SPOTTED KNAPWEED PLANT MANAGEMENT AND RESTORATION OF NATIVE GRASSLAND IN WATERTON LAKES NATIONAL PARK, ALBERTA

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THUNDER BAY, ONTARIO

April 11, 2018

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management
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April 11, 2018

Major Advisor | Second Reader

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ABSTRACT

The province of Alberta is known for its prairies, which are ecosystems dominated by temperate grasslands. These grasslands contribute to flora and fauna biodiversity, but are the most endangered ecosystems in the region, due to the invasion of non-native species. Waterton Lakes National Park in the Canadian prairies is the only Canadian national park that preserves these grasslands under the foothills parkland ecoregion, which is an environmentally sensitive site characterized by rough fescue. It is mostly threatened by spotted knapweed (*Centaurea stoebe*), a perennial plant that spreads from disturbed anthropogenic sites. The park's vegetation restoration team has applied two main types of invasive plant management techniques over the years, which are mechanical and chemical treatments. This research study attempts to identify effective ways for restoration of native plant communities in Waterton Lakes National Park, Alberta, by comparing the effective use of chemical and mechanical techniques from 2014 to 2017. Our results show that chemical herbicide was found to be economically efficient (with lesser number of persons) for higher abundance of spotted knapweed infestation in larger areas, whereas the mechanical treatment is ecologically efficient (little impact on native plant communities) for the control of spotted knapweed infestations in the flowering stage in smaller areas. We recommend an integrated management plan for control of invasive species that combines the effective use of chemical and mechanical techniques. The integrated management plan will help the park management in conservation and restoration of the fescue grasslands in the foothills parkland ecoregion, which are important for protecting the rare and endangered flora and fauna.

Keywords: Canadian prairies, chemical and mechanical treatment methods, fescue grasslands, herbicide, invasive plant species, Milestone, Parks Canada, restoration.

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ACKNOWLEDGEMENTS

The Thesis writing course in the Undergraduate Program provided by Natural Resources Management faculty in Lakehead University was both challenging and fun, and would not have been possible without the help of some important people. First of all, I would like to give my heartiest gratitude to the Vegetation Restoration Team Lead Mr. Robert Sissons and Resource Management Technician Mr. Roderick Watt from Parks Canada in Waterton Lakes National Park, Alberta for providing me all of the information I could have possibly needed and more. I would not be able to gather and understand my data without their professional supervision and guidance. I am very grateful to have had the opportunity to work in the vegetation restoration team at Waterton Lakes National Park, and I would also like to thank all the members of the team who have been working for many years to perform and record all the treatments. I would also like to give special thanks to Genoa Alger, Candace Jung and Sonya Oetterich for giving me access to the recorded data and also providing their own expertise. All of these people in vegetation management and restoration have been working really hard to treat the non-native species in their park, and it is a great honour to be able to represent a part of their years of vigorous efforts in this study. I could not have had the support of more knowledgeable and hard-working professionals for this project.

Next I would like to thank Dr. Jian Wang for providing his supervision and guidance for my thesis project. He has a great amount of knowledge in the field of restoration ecology, and has been extremely helpful for me to find more external resources. He was always encouraging me and ensuring that I never felt overwhelmed or lacking resources. Most importantly, he provided his constructive ideas so that I could use my data in a way so as to find the most significant results. I am very grateful to have had the opportunity to work under his supervision for the thesis.

I would also like to give my gratitude to Dr. Chander Shahi for his imminent guidance in statistical analysis. He also provided some really helpful information on different ways to analyze the data, as well as information on how to organize the data to better use it. He was humble and always willing to offer his help whenever I needed it.

Without all of these people, none of this project would have been possible or proceeded as smoothly as it did. I am beyond grateful for all of their knowledge and expertise. Besides the professionals, I also want to thank my family and friends for their continuous support and best wishes. Words cannot describe how appreciative I am for all the encouragement and advice that they have given to me.

In the end, I want to thank the Natural Resources Management Faculty in Lakehead University for providing us this unique opportunity for composing our own thesis projects. This overall experience will be very beneficial for my future, and I cannot be more proud to be an International student at Lakehead University under the NRM faculty.

INTRODUCTION

The province of Alberta is known for its prairies, which are ecosystems dominated by temperate grasslands, savannas, and shrubland vegetation type rather than trees. The grasslands, located in the southern part of the province of Alberta, are present in 14% of the provincial area (Gibson 2009). Grasslands contribute to flora and fauna biodiversity, providing important habitat for several species at risk in Alberta. However, grasslands are the most endangered ecosystems in the region (Gibson 2009). The grasslands, which used to occupy 3.8 million ha area in 1900, have been reduced to less than 0.65 million ha (Adams et al. 2003). Prairies in the province of Alberta have been reducing due to human impacts such as fire suppression, bison extirpation and non-native species invasion (Widenmaier and Strong 2010). A number of non-native plant species, introduced as a result of European colonization in the prairies, have become invasive in the Canadian prairies (Morse et al. 1995, Morin 1995). The invasive plant species become an aggressive competition to the native plants, and threaten the survival of endangered species and ecosystems throughout the Canadian prairies (Vitousek et al. 1997).

Waterton Lakes National Park, having an area of 505 km^2 (195 square miles) of rugged mountains and wilderness, is located in the southwest corner of Alberta, and borders Glacier National Park in Montana, United States (WLNP 2010). Waterton Lakes National Park has more than half of Alberta's plant species. This is the result of having four diverse ecoregions in its area, namely: (i) Foothills Parkland Ecoregion, (ii) Montane Ecoregion, (iii) Subalpine Ecoregion, and (iv) Alpine Ecoregion (WLNP 2010). Waterton Lakes National Park is the only Canadian national park that preserves Foothills Parkland Ecoregion, which is an environmentally sensitive site (PC 2017). Rough fescue (Festuca scabrella) grasslands characterize this region, and unlike cultivated grasses, these fescues retain much of their nutrient value through the winter that are accessible to foraging animals even in deep snow, thus providing important winter food when other grasses are unavailable (Desserud 2006). The park has been working on the conservation and restoration of the fescue grasslands, as they are important for protecting the rare and endangered flora and fauna. Invasive species have massively invaded and rapidly displaced native species of fescue grasslands in Waterton Lakes National Park. Therefore, the control of invasive species in the fescue grasslands of Waterton Lakes National Park warrants special attention.

Spotted knapweed (*Centaurea stoebe*), an invasive plant belonging to the sunflower (Asteraceae) family, is commonly found in the grasslands region of Waterton Lakes National Park (PC 2017). It is a perennial plant, and it lives and flowers for several years. It was accidentally introduced in North America from Europe in the later 1800s from contaminated alfalfa and clover seed and from soil used for ship ballast (Schram 2015). Spotted knapweeds are highly competitive herbs and can form dense colonies in grasslands. Their continuous spread over the years in Waterton Lakes National Park has been a threat especially in the Foothills Parkland Ecoregion.

The park's vegetation restoration team has applied three main types of invasive plant management techniques over the years, which are mechanical, chemical, and biological control. Mechanical techniques include hand pulling through roots and/or cutting seed heads, and are generally labour intensive, time consuming and cheaper than other methods (MacDonald et al. 2013). Chemical control methods include the use of herbicides, especially when mechanical control is not effective (Kaufman and Kaufman 2007). Herbicides may be selective or non-selective (broad spectrum), systemic or non-systemic, and pre-emergent or post-emergent (OSU 2017). In sensitive areas, where these control methods are difficult to implement, biological control is being applied as a part of long term planning. This involves releasing carefully selected insects that feed only on the targeted species of the invasive plant, and this method is still under experimentation.

RESEARCH OBJECTIVES

The **general research objective** of this thesis is to understand how the applications of chemical and mechanical methods have proven to be effective for restoration of native plant communities in Waterton Lakes National Park, Alberta.

The **Specific Objectives** are to:

1. Determine if there has been a change in the effective use of chemical techniques, in terms of amount of herbicide used, area treated and mean density of plants treated for control of spotted knapweed in past four years in Waterton Lakes National Park, Alberta.

2. Determine if there has been a change in the effective use of mechanical techniques in terms of number of persons used, area treated, mean density of plants treated, and mean abundance of plants treated for control of spotted knapweed in past four years in Waterton Lakes National Park, Alberta.

3. Comparing the use of chemical and mechanical techniques in terms of number of plants treated, mean area treated, mean density of plants treated, and average number of persons used for treatment for the control of spotted knapweed and restoration of native plant communities in Waterton Lakes National Park, Alberta.

To achieve our specific objectives, we developed the following **Null Hypotheses**:

1. There is no difference among the use of chemical treatments in terms of amount of herbicide used, area treated and mean density of plants treated in the past four years.
2. There is no difference among the use of mechanical treatments in terms of number of persons used, area treated, mean density of plants treated, and mean abundance of plants treated in the past four years.
3. There is no difference between the effects of chemical and mechanical treatment in terms of number of plants treated, mean area treated, mean density of plants treated, and average number of persons used for treatment in the past four years.

LITERATURE REVIEW

The literature review assimilates the details found in research papers published in peer-reviewed journals and management reports related to invasive species management in the Waterton Lakes National Park.

