WILD CHERVIL (*ANTHRISCUS SYLVESTRIS* (L.) HOFFM.) MANAGEMENT ON NOVA SCOTIA DYKES

by

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ABSTRACT

Wild chervil is an invasive weed on NS dykes that out-competes grasses that provide protective cover and limit soil erosion. Mowing timing and frequency, herbicide application timing and type, as well as both combined, were evaluated as management options for wild chervil on NS dykes. There were minimal no differences among mowing timings and no major benefit in mowing twice. Aminocyclopyrachlor + metsulfuron-methyl, aminopyralid/ metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron were the most effective herbicides evaluated. Application timings of aminocyclopyrachlor + metsulfuron-methyl were evaluated alone and in combination with mowing. Mowing did not improve efficacy and the most effective times to spray were the floral bud and bloom stages. HPLC-UV analysis found herbicide residue in roots of wild chervil plants sprayed at bloom. We conclude that herbicides effectively controlled wild chervil on NS dykes and that mowing was ineffective.

LIST OF ABBREVIATIONS AND SYMBOLS USED

Å	ångström
ae	acid equivalent
AHAS	actohydroxy acid
ai	active ingredient
ALS	acetolactate synthase
DAT	day after treatment
DF	dry flowable
GC	gas chromatography
GDD	growing degree days
HAT	hour after treatment
HPLC	high performance liquid chromatography
LS	liquid solution
LSS	liquid scintillation spectrometry
m	meter
M	molar
MA	Massachusetts
min	minute
mL	milliliter
mm	millimeter
MS	mass spectrometry
N/A	not applicable
nm	nanometer
NS	Nova Scotia
RH	relative humidity
SAS	Statistical Analysis Software
SAX	strong anion exchanger
SEM	standard error of the mean
SG	soluble granule
SPE	solid phase extraction
UPLC	ultra performance liquid chromatography
UV	ultraviolet
v.	version
v	volume
WG	wettable granule

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CHAPTER 1.0: INTRODUCTION

1.1 Introduction

Dyke structures were built to prevent flooding of dykelands caused by heavy rainfall and high tide events. Without proper maintenance, dykes may erode or fail with subsequent flooding of agricultural, commercial, and residential properties. Managing grass species on dykes is an important maintenance strategy. Grasses are encouraged to grow on dykes because their fibrous roots stabilize the dykes and reduce erosion.

In NS (Nova Scotia), wild chervil (*Anthriscus sylvestris* (L.) Hoffm.) is a problematic weed that hinders grass growth and damages dyke structures. It is non-native and an invasive weed that out-competes grasses growing on the dykes, leaving bare ground that is susceptible to soil erosion (van Mierlo and van Groenendael 1991). The development of an effective wild chervil management plan is the focus of this thesis because current practices, such as mowing in late summer and spot herbicide applications, are not effective and the species continues to spread. The impacts of mowing time and frequency, herbicide application timing and type, as well as mowing combined with herbicide application on wild chervil were evaluated in this project.

1.2 Nova Scotia Dykes

Dykelands are the most fertile lands in the Maritime Provinces of Eastern Canada and can be found along the Bay of Fundy coastline. French settlers built dykes and aboiteaux in the Maritimes in the 1630s to keep the salt water from pouring into the lowlands and also to discharge any water that accumulated on the dykelands (Figure 1.1). Early settlers used the dykelands for growing fibre crops, grains and oilseeds and later

used them for hay and pasture production. In 1948, the federal government passed the Maritime Marshland Rehabilitation Act which was a long-term program that focused on building and maintaining dykelands in the Maritimes. These responsibilities were assumed by the provinces in 1970. Each province provided landowners with guidance on how to care for dykeland drains. These structures still protect agricultural and urban areas of the province and in NS are managed by the NS Department of Agriculture.

