	Eastern Prairie; Fringed Orchid; Lakeside Daisy; Hill's Thistle; Dwarf Lake Iris; Tuberous Indian Plantain
2	Fathom Five National Park	Parks Canada	Ontario	Yes	Yes	Eastern Prairie; Fringed Orchid; Lakeside Daisy; Hill's Thistle; Dwarf Lake Iris; Tuberous Indian Plantain
3	Essex Forests and Wetlands Natural Areas	Nature Conservancy of Canada	Ontario	Yes	Yes	UNK
4	Happy Valley Forest	Nature Conservancy of Canada	Ontario	-	-	UNK
5	Long Point	Long Point Basin Land Trust	Ontario	Yes	Yes	Eastern Flowering Dogwood
6	Niagara	Nature Conservancy of Canada	Ontario	Yes	Yes	UNK
7	Norfolk Sandplain Natural Area	Nature Conservancy of Canada	Ontario	Yes	Yes	Eastern Flowering Dogwood; Common Greenbrier; American Chestnut

8	Pelee Island Natural Areas	Nature Conservancy of Canada	Ontario	Yes	Yes	UNK
9	Point Pelee National Park	Parks Canada	Ontario	Yes	Yes	Swamp Rose Mallow; Eastern Prickly Pear Cactus
10	St. Williams	St. Williams Conservation Reserve	Ontario	Yes	Yes	Eastern Flowering Dogwood; Spotted Wintergreen; American Ginseng
11	Tourbiere	Nature Conservancy of Canada	Quebec	Yes	Yes	Bog Fern; Halberd- leaved tearthumb; Swamp White Oak; Green Dragon; White Wood Aster
12	1000 Island National Park	Parks Canada	Ontario	Yes	Yes	Deerberry; Swamp Rose Mallow; Butternut; American Ginseng

Table 2a: Summary of invasive management efforts in St. Williams Conservation Reserve (SWCR) site locations

Plot	Location	Total Species Removed (#)	MGMT technique	Years of active management	Species at risk
SWCR	462/463	11	Mechanical/ Chemical	5	Unknown
SWCR	452/ 508	5	Mechanical/ Chemical	5	Unknown
SWCR	Southwestern	10	Mechanical/ Chemical	5	Unknown
SWCR	Big X	17	Mechanical/ Chemical	7	Unknown
SWCR	Parking lot area	3	Mechanical/ Chemical	5	Unknown
SWRC	Charlottville Rd south	12	Mechanical/ Chemical	4	Unknown
SWCR	Charlottville Rd north	7	Mechanical/ Chemical	4	Unknown
SWCR	East of Gibson Rd	Unknown	Mechanical/ Chemical	4	Unknown
SWCR	South front Rd	12	Mechanical/ Chemical	4	Unknown
SWCR	South Concession Rd 6	10	Mechanical/ Chemical	6	Unknown

Table 2b: Summary of invasive management efforts in Bruce Peninsula National Park (BPNP) at study locations

Plot	Location	Species Removed	Removal technique	Years of active management	Species at- risk
BPNP	Crane Lake Road	*Pastinaca sativa*	Chemical	5	non- plant SAR
BPNP	Dorcas Bay Road (Cecil Watson Property)	*Centaurea stoebe*	Mechanical	4	*Cirsium hilli*
BPNP	Shaw Ranch	*Pastinaca sativa*	Mechanical	5	non- plant SAR
BPNP	Ranger camp	*Centaurea nigrescens*	Chemical	More than 2 years, intermittently	non- plant SAR
BPNP	South of Historical Airstrip, Johnsons harbour	*Centaurea nigrescens*	Chemical	More than 2 years, intermittently	*Iris lacustris*
BPNP	Singing Sands Beach	*Centaurea stoebe*	Mechanical	9	*Arnoglossum plantagineum*
BPNP	Historical Airport Strip, Johnsons harbour	*Centaurea stoebe*	Chemical	2	*Iris lacustris* *Cirsium hilli*
BPNP	Dorcas Bay road (Cecil Watson property)	*Centaurea stoebe*	Mechanical/ Chemical	4	*Cirsium hilli*

Table 3: Invasive removal and non- removal sites in St. Williams Conservation Reserve. Global positions system (GPS) coordinate given in Degrees, Minutes, Seconds recorded in the World Geodetic System (WGS 84) using handheld Garmin eTrex 30.

Waypoint No.	Plot	Location	Treatment	Site (Replicate)	Latitude	Longitude
1	SWCR	Nursery Tract	Removal	1	N42° 42.592'	W80° 28.687'
2	SWCR	Nursery Tract	Removal	1	N42° 42.488'	W80° 28.668'
3	SWCR	Nursery Tract	Control	1	N42° 42.345'	W80° 29.258'
4	SWCR	Nursery Tract	Control	1	N42° 42.203'	W80° 29.010'
5	SWCR	Nursery Tract	Removal	2	N42° 42.273'	W80° 26.748'
6	SWCR	Nursery Tract	Removal	2	N42° 42.340'	W80° 26.842'
7	SWCR	Nursery Tract	Control	2	N42° 42.252'	W80° 26.858'
8	SWCR	Nursery Tract	Control	2	N42° 42.377'	W80° 26.888'
9	SWCR	Nursery Tract	Removal	3	N42° 41.782'	W80° 28.442'
10	SWCR	Nursery Tract	Removal	3	N42° 41.698'	W80° 28.353'
11	SWCR	Nursery Tract	Control	3	N42° 41.930'	W80° 28.271'
12	SWCR	Nursery Tract	Control	3	N42° 41.808'	W80° 28.153'
13	SWCR	Nursery Tract	Removal	4	N42° 42.870'	W80° 20.988'
14	SWCR	Nursery Tract	Removal	4	N42° 42.842'	W80° 21.207'
15	SWCR	Nursery Tract	Control	4	N42° 41.562'	W80° 28.904'
16	SWCR	Nursery Tract	Control	4	N42° 41.500'	W80° 28.984'
17	SWCR	Nursery Tract	Removal	5	N42° 43.040'	W80° 20.855'
18	SWCR	Nursery Tract	Removal	5	N42° 42.813'	W80° 20.595'