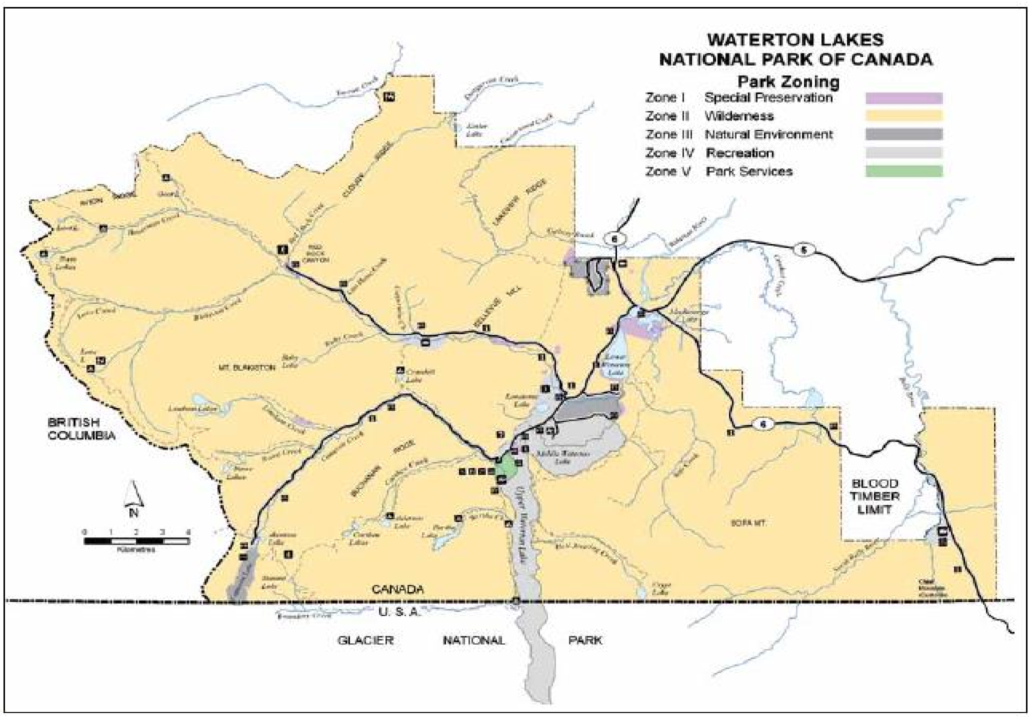
WATERTON LAKES NATIONAL PARK

Waterton Lakes National Park protects and presents a portion of the southern Rocky Mountains Natural Region, where some of the most ancient mountains in the Rockies meet the prairie grasslands (WLNP 2010). Tucked away in a quiet corner of southwest Alberta, Waterton Lakes National Park is a meeting place for people, culture, nature and history, resulting in a storied history and a richly diverse landscape (WLNP 2010). Established in 1895 in response to local citizen action, Waterton Lakes National Park is Canada's fourth national park (WLNP 2010). In 1932, the park was combined with Glacier National Park in the United States to form the Waterton-Glacier International Park, which is the world's first peace park (WLNP 2010). In 1995, the International Peace Park became a World Heritage Site because of its significant ecological, scenic and cultural values (WLNP 2010).

Parks Canada ensures that management of each national park gives the highest priority to the maintenance and restoration of ecological integrity, with the help of its mandate (WLNP 2010). The management plan document guides the overall direction of Waterton Lakes National Park of Canada for 10 to 15 years, and serves as a framework for all planning and decisions within the park (WLNP 2010). The document also highlights priority vegetation types found in the Montane ecosystem as areas for potential restoration (WLNP 2010).

Waterton Lakes National Park uses a zoning system, which is an integrated approach to the classification of land and water areas in the national park (WLNP 2010). Zones are classified according to the need to protect the ecosystem and the park's cultural resources. The Waterton Lakes National Park has been divided into five park zones as shown in Figure 1. Zone I areas require special preservation as they contain the best examples of the features that represent a natural region. Zone II, which covers 83%

of the park, contains extensive areas that are good representations of a natural region and that are conserved in a wilderness state. In both Zone I and II, the perpetuation of ecosystems with minimal human interference is the key consideration (WLNP 2010). In Zone III areas, visitors experience the park's natural and cultural heritage through outdoor recreational activities that require minimal services. However, motorized access is limited and controlled (WLNP 2010). Zone IV accommodates a broad range of opportunities for understanding, appreciation and enjoyment of the park's heritage, and also permits direct motorized access. It includes a 200 m right-of-way along major park roads, picnic areas, viewpoints, trailheads, parking areas, the golf course, and several campgrounds (WLNP 2010). The community/townsite of Waterton is the sole Zone V area in the park, where tourists' services and local shops are available (WLNP 2010).



Map 2: Zones in Waterton Lakes National Park

Figure 1. Management Zones of Waterton Lakes National Park.

Waterton Park has more than 1000 vascular plants with over half of Alberta's plant species concentrated into a relatively small area. About 200 of these vascular plant species are very rare plant species and are not found elsewhere in Alberta or Canada (WLNP 2010). This park is also a global hotspot for its variety of tiny ferns, known as moonworts. Due to its diverse flora, this park is also a habitat to many endangered and threatened fauna. It is home for more than 60 species of mammals, 250 species of birds, 24 species of fish, and 10 species of reptiles and amphibians, which thrive in different ecoregions in the park (WLNP 2010). Some areas of the park having significant and sensitive features that require special protection have been specially designated as Environmentally Sensitive Sites (ESS). For example, the foothills rough fescue grasslands are recognized as ESS in Waterton Lakes National Park (WLNP 2010).

FESCUE GRASSLANDS

Rough fescue (*Festuca scabrella*) grasslands are spread in the foothills parkland ecoregion. The fescue grasslands (Figure 2) are available to foraging animals throughout the year, as these retain their nutrient value even in the winter (Desserud 2006). The fescue grasslands provide habitat for several prairie species such as sharp tailed grouse, badgers, and thirteen-lined ground squirrels (WLNP 2010). These grasslands are also known to provide critical winter range for elk and important spring range for mule deer and sheep (WLNP 2010).

Figure 1. Fescue grasslands in Waterton Lakes National Park

Being an important component of the foothill parkland ecoregion flora and food for the endangered fauna of the region, the park management has been working on the conservation and restoration of these fescue grasslands. However invasive species, introduced as a result of past management practices and current disturbances, have led to non-native plant infestations and a loss of fescue grasslands (WLNP 2010). The invasive species have rapidly displaced native species of fescue grasslands in Waterton Lakes National Park. The native vegetation is also affected by climate change and environmental impacts. The deterioration will keep increasing with increasing competition by non-native plant species (WLNP 2010). Moreover, as roads and highways have been being built in the park for tourist sightings, problems of weed dispersal has increased (WLNP 2010). Because of the great danger posed by the invasive species, the Waterton Lakes National Park management plan focused on reducing the population of non-native plants along the highway corridors by at least 30% from 2010 to 2015.

Additionally in 2016, the park launched "CoRe: Rescue the Fescue Project" (WLNP 2016). The term CoRe refers to "Conservation" and "Restoration" of fescue grasslands (WLNP 2016). One of the project's main goals is to restore and maintain native fescue grasslands within the project area through reduction of priority non-native plants and re-vegetation of disturbed sites (WLNP 2016). The goal is to be achieved by at least a 10% decrease in the cover of priority invasive plants by 2019 versus 2014 levels (WLNP 2016). The restoration component of the project also involves re-vegetation in disturbed sites, but it can only be done after the present invasive species are eliminated (WLNP 2016).

The restoration of fescue grasslands is not an easy task, especially due to: (i) road corridors present next to the fescue area, (ii) highly disturbed nature of this environment of this region, and (iii) the extent of already established invasive species (Tyser et al. 1998). The roads provide access to tourists' spots in the Waterton Lakes National Park, and are constantly monitored and treated by the park's vegetation restoration team each year in order to reduce the spread of non-native plants.

SPOTTED KNAPWEED

Spotted knapweed (*Centaurea stoebe*), perennial tap-rooted Eurasian weed, is fast invading the rangelands in the western United States and Canada (Sheley et al. 1998). It was first recorded in Victoria, British Columbia in 1893 (Sheley et al. 1998). In

North America, spotted knapweed was most abundant in Montana in the 1980s (Harris and Cranston 1979), which shares the border with the province of Alberta in Canada.

Spotted knapweed grows to about 1 meter and usually has purple flowers as shown in Figure 3 (Sheley et al. 1998). Its stems are upright and branched, growing up to 1.5 meter tall (Anon 2014). The rosette leaves are about 15 cm long and deeply lobed (Anon 2014). On bolting stems, the leaves alternate and become pinnately divided (feather-like) and can be slightly hairy (Anon 2014). The flowers of spotted knapweed are purple or pinkish and the bracts on the flower's base have black tips, which is an important identifying feature of this plant (Anon 2014).

Figure 2. Spotted Knapweed (Alberta Invasive Species Council)

Spotted knapweed invasion is associated with reductions in biodiversity, wildlife, livestock forage, and increased erosion (Sheley et al. 1998). It degrades native plant communities including tallgrass savanna and sand barren habitats (Sherman and Powell 2017). It can occupy over 95% of the available plant community, and form near monocultures in areas like perennial grasses (Sherman and Powell 2017). It attains high densities on sunny, natural lands, where the land has not been previously disturbed (Sherman and Powell 2017). There is some evidence that it may produce allelopathic chemicals, a biological phenomenon by which a plant produces one or more chemicals that influence the germination, growth, survival and reproductions of other plants (Sherman and Powell 2017). This is especially concerning for the species designated under the Species at Risk Act (SARA) as being extirpated, endangered or of special concern in Canada (Sherman and Powell 2017). One such example is the half-moon hairstreak butterfly (*Satyrium semiluna*), as shown in Figure 4. It is given the status of Endangered under COSEWIC Designation, and Endangered under SARA, Schedule 1 (Environment Canada 2014). The destruction of their critical habitat in Waterton Lakes National Park has occurred due to the introduction of spotted knapweed, which potentially competes with half-moon hairstreak larval and nectar host plants, and can change the composition and structure of the plant, which in turn affect the butterfly habitat (Environment Canada 2014).