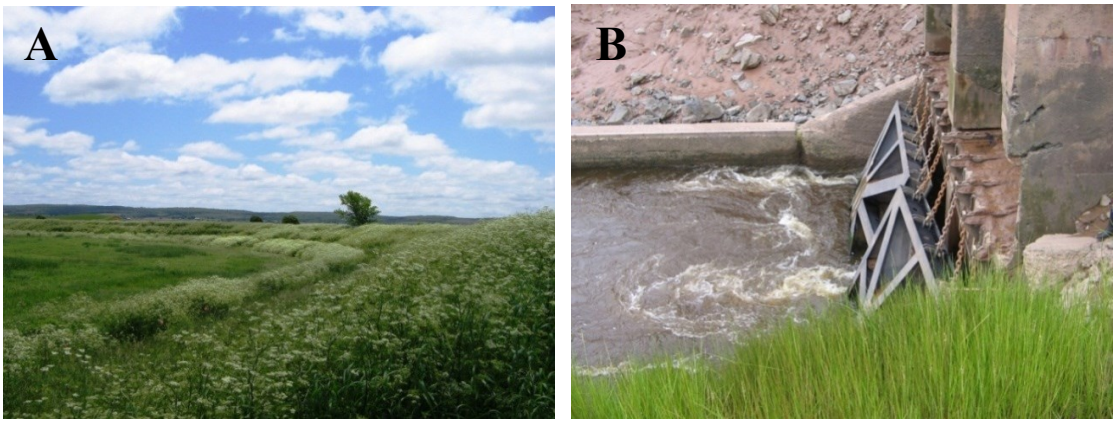

Figure 1.1. (A) A dyke in Onslow, NS having some of the greatest wild chervil pressures in the province, taken June 22nd, 2011 and (B) an aboiteau in Great Village, NS (photos taken by Eileen Beaton).

1.3 Weeds

Weeds are any plants growing in areas where they are not desired, that compete with desirable plants and are unusually persistent. Weeds can be designated as 'noxious' under provincial legislation. Noxious weeds are usually non-native, invasive and cause damage to croplands, natural ecosystems and/or human/animal health (Nova Scotia Department of Agriculture 2010). Invasive weeds are introduced accidentally or intentionally from their native habitat and can potentially harm agricultural and ecological systems (Hughes and Madden 2003). Wild chervil is considered a weed as well as noxious and invasive (Nova Scotia Department of Agriculture 2003).

1.3.1 Phenology

Phenology includes studying plant growth over time; in particular, noting the time at which each plant life stage occurs (Fenner 1998). The purpose of phenology is to attempt to correlate key growth stages with weather observations and/or dates and determine why these growth stages occur at particular times (Fenner 1998). This information allows accurate determination of plant growth rate and timing of growth stages in different locations. It is imperative to research the phenology of 'non-native invasive weeds' in order to initiate proper management strategies (Bryson and Carter 2004). Weed growth varies each year depending on weather conditions, making it difficult to determine the best time to spray herbicides (Cardina et al. 2011). Phenology data allow managers to anticipate timing of a weed's growth and development to ensure optimal application timing to maximize control and reduce the need for subsequent applications (Fidanza et al. 1996; Masin et al. 2005). Wu et al. (2013) conducted a phenology study with spreading dogbane (*Apocynum androsaemifolium*) and related growing degree days (GDD) to key growth stages of spreading dogbane and developed a model to help determine the most advantageous time to spray herbicides. They recommended spraying herbicides between 486 and 535 GDD, which is when the weed is in the 'early floral bud development' stage.

1.3.2 Physical Control

There have been many physical control methods evaluated for controlling wild chervil. Tillage, for example, with or without a herbicide pretreatment provided 92 to 98% control on a freshwater wetland in the Nisqually National Wildlife Refuge Complex in Washington two months after tillage (Miller and D'Auria 2011). Mowing is another

option to prevent seed formation and diminish nutrient reserves in plant root systems. The growth stage of plants at the time of mowing is important (Tipping 2008). Mowing perennial plants during the spring and summer is not effective because plants have optimal growing conditions with high temperatures and appropriate light and moisture to re-grow and store carbohydrates for the following spring. Mowing in late summer or fall in eastern Canada is more effective because it aids in depleting carbohydrates that would have been stored in the roots of the plants and reduces initial growth of the plants the following spring.