19	SWCR	Nursery Tract	Control	5	N42° 42.419'	W80° 20.820'
20	SWCR	Nursery Tract	Control	5	N42° 42.476'	W80° 20.697'
21	SWCR	Turkey Point Tract	Removal	6	N42° 42.425'	W80° 21.187'
22	SWCR	Turkey Point Tract	Removal	6	N42° 42.327'	W80° 21.308'
23	SWCR	Turkey Point Tract	Control	6	N42° 42.475'	W80° 21.753'
24	SWCR	Turkey Point Tract	Control	6	N42° 41.494'	W80° 20.731'
25	SWCR	Turkey Point Tract	Removal	7	N42° 42.275'	W80° 21.682'
26	SWCR	Turkey Point Tract	Removal	7	N42° 42.332'	W80° 21.612'
27	SWCR	Turkey Point Tract	Control	7	N42° 41.508'	W80° 20.555'
28	SWCR	Turkey Point Tract	Control	7	N42° 41.542'	W80° 20.404'
29	SWCR	Turkey Point Tract	Removal	8	N42° 42.153'	W80° 20.797'
30	SWCR	Turkey Point Tract	Removal	8	N42° 42.042'	W80° 20.555'
31	SWCR	Turkey Point Tract	Control	8	N42° 42.157'	W80° 27.943'
32	SWCR	Turkey Point Tract	Control	8	N42° 42.241'	W80° 28.007'
33	SWCR	Turkey Point Tract	Removal	9	N42° 41.655'	W80° 20.743'
34	SWCR	Turkey Point Tract	Removal	9	N42° 41.567'	W80° 20.658'
35	SWCR	Turkey Point Tract	Control	9	N42° 42.110'	W80° 27.898'
36	SWCR	Turkey Point Tract	Control	9	N42° 42.021'	W80° 27.812'
37	SWCR	Nursery Tract	Removal	10	N42° 41.658'	W80° 28.937'
38	SWCR	Nursery Tract	Removal	10	N42° 41.547'	W80° 29.155'
39	SWCR	Nursery Tract	Control	10	N42° 41.649''	W80° 28.937’

40	SWCR	Nursery Tract	Control	10	N42° 41.938'	W80° 28.090'
41	BPNP	Crane Lake Road	Removal	1	N45° 11.016'	W81° 24.488'
42	BPNP	Crane Lake Road	Removal	1	N45° 11.038'	W81° 24.552'
43	BPNP	Crane Lake Road	Control	1	N45° 10.994'	W81° 24.615'
44	BPNP	Crane Lake Road	Control	1	N45° 10.973'	W81° 24.665'
45	BPNP	Dorcas Bay Road (Cecil Watson Property)	Removal	2	N45° 11.411'	W81° 25.209'
46	BPNP	Dorcas Bay Road (Cecil Watson Property)	Removal	2	N45° 11.474'	W81° 25.142'
47	BPNP	Dorcas Bay Road (Cecil Watson Property)	Control	2	N45° 11.418'	W81° 25.114'
48	BPNP	Dorcas Bay Road (Cecil Watson Property)	Control	2	N45° 11.310'	W81° 25.084'
49	BPNP	Shaw Ranch	Removal	3	N45° 11.157'	W81° 25.474'
50	BPNP	Shaw Ranch	Removal	3	N45° 11.141'	W81° 25.435'
51	BPNP	Shaw Ranch	Control	3	N45° 11.067'	W81° 25.560'
52	BPNP	Shaw Ranch	Control	3	N45° 11.123'	W81° 25.503'
53	BPNP	Ranger Camp	Removal	4	N45° 13.012'	W81° 27.630'
54	BPNP	Ranger Camp	Removal	4	N45° 13.019'	W81° 27.635'
55	BPNP	Ranger Camp	Control	4	N45° 13.005'	W81° 27.670'
56	BPNP	Ranger Camp	Control	4	N45° 12.989'	W81° 27.648'
57	BPNP	South of historical airport strip, Johnsons Harbour	Removal	5	N45° 07.850'	W81° 32.111'

58	BPNP	South of historical airport strip, Johnsons Harbour	Removal	5	N45° 07.853'	W81° 32.108'
59	BPNP	South of historical airport strip, Johnsons Harbour	Control	5	N45° 07.947'	W81° 32.196'
60	BPNP	South of historical airport strip, Johnsons Harbour	Control	5	N45° 07.985'	W81° 32.229'
61	BPNP	Singing Sands Beach	Removal	6	N45° 11.419'	W81° 34.609'
62	BPNP	Singing Sands Beach	Removal	6	N45° 11.469'	W81° 34.657'
63	BPNP	Singing Sands Beach	Control	6	N45° 11.521'	W81° 34.768'
64	BPNP	Singing Sands Beach	Control	6	N45° 11.511'	W81° 34.949'
65	BPNP	Historical Airport Strip	Removal	7	N45° 07.983'	W81° 32.054'
66	BPNP	Historical Airport Strip	Removal	7	N45° 08.010'	W81° 32.062'
67	BPNP	Historical Airport Strip	Control	7	N45° 08.082'	W81° 32.154'
68	BPNP	Historical Airport Strip	Control	7	N45° 08.036'	W81° 32.083'
69	BPNP	Dorcas Bay Road (Cecil Watson Property)	Removal	8	N45° 09.601'	W81° 34.281'
70	BPNP	Dorcas Bay Road (Cecil Watson Property)	Removal	8	N45° 09.567'	W81° 34.389'
71	BPNP	Dorcas Bay Road (Cecil Watson Property)	Control	8	N45° 09.561'	W81° 34.215'
72	BPNP	Dorcas Bay Road (Cecil Watson Property)	Control	8	N45° 09.540'	W81° 34.278'

Table 4: Type 3 summary from *ANOVA* of the generalized linear- mixed models (*GLMM)* with poisson distribution testing for a difference of total plant species richness, total plant abundance, and exotic species abundance on treatment type of either control or removal in both Bruce Peninsula National Park (BPNP) and St. Williams Conservation Reserve (SWCR). Site was included as a random effect.