Figure 3. Halfmoon Hairstreak Butterfly (Environment Canada 2014)

Human activities are believed to be one of the largest contributors to the spread of knapweed, since the vehicles pick up seeds when driven on unpaved roads and off-road under dry conditions (Duncan et al. 2011). The seeds of knapweed have been recorded to travel over 160 miles under dry conditions, whereas the seeds drop off much more quickly under wet conditions (Duncan et al. 2011). According to a study in Glacier National park in Montana, the seed production in roadside areas was relatively high, presumably facilitating knapweed invasion and dispersal into adjacent prairie grassland vegetation (Tyser and Key 1988). The site in Figure 5 is known as Salamander Hill, and it is one of the many examples of infestation of spotted knapweed from roadside corridors and spreading uphill. Spotted knapweeds also have a negative impact on wildlife (Sheley et al. 1998). A research study predicted a loss of 220 elk annually in Montana because of knapweed infestations on the winter range (Sheley et al. 1998).

Figure 4. Spotted knapweed infestation on Salamander Hill.

MANAGEMENT TECHNIQUES

Any integrated weed management program requires sustainable efforts, constant monitoring, and the adoption of improved strategies (Sheley et al. 1998). The management of the Waterton Lakes National Park identified two priorities to control the invasive species in the region: (i) eradication of infestation, if practical, and (ii) patch eradication, suppression, and containment (Musto and Watt 2016). The parks management decided to treat dense infestations with herbicide applications to reduce competition, and providing time for seeded species to establish (Duncan et al. 2011). The common approaches adopted include a spring or early summer herbicide application, or a fall herbicide application (Duncan et al. 2011). Herbicide treatments generally have high efficacy on the target weed, and have the capability to shift the plant communities back to a grass-dominated structure (Rice et al. 1997). The chemical normally used is Milestone^{TM}, which contains an active substance propyzamide (500 g/L) and aminopyralid (5.3 g a.e./L), and is formulated as a suspension concentrate (SC) (Zotz et al. 2016). Milestone herbicide is applied as a post emergent to control broadleaf weeds, invasive plants and woody plants in rangeland, permanent pasture, industrial areas and other non-crop areas (Dow 2013). Figure 6 shows dead spotted knapweed plants.

Figure 5. Dead spotted knapweed plants three weeks after chemical application

The mechanical technique of managing knapweed infestation involves hand pulling method (Duncan et al. 2011). Since regrowth can occur from crowns, the entire crown portion of the plant must be removed (Duncan et al. 2011). The mechanical technique is more effective in areas with small infestations (Sheley et al. 1998). The mechanical and chemical techniques are also employed together to control invasive species infestation. According to a research study, integrated management of mechanical (hand pulling) and chemical technique (picloram) on an annual basis reduced the levels of spotted knapweed infestations (MacDonald et al. 2013). The alternative management techniques to control invasive plant species include prevention, and revegetation (Duncan et al. 2011). According to a research study in 2011, the biomass of knapweed was reduced by 93% at sites in western Montana where intermediate wheatgrass (Thinopyrum intermedium) was seeded 15 years ago (Duncan et al. 2011).

Figure 7 shows the amount of herbicide sprayed and hours spent controlling spotted knapweed as compared to all other invasive plant treatments in Waterton Lakes National Park for one year (Watt 2012).

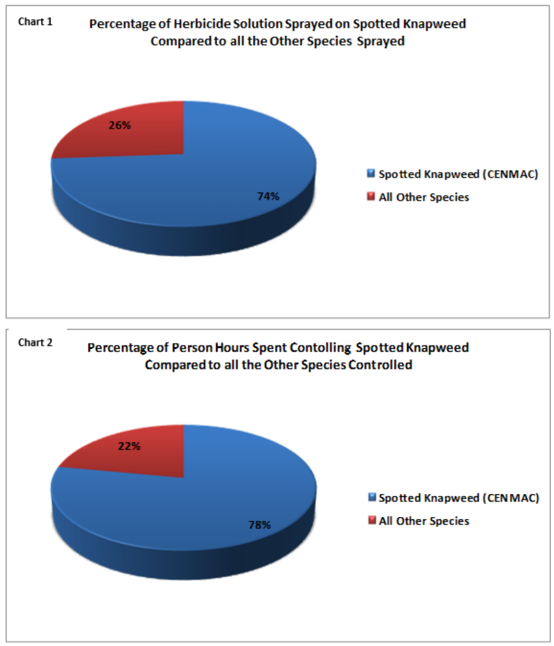


Figure 6. Comparison of the amount of herbicide used and person hours spent controlling spotted knapweed in Waterton Lakes National Park (Watt 2012)

METHODS AND MATERIALS

STUDY AREA

Figure 8 shows a Geographical Information System (GIS) map of the study area, with treatment sites of spotted knapweed from 2014 to 2017 in the Waterton Lakes National Park. This GIS map has been created using data obtained from the vegetation restoration team of Parks Canada for the Waterton Lakes National Park in August 2017.

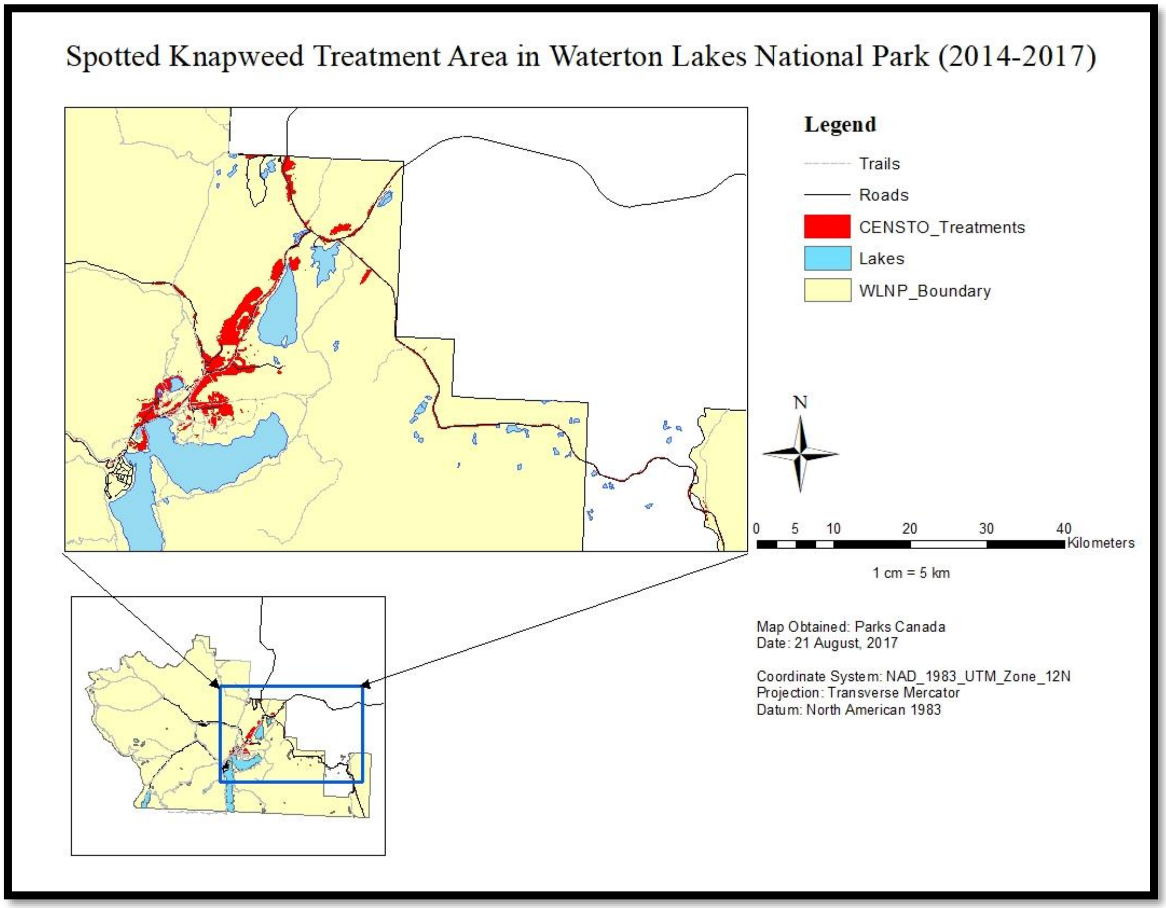


Figure 7. Spotted knapweed treatment area in Waterton Lakes National Park (2014-2017)

Within all of the treatment sites, shown in red colour in Figure 8, two sites, which contain the highest densities of spotted knapweed infestation, were given the highest priority for invasive species treatment. The first site is the Blakiston fan, circled in Figure 9, is an important habitat for elk and endangered species such as half-moon hairstreak butterfly. The treatment in this site has been done strategically, so as to contain the infestation within the Blakiston fan habitat. The second site is the roadsides, especially the Chief mountain highway (indicated by an arrow in Figure 9). This highway connects the Glacier National park to Waterton Lakes National Park, and is also a major source of infestation for spotted knapweed. The areas on both sides of the roads are treated each year to control the infestation of spotted knapweed.