There have been studies on a range of species that suggest optimal mowing time is species specific. For example, Tipping (2008) found that mowing plumeless thistle (*Carduus acanthoides*) over 6 years, at the bloom stage, significantly reduced the seed bank and plant densities when compared with mowing at the floral bud stage or at senescence. He also found that mowing musk thistle (*Carduus nutans*) at senescence significantly reduced plant density as opposed to mowing at either an 'early bloom stage' or a 'later bloom stage'.

Mowing wild chervil at different growth stages has been evaluated on several occasions. Hansson and Persson (1994) found that in Sweden, wild chervil was spreading rapidly into nature reserves. They found no differences in wild chervil control over four years after evaluating mowing at difference growth stages and either once or twice. Wild chervil populations decreased in each case but increased in the fourth year when mowing was not evaluated. They recommended doing a similar study over a longer time period and incorporating more frequent mowings and adding cattle grazing to the regime.

Mowing has had an effect on the reproductive allocation of wild chervil as well. Hansson and Persson (1994) found that mowing at bloom caused an increase in vegetative reproduction while Hannson (1994) found an increase when mowing as flowering wild chervil plants have senesced. On the other hand, van Mierlo and van Groenendael (1991) found that mowing at the beginning of bloom caused an increase in inflorescence development from axillary buds while decreasing the potential for vegetative reproduction. Darbyshire et al. (1999) conducted a similar study in Brooklyn, NS but found no differences in rootlet growth after mowing at different stages of wild chervil. Parr and Way (1988) also found no differences in control when mowing wild chervil in June or July on road verges in Cambridgeshire, England, but found that control increased as numbers of mowing increased.

Rosef and Bele (2008) found wild chervil to be a problem on roadsides and grasslands in central Norway. They evaluated mowing and animal grazing for wild chervil control and found that continuous (rather than rotational) cattle grazing controlled wild chervil more effectively than sheep grazing and the mowing regimes tested. They assumed that the cattle caused more crown damage than the sheep when grazing. Grazing, along with tillage, are not options to control wild chervil on NS dykes as these methods may damage the dykes.

1.3.3 Chemical Control

There is currently no effective management option for wild chervil infestations on NS dykes; therefore, more research is needed to identify an effective herbicide for control of wild chervil that does not hinder grass growth. Boyd (2010) has reported that aminocyclopyrachlor (60 g ai (active ingredient) ha^{-1}, DuPont) + metsulfuron- methyl (30

g ai ha^{-1}, DuPont), and aminocyclopyrachlor (70 g ai ha^{-1}, DuPont) + chlorsulfuron (30 g ai ha^{-1}, DuPont) were effective tank mix herbicides to spray on dykes at Onslow, NS. Darbyshire et al. (1999) also evaluated herbicides on wild chervil populations in NS. They reported that dichlorprop/ 2,4-D (2400 g ai ha^{-1}, Nufarm), clopyralid (360 g ai ha^{-1}, Dow AgroSciences), and dicamba (1100 g ai ha^{-1}, BASF) were the most effective herbicides evaluated. They also conducted many herbicide experiments in a third year forage crop at Harbour Centre, NS. They evaluated dicamba (1200 g ai ha^{-1}), clopyralid (200 g ai ha^{-1}), triclopyr (1500 g ai ha^{-1}), dicamba + 2,4-D amine (1200 + 1100 g ai ha^{-1}) and 2,4-D amine (1200 g ai ha^{-1}) but found no differences in control among treatments.