Area	**Response variable**	**Predictor variable**	**χ^2**	**df**	**p- value**
SWCR	Total abundance	Treatment	4.6548	1	0.03097*
SWCR	Total species richness	Treatment	0.0538	1	0.8165
SWCR	Exotic species abundance	Treatment	0.9754	1	0.3233
BPNP	Total abundance	Treatment	1.1574	1	0.282
BPNP	Total species richness	Treatment	2.602	1	0.1067
BPNP	Exotic species abundance	Treatment	7.9954	1	0.00469*

Table 5: Summary of means for tested parameters from both SWCR and BPNP

	St. Williams Conservation Reserve		Bruce Peninsula National Park	
	Control	Removal	Control	Removal
Species richness	34.1	33.5	40.2	40.25
Total abundance	1956.8	1361.2	1932.3	2170.6
Invasive abundance	6	5.6	43	77

60

Table 6: Summary of species threat level means extracted from COSEWIC and SARA survey of 79 t- risk species in Ontario, Canada

	Low	Medium	High	Unknown
Total number of species	2	17	16	23
Total			58	

List of Figures

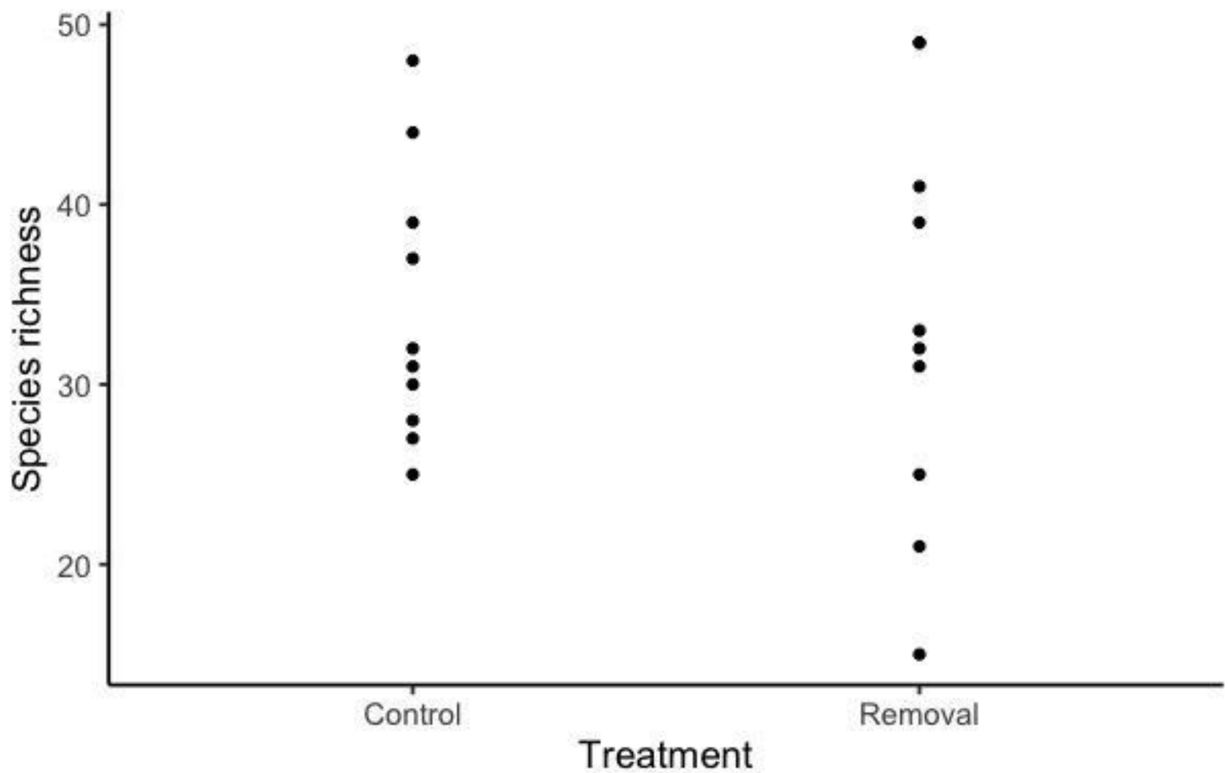

Figure 1: Species richness of St. Williams Conservation Reserve showing richness per site in control and removal plots. Means +/- SE = 34.1 +/- 2.41 and 33.5 +/- 3.56 for control and removal respectively.