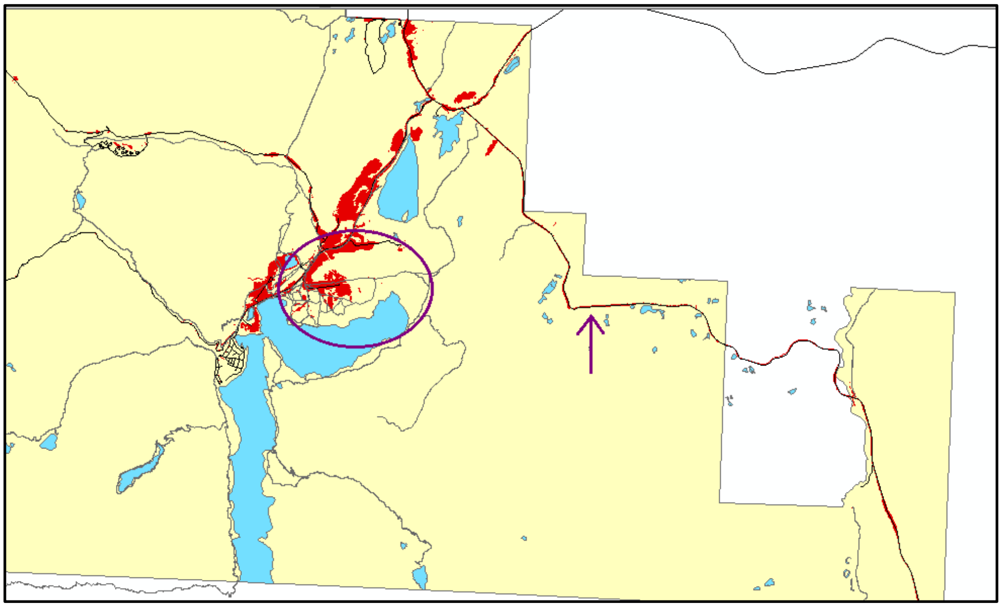


Figure 8. GIS Map showing Blakiston fan treatment site in Waterton Lakes National Park

TREATMENT AND DATA COLLECTION

Two types of treatments, chemical and mechanical, have been recorded in the study area. The chemical treatment involves the use of Milestone^{TM}, a selective herbicide applied in the months of May and June, before the seeds of knapweed are developed, and also in September to treat the plants which are growing again (since knapweed is a perennial plant). Milestone herbicide, applied as a post emergent, controls broadleaf weeds, invasive plants, and woody plants in rangeland, permanent pasture, industrial areas and other non-crop areas (Dow 2013). The herbicide is sprayed using 15 litres backpack sprayer, with low drift nozzles at the end of a long metal pipe, so that the chemical does not go beyond the sprayed plant. This method is also known as spot spraying. The chemical is mixed with water and blue dye to recognize the plant that has been sprayed. Since the treated area comes under Parks and Protected Areas, there are several precautions taken while using chemical treatment. A buffer zone of 30 meters around the water body is not sprayed with the chemical herbicide, so as to protect these water bodies from contamination. There is also no chemical treatment allowed under the following circumstances: (i) If the temperature is above 30 degrees, (ii) the wind is above 30 km/hour, and (iii) if there is a high chance of rain within two hours of chemical herbicide treatment. There are notice boards put up seven days before the treatment that remain there for about a month after the treatment to increase public awareness about chemical spraying (Figure 10).

Figure 9. Notice board indicating the use of herbicide in the treatment site

The mechanical treatment involves a number of techniques, such as hand pulling, digging and bagging, cutting seed-heads, etc. This treatment is mostly applied during the months of July and August, when the flowers and seeds are developed. The mechanical treatment is known to be most effective when the soil is moist. The bags used for disposing the plants are biodegradable (Figure 11).

Figure 10. Biodegradable bags used for collecting mechanically pulled spotted knapweed

After each area is treated, the details are recorded into a GPS Tablet in the form of a polygon. For each recorded polygon, the attributes are filled, which includes factors such as the treatment type (chemical or mechanical), treatment method (herbicide spraying, pulling, etc.), number of litres used (if chemical herbicide is used), number of people involved, density (plants treated per square meter) in the treated site, and several other attributes including location coordinates. The mean area refers to the average area of all sites treated in a given year, whereas the mean density refers to the average number of plants per square meter treated for all the sites treated in a given year. The area and density of each site is multiplied to obtain the abundance (or total number of plants treated) of treated plants in a particular site. The mean abundance refers to the average abundance of all sites treated in a given year. The mean area, mean density, and mean abundance is calculated from the data for each year. The records from GPS Tablet are transferred to the ArcMap using ArcPad. The ArcMap data is then converted into Microsoft Office Access database as shown in the flow diagram of data management in Figure 12.

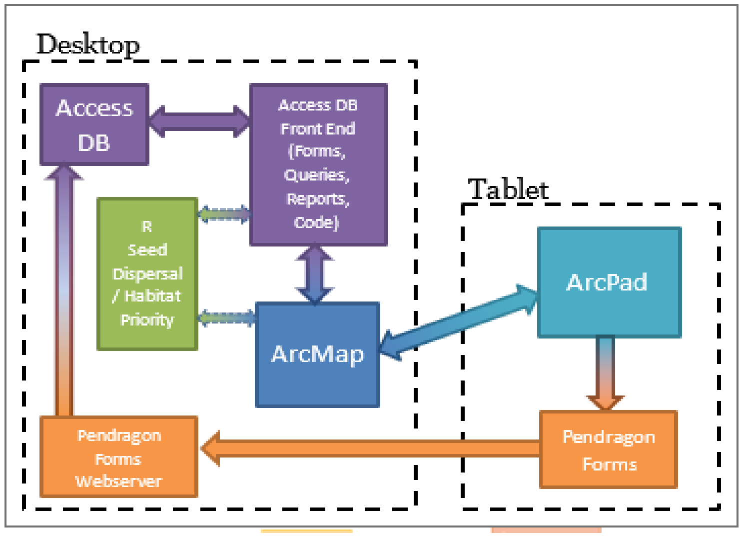


Figure 11. Data conversion flow diagram (Parks Canada 2017)

DATA ANALYSIS

The data obtained from Access database is then combined with "Attribute Table" of the ArcGIS Map, which contains the records of spotted knapweed treatment sites from 2014 to 2017. All these data are then extracted as Excel files, and analyzed with the help of one-way Analysis of Variance (ANOVA) using IBM SPSS Statistical Software Package. For the effective use of chemical techniques, we analyzed the amount of herbicide used, mean area treated and mean density of plants treated for control of spotted knapweed in past four years in Waterton Lakes National Park, Alberta. For the effective use of mechanical techniques, we analyzed number of persons used, area treated, mean density of plants treated, and mean abundance of plants treated for control of spotted knapweed in past four years in Waterton Lakes National Park, Alberta. For the purpose of comparison between the chemical and mechanical techniques, we analyzed the number of plants treated, mean area treated, mean density of plants treated, and average number of persons used for treatment for the control of spotted knapweed and restoration of native plant communities in Waterton Lakes National Park, Alberta.

RESULTS

CHEMICAL TREATMENT

Figure 13 shows the amount of herbicide (in litres) used to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The results of one-way ANOVA show that the amount of herbicide used for chemical treatment does not differ significantly (p-value = 0.159) during the years 2014 to 2017 (Table 1).

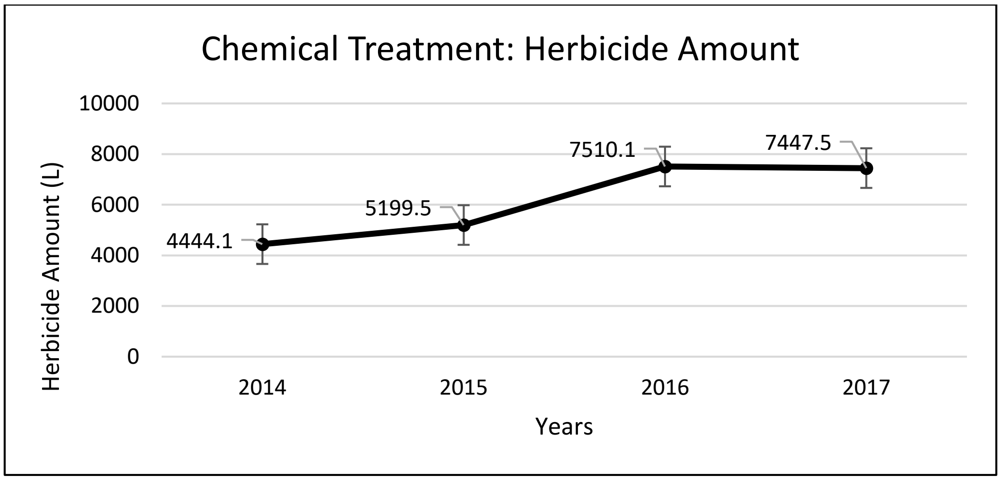


Figure 12. Amount of herbicide used for control of spotted knapweed

Table 1: ANOVA results for amount of herbicide used

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17260.707[a]	3	5753.569	1.728	.159
Intercept	527548.328	1	527548.328	158.450	.000
Year_Treat	17260.707	3	5753.569	1.728	.159
Error	3735630.935	1122	3329.439		
Total	4290386.831	1126			
Corrected Total	3752891.642	1125			

a. R Squared = .005 (Adjusted R Squared = .002)

Figure 14 shows the mean area treated with the help of chemical herbicide to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The trend line depicts that area treated with herbicide has significantly (p-value < 0.05) decreased in the years 2016 and 2017 (Table 2).