Herbicides have been evaluated for wild chervil control outside of NS as well. Miller and D'Auria (2011) reported 83% wild chervil control with glyphosate (Roundup Pro®, Monsanto) + ammonium sulfate and 73% control with clopyralid (430 g ae (acid equivalent) ha^{-1}) when sprayed on a freshwater wetland in the Nisqually National Wildlife Refuge Complex in Washington state. Oswald (1986) conducted a greenhouse experiment and found no regrowth of mature wild chervil plants after spraying with a tank mix of metsulfuron-methyl (5 g ai ha^{-1}) and chlorsulfuron (15 g ai ha^{-1}). The next most effective herbicide used was chlorsulfuron. He also found that young plants did not regrow after spraying with the tank mix and chlorsulfuron alone. Minimal control was found when metsulfuron-methyl was sprayed alone in both cases.

Other studies have been conducted with plants in the same taxonomic family as wild chervil such as wild carrot (*Daucus carota*) and poison hemlock (*Conium maculatum)*. For example, Stachler and Kells (1997) reported that the most effective fall treatment applied to established wild carrot in Lenawee County and Clinton County,

Michigan was glyphosate alone (1680 g ae ha^{-1}) or tank mixed with 2,4-D ester (560 g ae ha^{-1}, Dow AgroSciences). Jeffrey and Robison (1990) reported that glyphosate or 2,4-D applied in May at 1100 g ae ha^{-1} in alfalfa (*Medicago sativa*) controlled 97-98% of poison hemlock. Glyphosate is not a viable option for wild chervil control on dykes as it is a non-selective herbicide and would kill all plants including grasses on the dykes. Also, 2,4-D is not a viable option as it is one of the herbicides currently used on the dykes in NS and has poor efficacy on wild chervil. Effective herbicides should inhibit wild chervil growth and have limited to no impact on grass growth.

Herbicide efficacy may vary depending on growth stage at the time of spraying. Darbyshire et al. (1999) evaluated dichlorprop (2340 g ai ha^{-1}), clopyralid (300 g ai ha^{-1}), dicamba (2210 g ai ha^{-1}) and mecoprop (1300 g ai ha^{-1}) at different growth stages of wild chervil. They found that mecoprop sprayed at the bloom stage caused the greatest decrease in number of buds per plant. Boyd and White (2010) reported more effective control of goldenrods (*Solidago* spp.) when spraying mesotrione (101 g ha^{-1}, Syngenta) before bloom with a pre-emergent spraying of hexazinone (1920 g ha^{-1}, DuPont) versus applications at other growth stages. Bradley and Hagood (2002) also reported that metsulfuron-methyl (10 g ha^{-1}) provided more effective control of mugwort when applied in bloom rather than at the vegetative stage.

Applying herbicides combined with mowing(s) may optimize wild chervil control. Darbyshire et al. (1999) found mowing wild chervil at the pre-bloom stage then spraying the regrowth with mecoprop (1300 g ai ha^{-1}) caused a 96% reduction in plant density, a greater reduction when compared to plots where herbicides were sprayed without a mowing beforehand. Renz and DiTomaso (2006) found that mowing perennial

pepperweed (*Lepidium latifolium*) in the spring before spraying chlorsulfuron (52 g ai ha^{-1}) on the regrowth at the floral bud stage caused the greatest decrease in perennial pepperweed biomass 1 year after spraying at three different sites in California. Mislevy et al. (1999) also found that control of tropical soda apple (*Solanum viarum*) in Southern Florida, on a commercial ranch, was greatest when plants were mowed twice then sprayed with triclopyr (600 g ai ha^{-1}, Syngenta). A third mowing before applying triclopyr did not provide significant additional control. Bradley and Hagood (2002) also found more control of mugwort when mowing twice before spraying 5 weeks later than spraying alone.