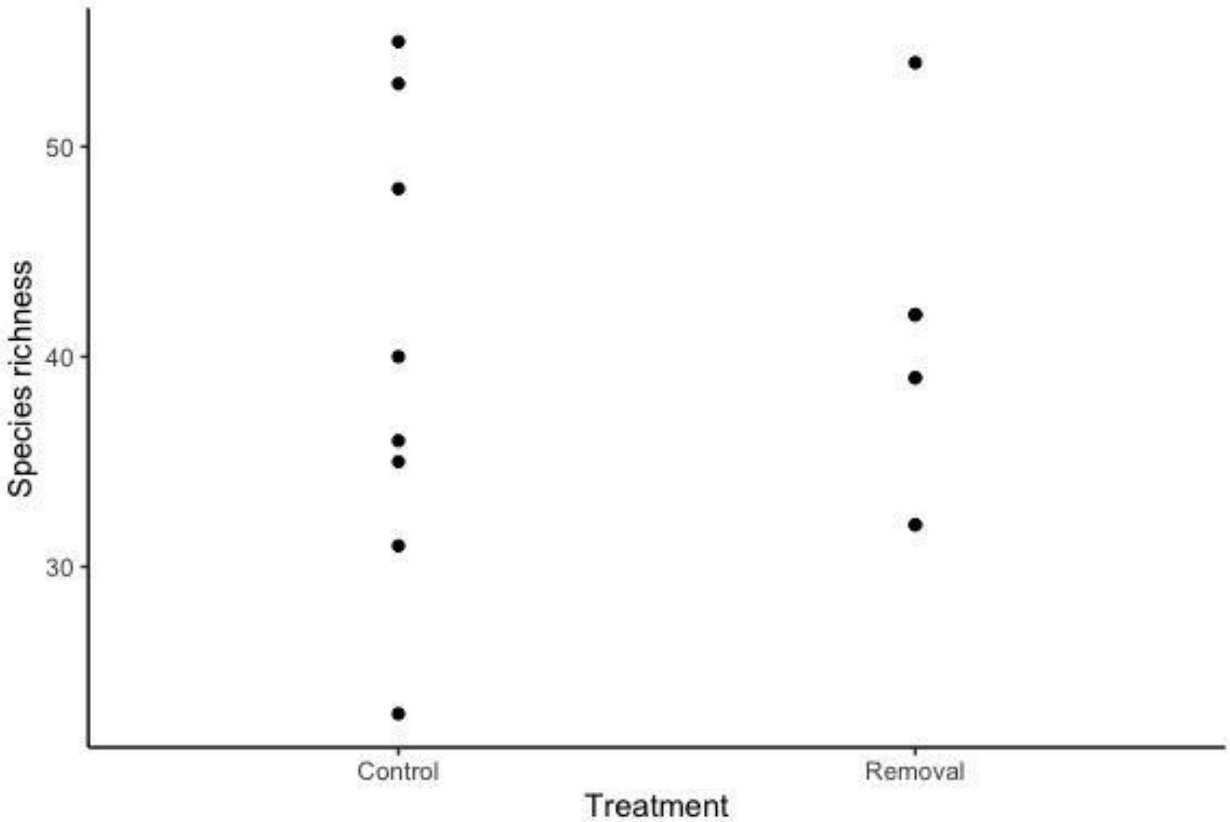

Figure 2: Species richness of Bruce Peninsula National Park showing richness per site in control and removal plots. Means +/- SE 40.2 +/- 3.94 and 40.3 +/- 2.45 for control and removal, respectively.

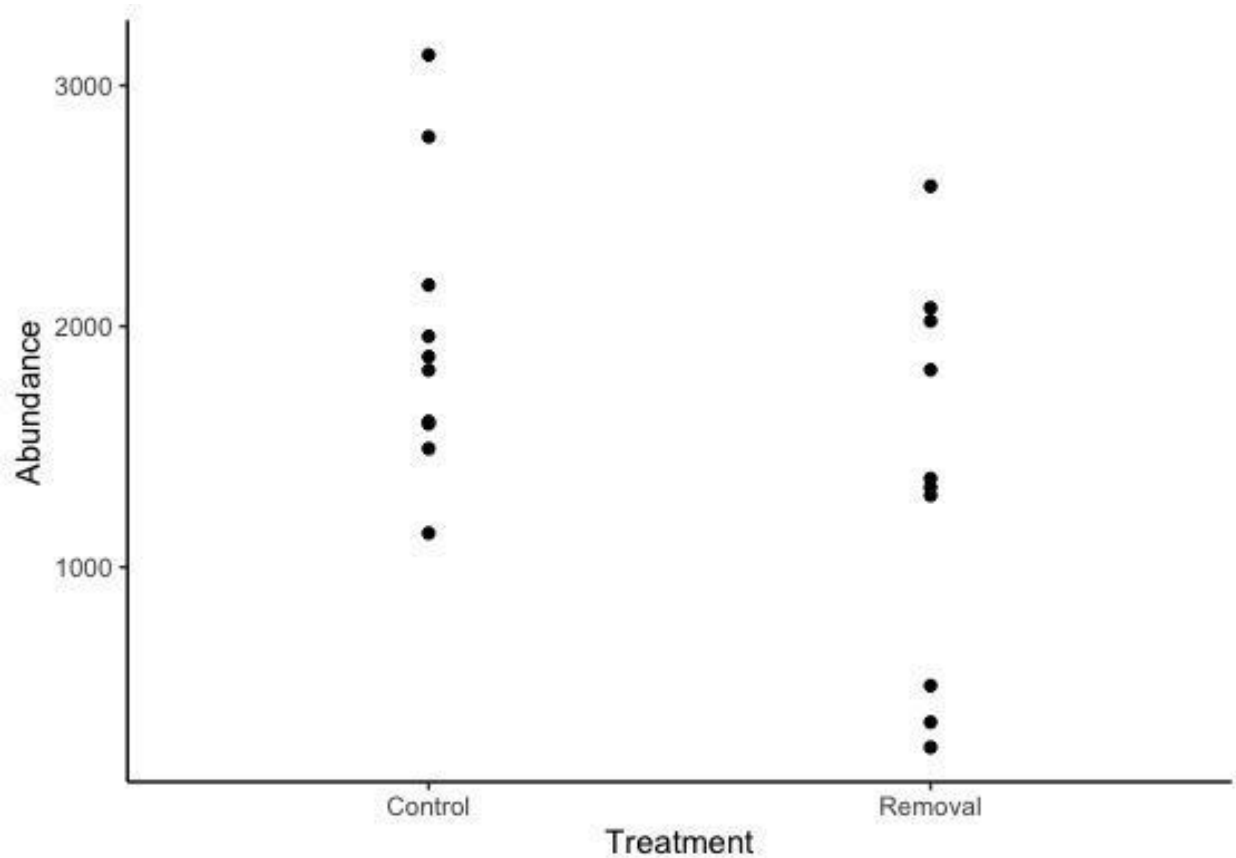

Figure 3: Total abundance of St. Williams Conservation Reserve between control and removal sites. Means +/-SE 1956.8 +/- 190.5 and 1361.2 +/- 249.9 for control and removal, respectively.