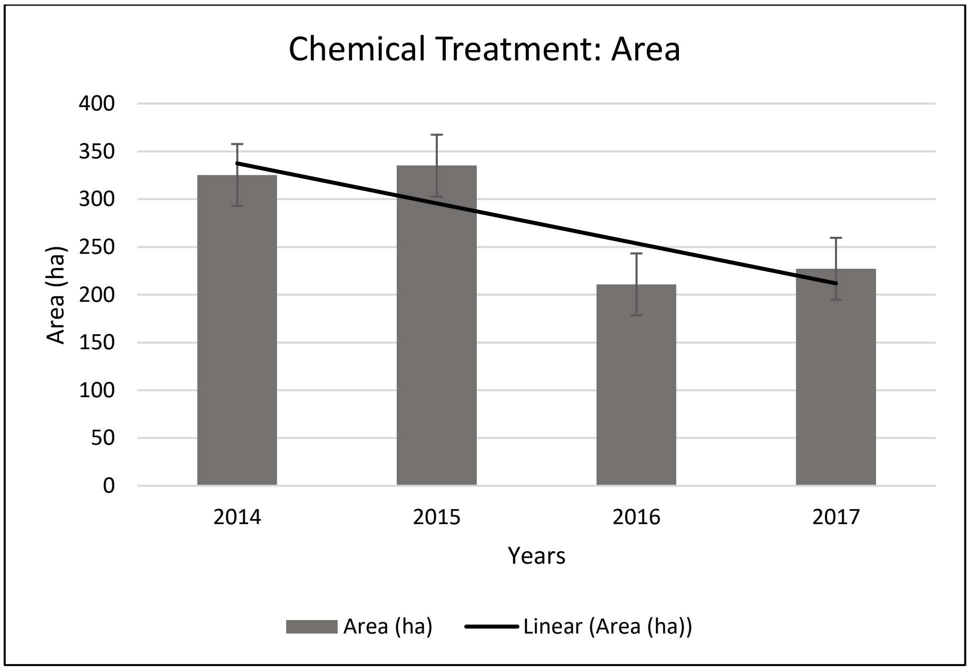


Figure 13. Area treated with chemical herbicide for control of spotted knapweed

Table 2: ANOVA results for area treated using chemical herbicide

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.377E9	3	2.459E9	6.070	.000
Intercept	1.101E11	1	1.101E11	271.694	.000
Year_Treat	7.377E9	3	2.459E9	6.070	.000
Error	4.545E11	1122	4.051E8		
Total	5.691E11	1126			
Corrected Total	4.619E11	1125			

a. R Squared = .016 (Adjusted R Squared = .013)

Figure 15 shows the mean density of treated spotted knapweed plants with the help of chemical herbicide to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The mean density treated in the year 2016 is significantly (p-value < 0.05) higher as compared to other years (Table 3).

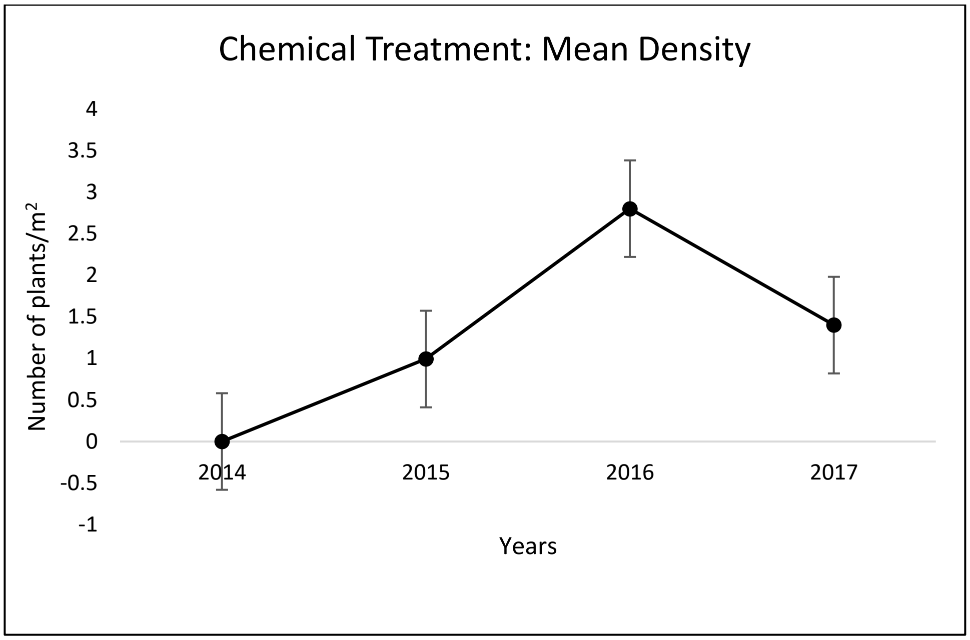


Figure 14. Mean density of treated spotted knapweed plants with chemical herbicide

Table 3: ANOVA results for mean density of plants treated using chemical herbicide

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1060.464[a]	3	353.488	42.563	.000
Intercept	1878.580	1	1878.580	226.197	.000
Year_Treat	1060.464	3	353.488	42.563	.000
Error	9318.289	1122	8.305		
Total	12408.270	1126			
Corrected Total	10378.752	1125			

a. R Squared = ..102 (Adjusted R Squared = .100)

MECHANICAL TREATMENT

Figure 16 shows the mean number of persons used for mechanical treatment to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The results of one-way ANOVA show that the number of persons used for mechanical treatment differs significantly (p-value < 0.05) during the years 2014 to 2017 (Table 4).

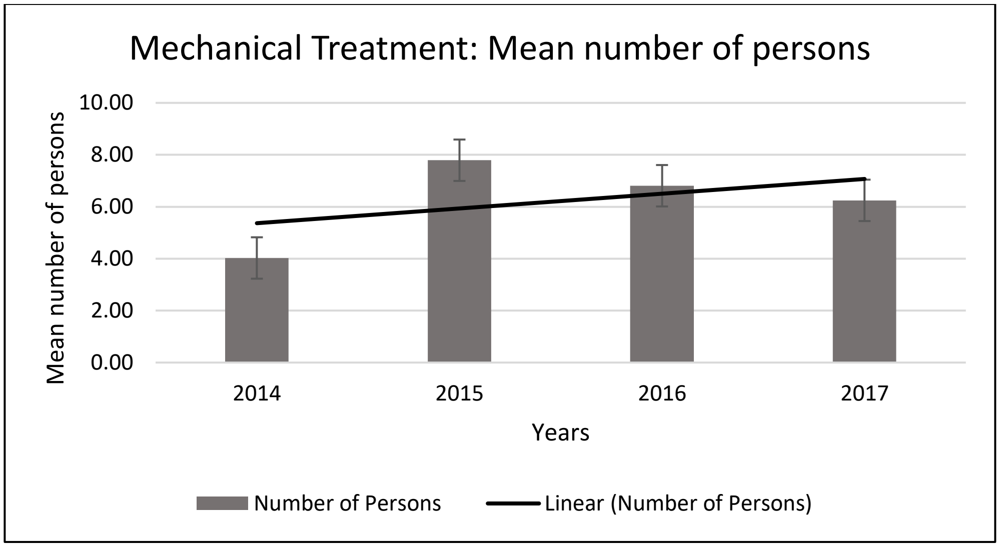


Figure 15. Mean number of persons used for mechanical treatment of spotted knapweed plants

Table 4: ANOVA results for mean number of persons used for mechanical treatment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1586.763[a]	3	528.921	5.993	.000
Intercept	32045.267	1	32045.267	363.062	.000
Year_Treat	1586.763	3	528.921	5.993	.000
Error	79790.457	904	88.264		
Total	115890.000	908			
Corrected Total	81377.220	907			

a. R Squared = .019 (Adjusted R Squared = .016)

Figure 17 shows the area treated with the help of mechanical treatment to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The trend line depicts that area treated with mechanical treatment was significantly (p-value < 0.05) higher in the year 2016 as compared to the other years (Table 5). The area under mechanical treatment has again decreased in the year 2017.

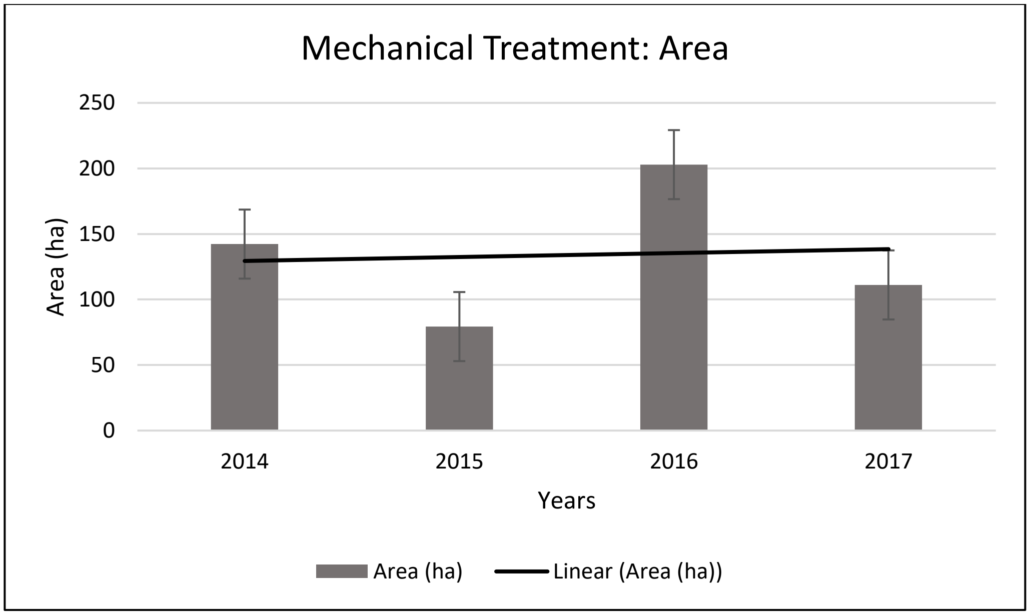


Figure 16. Mean area treated with mechanical treatment for control of spotted knapweed

Table 5: ANOVA results for mean area treated using mechanical treatment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.146E9	3	3.821E8	4.824	.002
Intercept	1.578E10	1	1.578E10	199.229	.000
Year_Treat	1.146E9	3	3.821E8	4.824	.002
Error	7.160E10	904	7.921E7		
Total	8.973E10	908			
Corrected Total	7.275E10	907			
a. R Squared = .016 (Adjusted R Squared = .012)					

Figure 18 shows the mean density of treated spotted knapweed plants with the help of mechanical treatment to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The mean density treated in the year 2016 is significantly (p-value < 0.05) higher as compared to other years (Table 6).