A variety of herbicides were identified with potential for activity on wild chervil (Table 1.1). Herbicides in groups two and four have been evaluated in previous studies mentioned. Many effectively controlled wild chervil and related species. Overdrive®, BASF includes a group four active ingredient (the sodium salt of dicamba) as well as a group 19 active ingredient (the sodium salt of diflufenzopyr). There have been no group 19 herbicides evaluated for wild chervil control to the author's knowledge.

Table 1.1. Mode of action, description, active ingredients, and trade names of herbicides to be evaluated for chervil control.

Mode of action	Description	Active ingredients	Trade name
Group 2			
ALS (acetolactate synthase)/AHAS (acetohydroxy acid) inhibitors	These chemicals prevent the normal function of ALS/AHAS which is crucial in amino acid (protein) synthesis and lead to death of the plant	metsulfuron-methyl	Escort®, DuPont
		chlorsulfuron	Telar®, DuPont
Group 4			
Auxin mimics	These chemicals increase the rate of cell division, affect protein synthesis, and cause malformed growth	aminocyclopyrachlor	MAT-28[a], DuPont
		aminopyralid	Milestone®, DuPont
		the sodium salt of dicamba	Overdrive®, BASF
Group 19			
Auxin transport inhibitors	These chemicals inhibit auxin transport in a plant	the sodium salt of diflufenzopyr	Overdrive®, BASF

[a]Aminocyclopyrachlor is not registered; the code name is listed.

1.3.3.1 Root Translocation of Herbicides

Qualitative and quantitative analysis of herbicides in plant roots is often done to measure herbicide efficacy. It is especially useful to quantify translocation in perennial weed species since herbicides must translocate into the plant roots to provide long-term control. Young et al. (2002) reported that herbicides need to be applied to perennial pepperweed (*Lepidium latifolium*) to best deplete the creeping root system. Hamdoun (1972) also reported that vegetative reproduction of Canada thistle (*Cirsium arvense*) had occurred from root tissue; therefore, herbicides need to be used that translocate into the root in order to prevent re-growth.

There has been no research conducted to quantify aminocyclopyrachlor (MAT-28, DuPont) + metsulfuron-methyl (Escort®, DuPont) movement in wild chervil roots, to the

author's knowledge; however, similar studies have been done with other perennial plants and herbicides. Herbicide translocation in plants varies with time of year and the growth stage of the weed. Determining when and where carbohydrates are stored in plants can help with management decisions (Hassan and Krueger 1980). Herbicides that move through the phloem can translocate to plant rhizomes when there is movement of photosynthetic assimilates going into the rhizomes (Bashtanova et al. 2009). Price et al. (2002) found that carbohydrate translocation in Japanese knotweed (*Fallopia japonica*), a perennial rhizomatous herb, varied according to different times of the year. Most of the synthesized carbohydrates were stored in the shoots in early summer and moved into the rhizomes in late summer where they were greatest before senescence in late fall.

The environment in which plants are grown and sprayed can also have an impact on herbicide translocation. An increase in plant tissue temperatures causes increased enzymatic activities, which, in turn, causes herbicide decomposition. Wills (1976) conducted a greenhouse study to quantify the difference in ^{14}C (carbon-14) bentazon translocation in soybeans (*Glycine max*) and common cocklebur (*Xanthium strumarium*) when sprayed under high or low air temperature, moisture and RH (relative humidity) levels. The herbicide was sprayed at a temperature of 25 or 35º C, and under soil moisture levels of 9 or 14% and RH levels of 35 or 96%. In the soybean plants, the greatest translocation occurred at 35º C, under 14% soil moisture and 35% RH. For common cocklebur, the greatest translocation occurred at 35º C and under 14% soil moisture and 96% RH.