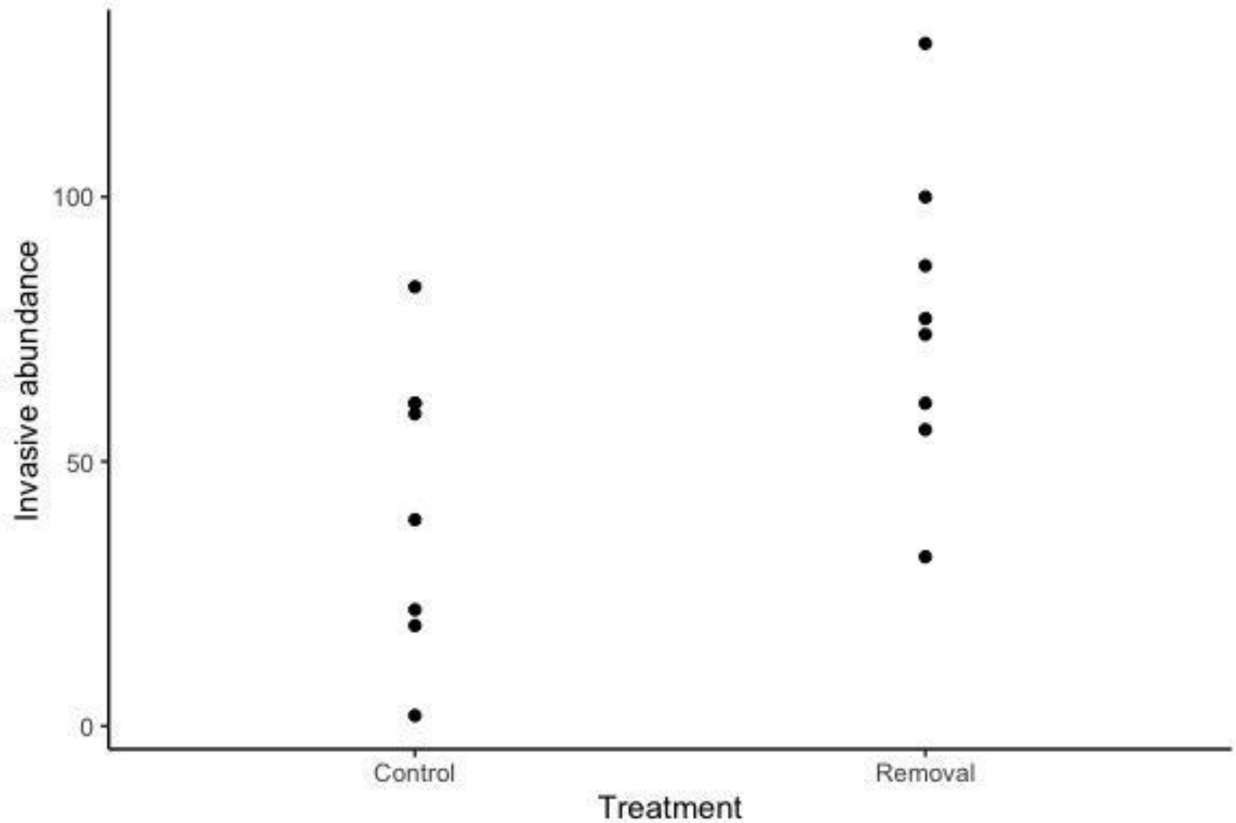

Figure 4: Abundance of invasive species found in control and removal sites at Bruce Peninsula National Park. Means +/- SE 43 +/- 9.7 and 77 +/- 10.4 for control and removal, respectively.

Appendix 1: Summary of SARA and COSEWIC survey of Ontario's 78 vascular plant species protected under the Species at- risk Act (SARA) and relative threat invasive plant species pose to each SARA species

Latin Name	COSEWIC Status	SARA Status	Report Source	Latest Review (Year)	Invasives listed as threat?	Species specified (if any)	Number of species listed	Level of threat
Agalinis gattingeri	Endangered	Endangered	SARA Recovery Strategy	2017	Yes	Smooth Brome; Kentucky Bluegrass; White Sweet Clover; Common St. Johns Wort; Common Reed	5	Medium
Agalinis skinneriana	Endangered	Endangered	SARA Recovery Strategy	2012	Yes	Scots Pine; White Sweet Clover; Canada Thistle; Common Reed; Black Locust	5	High
Aletris farinosa	Endangered	Threatened	SARA Recovery Strategy	2015	Yes	Scots Pine; Common Reed; Multiflora Rose; Autumn Olive; Black Locust; Sweet Clover; Common Buckthorn	7	Medium
Ammannia robusta	Endangered	Endangered	SARA Recovery Strategy	2015	Yes	Common Reed; Creeping Jenny	2	Medium
Arisaema dracontium	Special Concern	Special Concern	No document					
Aristida basiramea	Endangered	Endangered	SARA Recovery Strategy	2007	Yes	Glossy Buckthorn; Scots Pine; Spotted Knapweed; White Sweet Clover; Mouse- eared Hawkweed; Sheep Sorel	6	Medium
Arnoglossum plantagineum	Special Concern	Special Concern	COSEWIC Assesement and Status report	2002	No	N/A	0	None

Asclepias quadrifolia	Endangered	No Status	COSEWIC Assesement and Status report	2010	Yes	Common Buckthorn; Pale- Swallow wort	2	High
Asplenium scolopendrium var. americanum	Special Concern	Special Concern	COSEWIC Assesement and Status report	2016	Yes	Garlic Mustard; Common Buckthorn; Pale Swallow- wort	3	Low
Bartonia paniculata ssp. paniculata	Threatened	Threatened	SARA Recovery Strategy	2016	Yes	Glossy Buckthorn; Common Reed	2	High
Betula lenta	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	N/A	0	Unknown
Buchnera americana	Endangered	Endangered	SARA Recovery Strategy	2014	Yes	Common Reed	1	Medium
Camassia scilloides	Threatened	Threatened	SARA Recovery Strategy	2015	Yes	Garlic Mustard; Norway Maple	2	Unknown
Carex juniperorum	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Common Buckthorn; Common Lilac	2	Unknown
Carex lupuliformis	Endangered	Endangered	SARA Recovery Strategy	2014	Yes	Purple Loosestrife; Reed Canary Grass; Reed Manna Grass; Common Buckthorn	4	Medium
Castanea dentata	Endangered	Endangered	SARA Recovery Strategy	2016	No	N/A	0	None
Celtis tenuifolia	Threatened	Threatened	SARA Recovery Strategy	2011	Yes	Garlic Mustard; Common Buckthorn; Norway Maple; White Mulberry; White Sweet Clover	5	Medium
Chimaphila maculata	Threatened	Endangered	SARA Recovery Strategy	2015	Yes	N/A	0	None