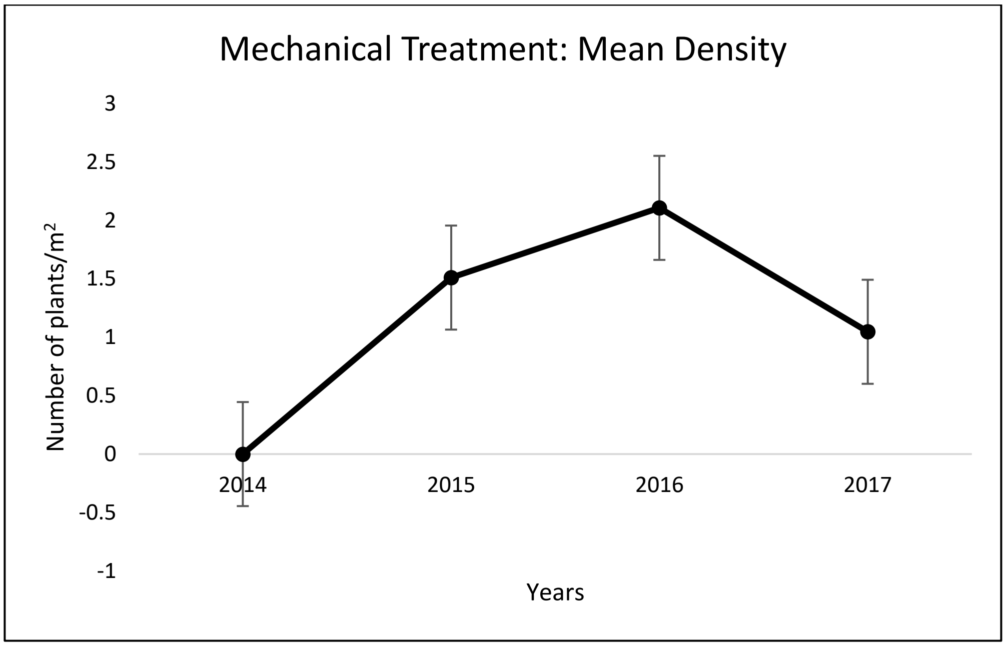


Figure 17. Mean density of treated spotted knapweed plants with mechanical treatment

Table 6: ANOVA results for mean density of plants treated using mechanical treatment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1101.474[a]	3	367.158	14.746	.000
Intercept	2181.367	1	2181.367	87.610	.000
Year_Treat	1101.474	3	367.158	14.746	.000
Error	22508.248	904	24.899		
Total	26408.000	908			
Corrected Total	23609.722	907			

a. R Squared = .047 (Adjusted R Squared = .043)

Figure 19 shows the mean abundance of treated spotted knapweed plants with the help of different methods of mechanical treatment to control the spread of spotted knapweed in the past four years (2014-2017) in Waterton Lakes National Park, Alberta. The mean abundance treated with cut-bag, cut-seedhead, and pull methods is significantly (p-value < 0.05) higher as compared to other methods (Table 7).

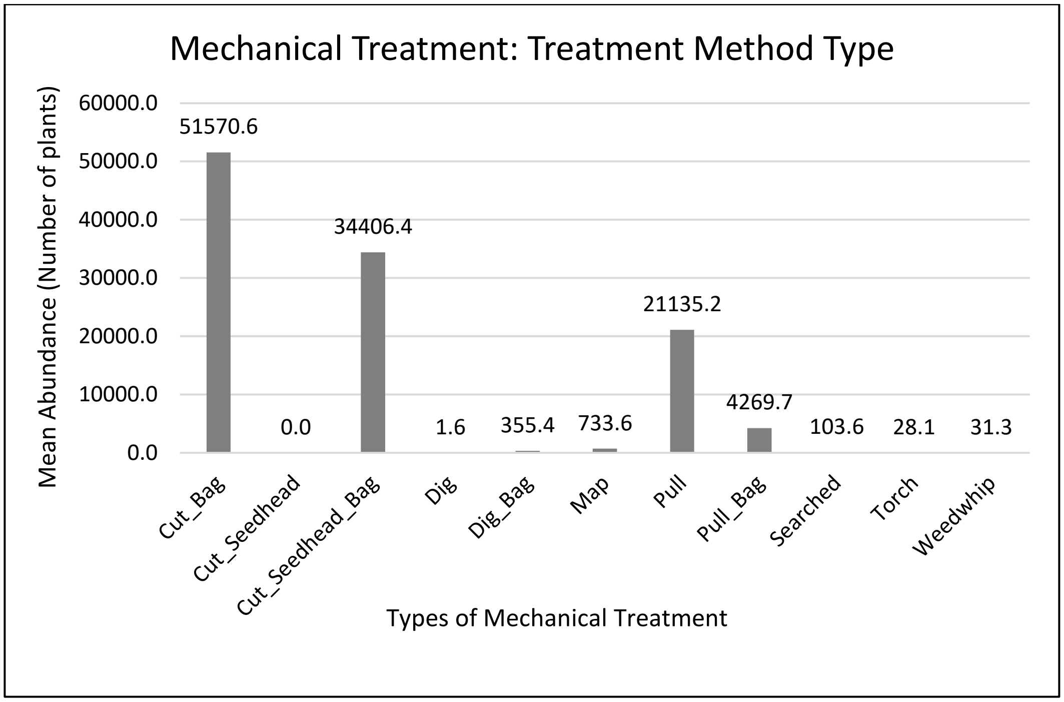


Figure 18. Mean abundance of treated plants with types of mechanical treatment.

Table 7: ANOVA results for mean abundance of treated plants using different types of mechanical treatment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7510405639.000[a]	8	938800704.800	2.688	.006
Intercept	2159873742.000	1	2159873742.000	6.185	.013
Year_Treat	7510405639.000	8	938800704.800	2.688	.006
Error	313929010400.000	899	349198009.300		
Total	339729940600.000	908			
Corrected Total	321439416000.000	907			

a. R Squared = .023 (Adjusted R Squared = .015)

COMPARISON OF CHEMICAL AND MECHANICAL TREATMENT

The comparison between chemical and mechanical treatment methods has been made using the following factors: (i) number of plants treated, (ii) mean area treated, (iii) mean density of plants treated in affected areas, and (iv) the average number of people working under each treatment. The records in the category "NA" indicate the absence of spotted knapweed in those areas.

A comparison of the mean abundance of spotted knapweed plants treated by chemical and mechanical control methods in the past four years (2014-2017) is shown in Figure 20. The data shows significantly (p-value < 0.05) more plants that have been treated by chemical treatment than by mechanical treatment (Table 8).

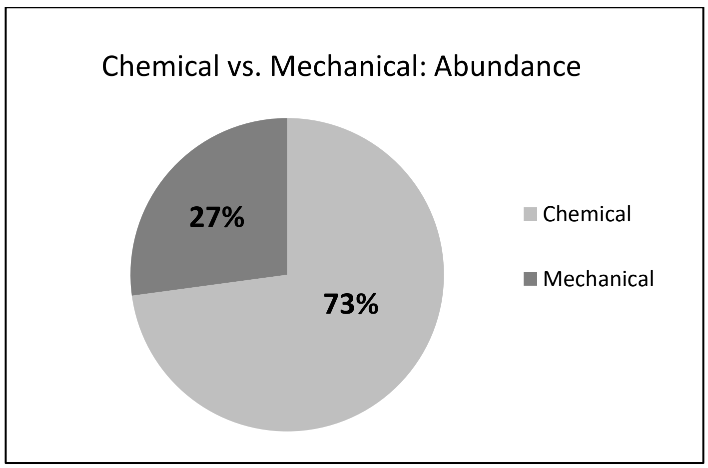


Figure 19. Total number of plants (abundance) treated by each type of treatment (2014-2017)

Table 8: ANOVA results for comparison of number of plants

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.024E10	2	1.512E10	11.093	.000
Intercept	4.366E10	1	4.366E10	32.030	.000
Year_Treat	3.024E10	2	1.512E10	11.093	.000
Error	3.271E12	2400	1.363E9		
Total	3.396E12	2403			
Corrected Total	3.302E12	2402			

a. R Squared = .009 (Adjusted R Squared = .008)

A comparison of the mean area treated under chemical and mechanical treatment in shown in Figure 21. The data shows that on an average significantly (p-value < 0.05) larger mean area has been treated with the chemical treatment (54%) as compared to the mechanical treatment methods (24%) over the four years (2014-2017) in the Waterton Lake National Park (Table 9).