Bukun et al. (2010) compared root translocation of ^{14}C aminocyclopyrachlor free acid versus the methyl ester in Canada thistle (*Cirsium arvense*). Both formulations were

applied at a rate of 140 g ai ha^{-1} with 1% v/v methylated seed oil. There was no significant difference between the translocation of the two herbicide formulations at 192 HAT (hours after treatment). Most of the methyl-ester had been converted to the free acid 6 HAT; furthermore, the free acid was the only form of the aminocyclopyrachlor that translocated into the roots of Canada thistle. Bell et al. (2011) quantified applied ^{14}C aminocyclopyrachlor in the roots of rush skeletonweed (*Chondrilla juncea*). The plant was grown from root fragments and ^{14}C aminocyclopyrachlor was applied to plants in the 4-5 leaf stage at a rate of 210 g ai ha^{-1} including a 0.25% v/v non-ionic surfactant. These authors reported that 3.6% of the applied herbicide was detected in the roots 72 HAT. Both research groups conducted their studies in a greenhouse and applied radio-labeled herbicides. LSS (liquid scintillation spectrometry) was used to quantify the herbicide present in plant roots. Both studies involved harvesting roots at different times throughout the experiment ranging from 2 to 192 HAT.

Translocation is often measured using chromatography techniques. Avula et al. (2011) compared HPLC (high performance liquid chromatography) and UPLC (ultra-performance liquid chromatography) for determining magnoflorine and saponin in roots of blue cohosh (*Caulophyllum thalictroides*). They preferred UPLC as it provided shorter run times of 8 min while maintaining good resolution compared with HPLC where the run time was about 35 min. Farag et al. (2007) used HPLC–UV (ultraviolet)–MS (mass spectrometry), HPLC–MS–MS, and GC (gas chromatography)–MS to identify and quantify polyphenols in barrel medic (*Medicago truncatula*) roots. They were not able to detect all compounds using HPLC-UV-MS; therefore, GC-MS techniques were used to help identify sugars and functional groups.

1.4 Wild Chervil

Wild chervil is a non-native species to NS and has become invasive. According to Darbyshire et al. (1999), the first recorded sighting of wild chervil in N.S was in Bedford in 1971 and it has been found growing in dry to moist conditions in varied soil environments with soils having a pH in the range of 4.1-6.7. It grows on roadsides and dykes, and has spread into dykelands. Wild chervil is considered a noxious weed under NS legislation as well as in Washington State, British Columbia's Fraser Valley, and Grey County, Ontario. Wild chervil is a monocarpic perennial plant deliberately introduced to Canada from Eurasia. Cotyledons appear in late April and early May. Seedings grow approximately six leaves while older plants form a dense rosette and start to flower by the end of June. Seeds will mature in late June or early July. The flowering stems will senesce by August leaving rosettes becoming more established. Seeds will fall off the stems gradually from late July and September. Wild chervil grows a thick tap root up to 2 m long and leaves are triangular in shape and pinnately compound with many leaflets.

1.4.1 Wild Chervil Growth and Reproduction

Wild chervil produces a basal rosette from the crown tissue and usually flowers in its third or fourth year of growth followed by termination of the plant's life cycle (van Mierlo and van Groenendael 1991). A single flowering plant may produce between 800 and 1200 seeds that range in weight from 4.8 to 5.2 mg and have no dispersal mechanism (van Mierlo and van Groenendael 1991). Seed germination occurs at the end of winter if a chilling period of less than 5 ºC has occurred for about three months, allowing the embryos to mature and gain nutrients from the endosperm (van Mierlo and van

Groenendael 1991). Roberts (1979) found that approximately 79% of seeds germinate in the first year, and then 3% germinate the next year.

Wild chervil plants may also undergo vegetative reproduction which can simultaneously occur with seed production. Side rosettes form on rootlets attached to the main taproot and become separate plants over time (Figure 1.2 F). The roots of these plants form a scar where they were initially attached to the parent plant (van Mierlo and van Groenendael 1991). Wild chervil plants will typically produce 1 to 2 rootlets each year. Vegetative reproduction allows wild chervil to grow large populations without relying on seed production (Darbyshire et al. 1999).