Cirsium hillii	Threatened	Threatened	SARA Recovery Strategy	2011	No	None	0	None
Cirsium pitcheri	Special Concern	Special Concern	SARA Recovery Strategy	2011	Yes	Common Reed; Silver Berry	2	Medium
Collinsia verna	Extirpated	Extirpated	SARA Recovery Strategy	2010	No	N/A	0	None
Cornus florida	Endangered	Endangered	SARA Recovery Strategy	2014	No	N/A	0	None
Cypripedium candidum	Threatened	Endangered	SARA Recovery Strategy	2014	Yes	Common Reed	1	High
Desmodium illinoense	Extirpated	Extirpated	SARA Recovery Strategy	2017	Yes	Unknown	0	Unknown
Eleocharis equisetoides	Endangered	Endangered	SARA Recovery Strategy	2006	Yes	Common Reed	1	Unknown
Eleocharis geniculata	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Common Reed	1	Unknown
Enemion biternatum	Threatened	Threatened	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Goutweed	2	Medium
Eurybia divaricata	Threatened	Threatened	COSEWIC Assesement and Status report	2002	Yes	Unknown	0	Unknown
Floerkea proserpinacoides	Not at Risk		under consideration					
Frasera caroliniensis	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Japanese Barberry; Multiflora Rose; Tartanian Honeysuckle; Sweet White Clover; Dame's Rocket;	8	High

						Dog- strangling Vine; Common Buckthorn		
Fraxinus quadrangulata	Threatened	Special Concern	COSEWIC Assesement and Status report	2014	Yes	No	0	Unknown
Gentiana alba	Endangered	Endangered	SARA Recovery Strategy	2012	Yes	Black Locust; Common Reed; White Sweet Clover	3	Medium
Gymnocladus dioicus	Threatened	Threatened	SARA Recovery Strategy	2014	Yes	Dog - Strangling Vine; Kudzu	2	Medium
Hibiscus moscheutos	Special Concern	Special Concern	COSEWIC Assesement and Status report	2004	Yes	Common Reed; Hybrid Cattail; Purple Loosestrife; Flowering Rush; Common Thistle; Scots Pine; Teasel; Black Alder	8	High
Hydrastis canadensis	Threatened	Threatened	No document					
Iris lacustris	Special Concern	Special Concern	SARA Recovery Strategy	2011	No	N/A	0	None
Isoetes engelmannii	Endangered	Endangered	SARA Recovery Strategy	2007	Yes	None	0	Medium
Isotria medeoloides	Endangered	Endangered	SARA Recovery Strategy	2007	No	N/A	0	None
Isotria verticillata	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Garlic Mustard	1	Unknown
Juglans cinerea	Endangered	Endangered	SARA Recovery Strategy	2010	No	N/A	N/A	Unknown
Justicia americana	Threatened	Threatened	SARA Recovery Strategy	2011	Yes	Common Reed; Hybrid Cattail; Reed Canary Grass;	5	Unknown

						Purple Loostrife; Yellow Flag Iris		
Lespedeza virginica	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Autumn Olive; Crown Vetch; Spotted Knapweed	3	Unknown
Liatris spicata	Threatened	Threatened	SARA Recovery Strategy	2014	Yes	Common Reed; Purple Loosestrife; White Sweet Clover	3	High
Liparis liliifolia	Threatened	Threatened	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Scots Pine; Common Buckthorn; Multiflora Rose; Red Raspberry	5	Medium
Lipocarpha micrantha	Endangered	Endangered	SARA Recovery Strategy	2017	Yes	Reed Canary Grass; Common Reed	2	Unknown
Magnolia acuminata	Endangered	Endangered	SARA Recovery Strategy	2007	No	N/A	0	None
Morus rubra	Endangered	Endangered	SARA Recovery Strategy	2011	Yes	White Mulberry; Common Buckthorn; Glossy Buckthorn; Norway Maple; Tree of Heaven; European Alder; Garlic Mustard; Dog- strangling Vine	8	Unknown
Opuntia humifusa	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Day Lily; Spotted Knapweed; White sweet clover	3	Unknown
Panax quinquefolius	Endangered	Endangered	SARA Recovery Strategy	2015	Yes	Garlic Mustard; Japanese Barberry; Multiflora Rose; Dog- strangling Vine; Common Buckthorn	5	High
Phegopteris hexagonoptera	Special Concern	Special Concern	No document	N/A	N/A	N/A	N/A	Unknown
Plantago cordata	Endangered	Endangered	SARA Recovery Strategy	2013	No	None	0	None

Platanthera leucophaea	Endangered	Endangered	SARA Recovery Strategy	2012	Yes	Common Reed; Common Buckthorn	2	High
Polygala incarnata	Endangered	Endangered	SARA Recovery Strategy	2013	Yes	Common Reed; White Sweet Clover Canada Thistle Black Locust	4	High
Potamogeton hillii	Special Concern	Special Concern	COSEWIC Assesement and Status report	2005	Yes	None	0	Unknown
Potamogeton ogdenii	Endangered	Endangered	SARA Recovery Strategy	2016	No	N/A	0	None
Ptelea trifoliata	Special Concern	Threatened	SARA Recovery Strategy	2012	Yes	Common Reed; Silver Poplar; Black Locust; Norway Maple; Scots Pine; Silver Birch; White Mulberry; Common Alder; Kentucky Bluegrass; Canada Bluegrass; Spotted Knapweed; Bouncing Bet; Japanese Barberry; Sweet White Clover	14	Medium
Pycnanthemum incanum	Endangered	Endangered	SARA Recovery Strategy	2006	Yes	Common Buckthorn; Tartanian Honeysuckle; Willow; Garlic Mustard	4	High
Quercus shumardii	Special Concern	Special Concern	COSEWIC Assesement and Status report	1999	No	N/A	0	None
Rosa setigera	Special Concern	Special Concern	SARA Management Plan	2014	Yes	Autumn Olive	1	Low

Rotala ramosior	Non-active	Endangered	COSEWIC Assesement and Status report	2015	No	N/A	0	None
Sida hermaphrodita	Endangered	Endangered	SARA Recovery Strategy	2015	Yes	Common Reed	1	High
Smilax rotundifolia	Threatened	Threatened	SARA Recovery Strategy	2017	No	None	0	Unknown
Solidago houghtonii	Special Concern	Special Concern	COSEWIC Assesement and Status report	2005	Yes	Unknown	0	Unknown
Solidago riddellii	Special Concern	Special Concern	SARA Management Plan	2015	Yes	Common Reed; White Sweet Clover; Reed Canary Grass; Smooth Brome	4	Medium
Solidago speciosa	Endangered	No Status	SARA Recovery Strategy	2012	Yes	Common Reed; Black Locust; Sweet White Clover	3	Medium
Solidago speciosa	Threatened	No Status	SARA Recovery Strategy	2012		Common Reed; Black Locust; Sweet White Clover	3	Medium
Stylophorum diphyllum	Endangered	Endangered	SARA Recovery Strategy	2002	Yes	Garlic Mustard; Japanese Knotweed; Herb Robert	3	Unknown
Symphyotrichum praealtum	Threatened	Threatened	SARA Recovery Strategy	2015	Yes	Black Locust; Common Buckthorn; White Sweet Clover; Common Reed	4	Unknown
Symphyotrichum prenanthoides	Special Concern	Threatened	COSEWIC Assesement and Status report	2012	Yes	Common Reed; Spotted Knapweed; Glossy Buckthorn; Garlic Mustard; Reed Canary Grass; Dame's Rocket; Amur Honeysuckle	6	High