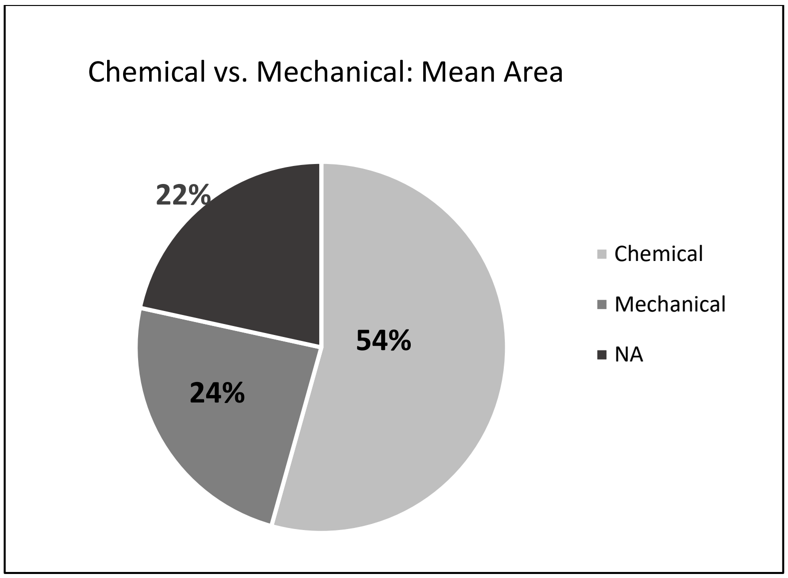


Figure 20. Comparison of mean area treated (2014-2017)

Table 9: ANOVA results for comparison of mean area treated

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.856E10	2	9.281E9	32.791	.000
Intercept	6.859E10	1	6.859E10	242.315	.000
Year_Treat	1.856E10	2	9.281E9	32.791	.000
Error	6.793E11	2400	2.830E8		
Total	8.090E11	2403			
Corrected Total	6.979E11	2402			
a. R Squared = .027 (Adjusted R Squared = .026)					

A comparison of the mean density (plants/sq. m) treated under chemical and mechanical treatment is shown in Figure 22. The data shows that on an average significantly (p-value < 0.05) larger mean density has been treated with the mechanical treatment (56%) as compared to the chemical treatment methods (42%) over the four years (2014-2017) in the Waterton Lake National Park (Table 10).

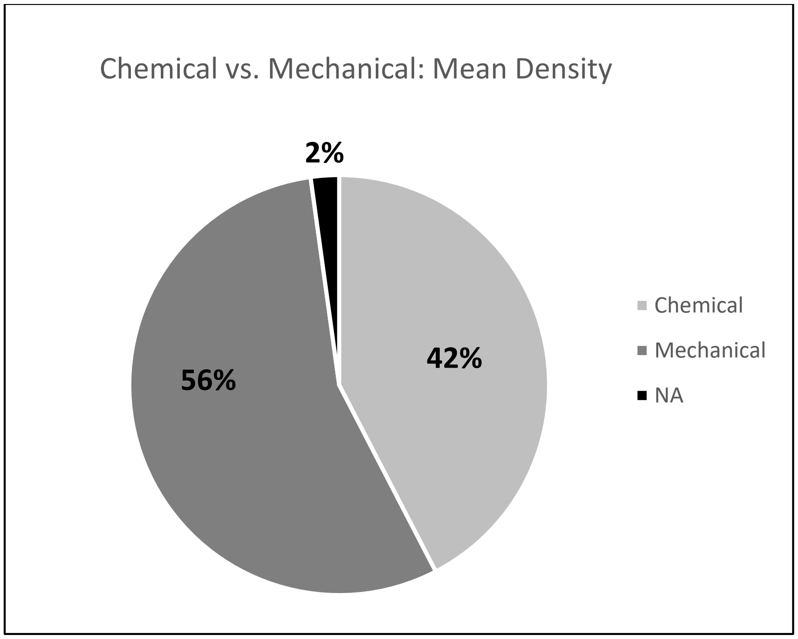


Figure 21. Comparison of mean area treated (2014-2017)

Table 10: ANOVA results for comparison of mean density treated

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	749.485[a]	2	374.743	26.321	.000
Intercept	2134.475	1	2134.475	149.922	.000
Year_Treat	749.485	2	374.743	26.321	.000
Error	34169.463	2400	14.237		
Total	38999.020	2403			
Corrected Total	34918.948	2402			
a. R Squared = .021 (Adjusted R Squared = .021)					

A comparison of the average number of persons working under chemical and mechanical treatment is shown in Figure 23. The data shows that on an average significantly (p-value < 0.05) higher number of persons working under the mechanical treatment (43%) as compared to the chemical treatment methods (32%) over the four years (2014-2017) in the Waterton Lake National Park (Table 11).

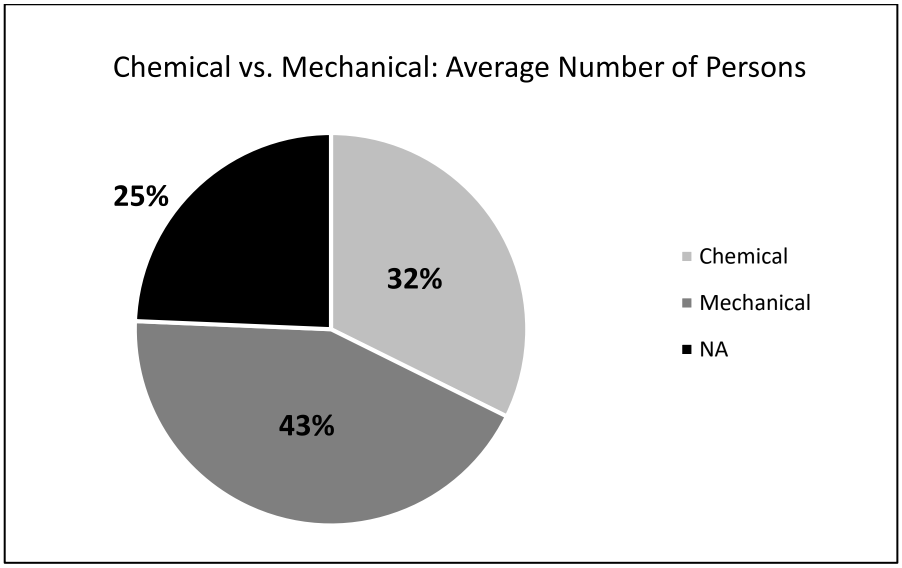


Figure 22. Comparison of average number of persons working (2014-2017)

Table 11: ANOVA results for comparison of average number of persons working

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2283.164[a]	2	1141.582	30.122	.000
Intercept	43082.406	1	43082.406	1136.775	.000
Year_Treat	2283.164	2	1141.582	30.122	.000
Error	90957.136	2400	37.899		
Total	153726.000	2403			
Corrected Total	93240.300	2402			

a. R Squared = .024 (Adjusted R Squared = .024)

DISCUSSION

CHEMICAL TREATMENT

The results of data analysis for chemical treatment show a gradual increase in the amount of chemical herbicide used over the study period of four years (2014-2017), but the increase in use of chemical herbicide was not found to be statistically significant. This proves our hypothesis correct that there is no difference in the amount of chemical herbicide used over four years. However, we found that the mean area treated with chemical herbicide over the study period has significantly decreased over the study period, whereas the mean density (plants per square meter) has shown a significantly increasing trend over the study period. Therefore, our hypothesis in terms of no change in mean area treated and mean density of the plants treated during the study period has been proven false.

Since in our results, the area under chemical herbicide treatment decreased, and density of plants treated increased during the study period, it proves that the chemical herbicide is very effective for highly dense areas affected by spotted knapweed infestation. Of all the methods used to control invasive species infestation, chemical herbicide application has been the most researched one, and it also carries the most negative public opinion. However, because of effective performance of the chemical herbicides and low labor cost associated with their use, herbicides often represent the most cost-effective means to control invasive species for land restoration and rehabilitation purposes (Beck 2013). The use of chemical herbicides is suggested as an efficient and cost effective solution to control weed population with limited budget (Beck 2013).

MECHANICAL TREATMENT

The results of data analysis for mechanical treatment show a gradual increase (statistically significant) for all the factors, i.e., area, density, and number of persons working in a given mechanically treated site over the period of four years (2014-2017. Therefore, our hypothesis in terms of no change in number of persons working, mean area treated and mean density of the plants treated during the study period has been been proven false. Moreover, it was also found that the mechanical methods of treatment have not been used in equal proportions, since cutting and hand-pulling was used more often than digging and torching of spotted knapweed. Thus, our hypothesis in terms of no difference in different types of mechanical treatments has also been proven false.

The results of increase in area treated and increase in density of plants treated, using mechanical methods of treatment to control spotted knapweed infestations, simultaneously means that the number of persons required for mechanical treatment would also increase. Although, the number of persons required for mechanical treatment is high, this method is known to be ecologically safe and effective. The hand pulling of adult spotted knapweed reduces invasive species cover, allowing for increased native species establishment due to decreased competition (Martin 2014). Therefore, the mechanical treatment for spotted knapweed infestation is more useful for the control of smaller areas of infestations (DiTomaso 2000).

COMPARISON OF CHEMICAL AND MECHANICAL TREATMENTS

Over the period of four years (2014-2017), the park restoration team has been able to treat more spotted knapweed plants with chemical method than with mechanical methods of treatment. In fact, chemical herbicide has treated almost three times more spotted knapweed plants than mechanical treatment over the past four years. We also found that in addition to treating higher number of spotted knapweed plants, the chemical treatment method has also treated larger areas of infestation than mechanical treatment.

Interestingly, the mean density of plants treated under mechanical method has been greater than the chemical method. This is because mechanical treatment is done mostly in the flowering stage of spotted knapweeds, when the density of plants with bright purple flowers is high. Whereas during chemical spraying season, the plants are just bolting from the surface and their density is relatively small. However, the average number of persons required for mechanical treatment is significantly higher than the chemical treatment.

Therefore, chemical treatment is more effective when treating invasive species infestations with higher abundance in larger areas with lesser number of persons.

Whereas, the mechanical treatment method is more labour intensive and treats fewer plants in the same time as chemical treatment. However, the mechanical treatment method is able to treat high density infestations in the flowering stage as compared to the chemical treatment. This is supported by past research done in Colorado State University, which shows that hand-pulling controlled almost 100% of spotted knapweed plants in the flowering stage, whereas chemical treatment was able to control only 79% of spotted knapweed plants (Beck 2013).