1.5 Summary

There is a dire need to manage wild chervil on NS dykes as the methods that are currently employed are not effective. There has been very little research conducted in NS; therefore, more management options should be explored. The main objective of this project was to develop a management plan for wild chervil on NS dykes. The specific objectives were to:

1) determine the impact of mowing timing on wild chervil growth and development;
2) determine the impact of mowing timing and frequency on wild chervil regrowth following mowing, vegetative reproduction and root biomass;
3) measure the efficacy of the following herbicides and tank mixes recommended by DuPont;
    - aminocyclopyrachlor (MAT-28, DuPont) + metsulfuron-methyl (Escort®, DuPont)

- aminocyclopyrachlor (MAT-28, DuPont) + chlorsulfuron (Telar®, DuPont)
- aminopyralid (Milestone®, DuPont)
- aminopyralid, present as potassium salt/ metsulfuron-methyl (Clearview™, Dow AgroSciences)
- sodium salt of diflufenzopyr/ sodium salt of dicamba (Overdrive®, BASF)

4) determine optimal application timing for the tank mix: aminocyclopyrachlor (MAT-28, DuPont) + metsulfuron-methyl (Escort®, DuPont), through evaluation of the impact of application timing on foliage damage and herbicide translocation from the foliage to the root.

The hypotheses are:

1) Mowing at the peak height and floral bud stages will cause the greatest regrowth and development after mowing in regard to height, biomass and flowering.
2) Mowing at different growth stages either once or twice per season will not cause a difference in biomass one month after mowing and in late fall or affect rootlet growth and root biomass.
3) Aminocyclopyrachlor (MAT-28, DuPont) + metsulfuron-methyl (Escort®, DuPont) and aminocyclopyrachlor (MAT-28, DuPont) + chlorsulfuron (Telar®, DuPont) will both cause the greatest wild chervil foliage damage and reduction in ground cover.
4) Applying aminocyclopyrachlor (MAT-28, DuPont) + metsulfuron-methyl (Escort®, DuPont) when wild chervil is in the floral bud stage will cause the greatest foliage damage and translocation from the foliage to the root.

CHAPTER 2.0: PHYSICAL CONTROL OF WILD CHERVIL- MOWING TIMING AND FREQUENCY

2.1 ABSTRACT

Mowing is a common practice used to manage perennial weeds and the plant growth stage at mowing can affect the level of control achieved. A field study was conducted in 2011 and 2012 to evaluate different mowing regimes for wild chervil management. Mowing times included: peak height, floral bud, bloom, seed set, seed maturity I and seed maturity II stages. Seed maturity I was characterized by an area where there were mainly wild chervil plants with mature seeds whereas seed maturity II included additional vegetative wild chervil plants becoming established as rosettes as well. Mowing was done either once or with a second mowing per season. The second mowing occurred when wild chervil shoot regrowth stopped or slowed dramatically following the first mowing. Biomass samples were collected one month after mowing and in the fall and root samples were collected in fall 2012 from unmowed control plots and plots where plants were mowed once at peak height and seed set each year and also those mowed at the same growth stages with an additional mowing each year. None of the mowing regimes significantly affected wild chervil growth, development, re-growth following mowing, vegetative reproduction or root biomass. Generally, there was no difference in wild chervil management among any of the mowing regimes. We conclude that mowing is not an effective short-term management strategy.

2.2 Introduction

Physical weed management strategies include hand-weeding, grazing, burning, mulching, tillage and mowing. Mowing is the most frequently evaluated method in perennial weed studies. Hansson and Persson (1994) conducted a four year experiment in Sweden to determine if there were any differences in wild chervil management when mowing occurred once or twice per season at different growth stages. They found no differences among any of the mowing times and frequencies. Similar studies have been done with other plant species. For example, Tipping (2008) found that mowing plumeless thistle at the bloom stage over 6 years was optimal as was mowing musk thistle at senescence.