Symphyotrichum sericeum	Threatened	Threatened	SARA Recovery Strategy	2016	Yes	Common Tansy; Quackgrass; Common Reed; Reed Canary grass	4	High
Symphyotrichum shortii	Not at Risk		No document	N/A	N/A	N/A	0	N/A
Tephrosia virginiana	Endangered	Endangered	SARA Recovery Strategy	2015	Yes	Autumn Olive; Multiflora Rose; Norway Maple; Periwinkle; Oriental Bittersweet	5	Unknown
Tetraneuris herbacea	Threatened	Threatened	SARA Recovery Strategy	2011	Yes	Unknown	0	Unknown
Trichophorum planifolium	Endangered	Endangered	SARA Recovery Strategy	2007	Yes	No	0	Unknown
Trillium flexipes	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Tartanian Honeysuckle	2	High
Triphora trianthophoros	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Japanese Barberry	2	Unknown
Vaccinium stamineum	Threatened	Threatened	SARA Recovery Strategy	2010	Yes	Common Buckthorn; Garlic Mustard	2	Medium
Viola pedata	Endangered	Endangered	SARA Recovery Strategy	2016	Yes	Garlic Mustard; Common Knapweed	2	Unknown
Woodsia obtusa	Threatened	Threatened	SARA Recovery Strategy	2012	Yes	Common Buckthorn	1	High

Appendix 2: List of abbreviations and definitions

ANOVA	Analysis of variance
BPNP	Bruce Peninsula National Park
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
EICA	Evolution of increased competitive ability
GLMM	Generalized linear- mixed models
IUCN	International Union for Conservation of Nature
NHIC	National Heritage Information Centre
PAs	Protected areas
SARA	Species At Risk Act
SAR	Species at risk
S rank	the conservation status of a species or plant community within a Particular province, territory or state
S1	Extremely rare in Ontario; usually 5 or fewer occurrences in the province or very few remaining individuals; often especially vulnerable to extirpation
S2	Very rare in Ontario; usually between 6 and 20 occurrences in the province or with many individuals in fewer occurrences; often susceptible to extirpation
S3	Rare to uncommon in Ontario; usually between 21 and 100 occurrences i the province; may have fewer occurrences, but with a large number of individuals in some populations; may be susceptible to large-scale disturbances
S4	Common and apparently secure in Ontario; usually with more than 100 occurrences in the province
S5	Very common and secure in Ontario

SE rank	Exotic rank given using similar criteria as seen above
SH	Individuals who lack enough information about them to receive a rank designation
SWCR	St. Williams Conservation Reserve

Appendix 3: Inventory of species observed St. Williams Conservation Reserve

Acer negundo
Acer pensylvanicum
Acer platanoides
Acer rubrum
Acer saccharum
Acer x
Actaea pachypoda
Actaea rubra
Alliaria petiolata
Alnus incana
Ambrosia artemisiifolia
Amelanchier arborea
Amelanchier spp.
Anemone americana
Anenome canadensis
Aquilegia canadensis
Aralia nudicaulis
Arisaema triphyllum
Aronia melanocarpa
Asclepias syriaca
Berberis thunbergii
Betula alleghaniensis
Betula papyrifera
Botrychium spp.
Botrychium virginianum
Cardamine diphylla
Carex spp.
Carex spp.
Carpinus caroliniana
Carya ovata
Celastrus orbiculatus
Celastrus scandens
Chamaepericlymenum canadense
Chamerion angustifolium
Chelidonium majus
Chimaphila maculata
Chimaphila umbellata
Circaea alpina
Cornus alternifolia
Cornus canadensis

Cornus rugosa
Corylus americana
Corylus cornuta
Crataegus spp.
Dendrolycopodium spp.
Dichanthelium spp.
Diervilla lonicera
Dioscorea quaternata
Dioscorea villosa
Diphasiastrum digitatum
Diphasiastrum spp.
Dryopteris spp.
Epilobium ciliatum/
Equisetum spp.
Euonymus obovata
Fagus grandifolia
Fragaria spp.
Fraxinus americana
Fraxinus pensylvanica
Fraxinus spp.
Galium circaezans
Galium lanceolatum
Galium spp.
Gaultheria procumbens
Gaylussacia baccata
Geranium maculatum
Geranium robertianum
Geum aleppicum
Geum canadense
Hamamelis virginiana
Hieracium spp.
Hydrophyllum virginianum
Hypericum perforatum
Ilex verticillata
Impatiens capensis
Kalopanax septemlobus
Lindera benzoin
Lolium perenne
Lonicera canadensis
Lonicera dioica
Lonicera spp.
Lonicera tatarica

Lycopodium spp.
Lysimachia borealis
Lysimachia spp.
Maianthemum canadense
Maianthemum racemosum
Maianthemum spp.
Maianthemum stellatum
Medeola virginiana
Mitchella repens
Monarda fistula
Nepeta cataria
Onoclea sensibilis
Orthilia secunda
Osmorhiza claytonii
Osmunda cinnamomea
Ostrya virginiana
Oxalis stricta
Parthenocissus inserta
Parthenocissus quinquefolia
Persicaria virginiana
Phryma leptostachya
Physocarpus opulifolius
Picea abies
Picea glauca
Pinus resinosa
Pinus strobus
Pinus sylvestris
Poa spp.
Poa pratensis
Poa spp.
Podophyllum peltatum
Polygala paucifolia
Polygonatum biflorum
Polygonatum pubescens
Polygonatum spp.
Polystichum acrostichoides
Populus spp.
Populus grandidentata
Potentilla simplex
Prunella vulgaris
Prunus serotina
Prunus spp.