POTENTIAL ERRORS

There are a few potential errors that may have affected our data. One of the errors is the missing data for density (plants per square meter) for the year 2014. However, our results of mean density analysis show an increase in mean density from the year 2015 to 2017, which is irrespective of the mean density in 2014.

Another source of error may come from the underlying assumption that some plants are missed during these treatments in each of the treated areas for spotted knapweed infestation. However, this error has been reduced by the vegetation restoration team of Waterton Lake National Park by re-visiting all the chemically treated areas after two months of herbicide treatment, and then applying the mechanical treatment in the same area, if the infestation still exists.

A minor human error could have been due to different amount of chemical herbicide used by different sprayers. Each person adopts different spraying method and may use different amount of chemical on each plant. All such human errors in data are captured by showing the standard errors in our results.

FUTURE RECOMMENDATIONS

Based on our research and results, we can provide a few recommendations for achieving an optimum integrated management of chemical and mechanical treatments for controlling the invasive species. The most important aspect for effective and efficient control of invasive species is to control the abundance of invasive species before the seeds of invasive species develop (Beck 2013). For this purpose, the chemical treatment method represents the most effective and economically efficient means to control the invasive species population (Beck 2013). In this study, we also found that chemical treatment method is effective in highly abundant larger areas of spotted knapweed infestation. Milestone herbicide used in this study, has also been found to be effective on agricultural plants. However, more research is needed to test the impact of Milestone herbicide on structural changes in the native plant community. Contrary to the general belief that a chemical herbicide used for the control of invasive species will eliminate native herbs and shrubs, the reality may be very different. The research community has been studying the extent of injury caused to the native grasses, herbs and shrubs by the use of chemical herbicides (Beck 2013). In addition, the mechanical treatment is suggested as a follow-up of chemical treatment in the same area, in order to treat isolated spotted knapweed infestations or for removing small numbers of knapweed that survived herbicide applications (MacDonald et al. 2013). Furthermore, the alternative treatment methods using biological treatments such as revegetation and insects also need to be studied and applied.

Another important thing to consider is the biology and ecology of invasive plant species. In our results, spotted knapweed plant shows an erratic behaviour in its spread from 2014 to 2017. This behaviour may be linked to the weather patterns or the soil conditions, but there are not enough studies to prove that. Therefore, it is important to monitor the invasive plant species behaviour in a natural diverse community for a long term management plan. This includes an understanding of invasion dynamics associated with reproduction, growth, spread, resource use, soil conditions favoring growth, and competitive interactions with other species (DiTomaso 2000).

Overall, it is important to understand that the natural plant communities present a more complicated situation compared with crop production systems and the desired outcome of management actions on natural vegetation sites is more complex (Rice et al. 1997).

CONCLUSION

Spotted knapweed (*Centaurea stoebe*), an invasive plant species has infested the Waterton Lake National Park, and has been providing an aggressive competition to the native plants, thereby threatening the survival of endangered species and ecosystems throughout the Canadian prairies. The fescue grasslands in the foothills parkland ecoregion of the Waterton Lake National Park, which contribute to flora and fauna biodiversity, have been severely affected due to the invasion of non-native spotted knapweed species. We analyzed the effectiveness of two main types of invasive plant management techniques, mechanical and chemical, adopted by the Waterton Lakes National Park's vegetation restoration team over a period of four years (2014-2017). We found that the use of chemical treatment over the study period has decreased in terms of area treated, but increased in terms of the density of plants. We also found that there has been an increase in the use of mechanical treatment over the study period in terms of area, density, and average number of people employed for treatment. Under mechanical treatment, cutting and hand-pulling were the two most commonly used methods.

Our results show that both chemical and mechanical techniques are effective ways for restoration of native plant communities in Waterton Lakes National Park, Alberta. However, chemical techniques are economically efficient in highly abundant large areas of infestation, whereas the mechanical techniques are ecologically efficient for smaller areas with high density infestations. Therefore, an integrated mechanical and chemical techniques invasive species management plan will help the park management in conservation and restoration of the fescue grasslands in the foothills parkland ecoregion, which are important for protecting the rare and endangered flora and fauna. The results of this thesis provide an insight into the invasive species management in the Waterton Lakes National Park in the Canadian prairies, which is the only Canadian national park that preserves the environmentally sensitive fescue grasslands.

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APPENDIX I: CASE SUMMARIES FROM ANOVA

Table 12. Case Summary of Area (ha) treated by chemical and mechanical treatment (2014-2017).

Year_Treat	Treatment	Number of Records	Area (ha)
2014	Chemical	238	325.3311
2015	Chemical	300	335.0895
2016	Chemical	279	210.8589
2017	Chemical	309	227.204
Total	**Chemical**	**1126**	**1098.484**
2014	Mechanical	278	142.2535
2015	Mechanical	177	79.3298
2016	Mechanical	463	202.8801
2017	Mechanical	359	111.0972
Total	**Mechanical**	**1277**	**535.5607**

Table 13. Case Summary of Density treated in chemical and mechanical treatment (2014-2017).

Treatment	Year_Treat	Mean	Minimum	Maximum
Chemical	2014	0	0	0
	2015	0.992	0.5	11
	2016	2.801	0.5	34
	2017	1.4	0.1	17
Mechanical	2014	0	0	0
	2015	1.511	0	25
	2016	2.108	0	100
	2017	1.047	0	50
Total	2014	0	0	0
	2015	1.184	0	25
	2016	2.369	0	100
	2017	1.211	0	50

Table 14. Case summary of sum of Herbicide treatment (2014-2017).

Treatment	Year_Treat	Herbicide amount (L)
Chemical	2014	4444.1
	2015	5199.5
	2016	7510.1
	2017	7447.5
	Total	**24601.2**

Table 15. Mean Abundance of different mechanical treatment method.

Treatment Method	Mean Abundance
Cut_Bag	51570.6
Cut_Seedhead	0.0
Cut_Seedhead_Bag	34406.4
Dig	1.6
Dig_Bag	355.4
Map	733.6
Pull	21135.2
Pull_Bag	4269.7
Searched	103.6
Torch	28.1
Weedwhip	31.3
Total	**6267.7**

Table 16. Case summary of Abundance of plants treated by chemical and mechanical treatment.

Treatment Type	Abundance
Chemical	10942796.1
Mechanical	4075266.4
NA	43274.1
Total	**15061336.6**

Table 17. Case Summary of Mean Area treated by chemical and mechanical treatment.

Treatment Type	**Mean Area**
Chemical	9755.6
Mechanical	4324.0
NA	3873.6
Total	**6800.0**

Table 18. Case Summary of Mean Density treated by chemical and mechanical treatment.

Treatment Type	**Density (# of plants per sq. m)**
Chemical	1.343
Mechanical	1.756
NA	0.069
Total	**1.303**

Table 19. Case Summary of Mean number of persons used for chemical and mechanical treatment.

Treatment Type	Number of Persons
Chemical	4.60
Mechanical	6.17
NA	3.46
Total	**5.02**

Table 20. Case Summary of total Area treated in all treatments (2014-2017).

Year_Treat	N	Area Sum
2014	516	4675846.82
2015	477	4144193.23
2016	742	4137389.69
2017	668	3383012.50
Total	**2403**	**16340442.23**

Table 21. Case Summary of total Area treated in chemical and mechanical treatment.

Treatment	N	Area Sum
Chemical	1126	10984835.67
Mechanical	1277	5355606.56
Total	**2403**	**16340442.23**

Table 22. Case Summary of Area treated in all types of treatment (2014-2017).

Year_Treat	Treatment Type	N	Sum
2014	Chemical	238	3253311.38
	Cut_Bag	1	1632.28
	Cut_Seedhead	1	78.14
	Dig_Bag	2	6.25
	Pull_Bag	223	1396871.30
	Searched	51	23947.46
	Total	516	4675846.82
2015	Chemical	300	3350895.28
	Cut_Bag	1	34380.41
	Dig_Bag	1	12.50
	Map	2	362.03
	Pull_Bag	151	642100.88
	Searched	22	116442.12
	Total	477	4144193.23
2016	Chemical	279	2108588.96
	Cut_Seedhead_Bag	1	344.06
	Map	5	3561.00
	Pull	5	70974.53
	Pull_Bag	339	1193182.36
	Searched	113	760738.77
	Total	742	4137389.69
2017	Chemical	309	2272040.05
	Dig	1	3.13
	Dig_Bag	4	4413.63
	Map	1	3.13
	Pull	2	10873.85
	Pull_Bag	174	571328.00
	Searched	175	524316.33
	Torch	1	3.13
	Weedwhip	1	31.27
	Total	668	3383012.50
Total	Chemical	1126	10984835.67
	Cut_Bag	2	36012.69
	Cut_Seedhead	1	78.14

Cut_Seedhead_Bag	1	344.06
Dig	1	3.13
Dig_Bag	7	4432.39
Map	8	3926.16
Pull	7	81848.37
Pull_Bag	887	3803482.54
Searched	361	1425444.68
Torch	1	3.13
Weedwhip	1	31.27
Total	2403	16340442.23

Table 23. Case Summary of Mean Number of Persons used in each type of treatment (2014-2017).

Year_Treat	**Treatment**	**Number of Persons**
2014	Chemical	4.29
	Mechanical	3.96
	Total	4.12
2015	Chemical	4.35
	Mechanical	7.15
	Total	5.39
2016	Chemical	4.95
	Mechanical	5.92
	Total	5.56
2017	Chemical	4.77
	Mechanical	4.92
	Total	4.85
Total	Chemical	4.60
	Mechanical	5.38
	Total	5.02