Prunus virginiana
Pteridium aquilinum
Pyrola elliptica
Quercus alba
Quercus muhlenbergii
Quercus rubra
Quercus spp.
Quercus velutina
Ranunculus abortivus
Rhamnus cathartica
Rhus typhina
Ribes cynosbati
Rosa blanda
Rosa carolina
Rosa multiflora
Rosa spp.
Rubus spp.
Rumex acetosella
Rumex spp.
Sambucus canadensis
Sambucus nigra
Sambucus racemosa
Sanicula canadensis
Sassafras albidum
Smilax herbacea
Smilax hispida
Solanum dulcamara
Solidago spp.
Sorbus aucuparia
Streptopus lanceolatus
Streptopus roseus
Swida alternifolia
Swida racemosa
Symphyotrichum spp.
Symphyotrichum urophyllum
Taraxacum erythrospermum
Taraxacum officinale
Taraxacum spp.
Thalictrum dioicum
Tilia americana
Toxicodendron radicans
Trientalis borealis

Trillium grandiflorum
Unknown herb
Unknown shrub
Unknown tree
Urtica dioica
Uvularia sessilifolia
Vaccinium angustifolium
Vaccinium pallidum
Vaccinium spp.
Veronica officinalis
Viburnum acerifolium
Viburnum lentago
Viburnum opulus
Viburnum rafinesquianum
Viola pubescens
Viola sagittata
Viola spp.
Vitis aestivalis
Vitis riparia

Appendix 4: Inventory of species observed at Bruce Peninsula National Park

Abies balsamea
Abies spp.
Acer saccharum
Achillea millefolium
Agrimonia gryposepala
Alnus incana
Amelanchier spp.
Anemone canadensis
Anticlea elegans
Apocynum androsaemifolium
Apocynum cannabium
Aralia nudicaulis
Arctium minus
Arctostaphylos uva-ursi
Arenaria serpyllifolia
Argentina anserina
Artemisia campestris
Asclepias syriaca
Betula alleghaniensis
Betula papyrifera
Botrypus virginianus
Bromus marginatus
Cakile edentula
Calamagrostis askansana
Calamagrostis canadensis
Campanula rotundifolia
Carex spp.
Carex vulpinoidea
Castilleja coccinea
Centaurea jacea
Centaurea nigrescens
Centaurea spp.
Centaurea stoebe
Cerastium arvense
Cerastium spp.
Cichorium intybus
Clinopodium acinos
Clinopodium arkansanum
Clinopodium vulgare
Comandra umbellata

Cornus racemosa
Cornus rugosa
Cornus stolonifera
Crataegus monogyna
Crepis spp.
Cucurbita pepo
Cynoglossum officinale
Cypripedium parviflorum
Danthonia spicata
Dasiphora floribunda
Dasiphora fruticosa
Daucus carota
Dichanthelium spp.
Diervilla lonicera
Echium vulgare
Elymus canadensis
Elymus repens
Epilobium spp.
Epipactis helleborine
Equisetum spp.
Erigeron spp.
Erigeron strigosus
Eurybia macrophylla
Euthamia graminifolia
Fragaria spp.
Fragaria virginiana
Fraxinus americana
Fraxinus nigra
Fraxinus pennsylvanica
Galium spp.
Geum aleppicum
Halenia deflexa
Hieracium spp.
Houstonia canadensis
Hypericum kalmianum
Hypericum majus
Hypericum perforatum
Iris spp.
Juncus articulatus
Juncus spp.
Juniperus communis
Juniperus horizontalis

Lactuca serriola
Lathyrus japonicus
Lepidium campestre
Leucanthemum vulgare
Lilium philadelphicum
Linnaea borealis
Linum catharticum
Linum spp.
Lithospermum officinale
Lolium arundinaceum
Lonicera spp.
Lotus corniculatus
Lysimachia ciliata
Maianthemum canadense
Maianthemum stellatum
Malus spp.
Medicago lupulina
Medicago sativa
Melilotus albus
Melilotus officinalis
Mentha arvensis
Nabalus racemosus
Oenothera biennis
Oenothera spp.
Ostrya virginiana
Oxalis stricta
Packera paupercula
Pastinaca sativa
Phleum pratense
Physocarpus opulifolius
Picea glauca
Picea mariana
Picea spp.
Pilosella aurantiaca
Pilosella caespitosa
Pilosella officinarum
Pinus banksiana
Pinus spp.
Plantago lanceolata
Plantago major
Poa compressa
Poa spp.

Polygaloides paucifolia
Polygonatum pubescens
Populus balsamifera
Populus grandidentata
Populus spp.
Populus tremuloides
Potentilla anserina
Potentilla recta
Poterium sanguisorba
Prunella vulgaris
Prunus pumila
Prunus serotina
Prunus spp.
Prunus virginiana
Pteridium aquilinum
Quercus rubra
Ranunculus abortivus
Ranunculus acris
Ranunculus recurvatus
Ranunculus spp.
Rosa acicularis
Rosa blanda
Rubus spp.
Rumex obtusifolius
Salix cordata
Salix spp.
Saponaria officinalis
Scirpus spp.
Shepherdia canadensis
Silene vulgaris
Sisyrimchium spp.
Sisyrinchium montanum
Sisyrinchium spp.
Solanum dulcamara
Solanum spp.
Solidago altissima
Solidago ptarmicoides
Solidago spp.
Sorbus decora
Streptopus lanceolatus
Symphoricarpos albus
Symphyotrichum boreale

Symphyotrichum ciliolatum
Symphyotrichum cordifolium
Symphyotrichum lanceolatum
Symphyotrichum lateriflorum
Symphyotrichum puniceum
Symphyotrichum spp.
Taraxacum officinale
Taraxacum spp.
Taxus canadensis
Thalictrum dioicum
Thuja occidentalis
Tilia americana
Tragopogon dubius
Tragopogon spp.
Triantha glutinosa
Trifolium pratense
Trifolium repens
Tsuga canadensis
Tussilago farfara
Unknown herb
Unknown shrub
Unknown tree
Verbascum thapsus
Veronica officinalis
Viburnum lentago
Vicia cracca
Viola blanda
Viola spp.
Vitis riparia