Canada thistle is a troublesome weed that has been the focus of many studies using mowing regimes. According to Hamdoun (1972), as long as roots of Canada thistle contain an adequate level of carbohydrates, the plant can re-grow from rootlets on root fragments as small as 10 mm long. Carbohydrate reserves in the roots change throughout the year (McAllister and Haderlie 1985). Tworkoski (1992) found that root reserves were greatest at the peak vegetative height and floral bud stages and decreased thereafter; however, the reserves increased in late summer and fall. He concluded that Canada thistle should be mowed during the bloom stage because carbohydrate reserves in the roots were lowest at this time. The carbohydrates become depleted in the roots as shoots regrow after mowing and, as mowing frequency increases, the carbohydrates in the roots will be used for new growth and will not be stored between mowings (Graglia et al. 2006; Hatcher and Melander 2003). Photosynthate production is reduced and carbohydrate reserves in roots needed for regrowth and survival the following year decrease (Bicksler et al. 2012). Graglia et al. (2006) found a linear negative relationship between number of mowing and hoeing passes of Canada thistle in spring barley crops and the above ground biomass of the weed the following year. A considerable number of mowing and hoeing passes however were necessary to achieve high weeding effectiveness.

Different mowing regimes should be evaluated for management of wild chervil on NS dykes. Field trials were established on dykes with severe wild chervil infestations in Colchester County, NS in 2011 and continued in 2012. The impact of mowing timing and frequency on wild chervil growth, development, re-growth following mowing, vegetative reproduction and root biomass were evaluated. The following hypotheses were tested: a) mowing at the peak height and floral bud stages will cause the greatest

regrowth and development after mowing in regard to height, biomass and flowering; and b) mowing at different growth stages either once or twice per season will not cause a difference in biomass one month after mowing and in late fall or affect rootlet growth and root biomass.

2.4 Materials and Methods

In 2011, a mowing trial was established in Onslow, Nova Scotia (45°22'3"N 63°25'1"W) on the inland side of a dyke and was repeated on another dyke in Great Village, Nova Scotia (45°25'30"N 63°35'57"W). The experiment was continued at both sites in 2012. Trials were established on dykes infested with dense populations of wild chervil. The dykes are typically covered with a mixture of grass species with very few broadleaf species. Mowing times included: peak vegetative height (hereafter referred to as peak height) (Figure 1.2 A), floral bud (Figure 1.2 B), bloom (Figure 1.2 C1, C2), seed set (Figure 1.2 D), seed maturity I and seed maturity II (Figure 1.2 E1, E2). The seed maturity stage was broken down into two sub-stages where seed maturity I was characterized by an area where there were mainly wild chervil plants with mature seeds whereas seed maturity II included additional vegetative wild chervil plants becoming established as rosettes as well. The second mowing was conducted when maximum height was achieved and wild chervil growth slowed dramatically as measured from the weekly/biweekly height measurements.

The experiment was a split-plot in a randomized complete block design with 4 blocks where the main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing. Main plots were 6 m by 2 m while sub-plots were 3 m by 2 m. An unmowed control was included as a main plot and in 2012,

the plot was split and one sub-plot was left unmowed and the other sub-plot was mowed once at peak height.

Height and growth stage observations were recorded from the mowing trials on a weekly basis starting in mid-May of each year. These data were used to track the growth of wild chervil and to determine when the wild chervil reached its maximum height after the first mowing. Observations were recorded weekly up to late summer when plant growth began to slow, then biweekly after that. Biomass samples were collected on the day of mowing, one month after mowing, and in late fall. Fall biomass collections in Onslow occurred on September 27th, 28th and October 3rd, 2011 then on October 1st-3rd, 2012 while those in Great Village occurred on September 29th, October 3rd, October 7th and 8th, 2011 and on September 24th-28th, 2012. Root samples were also collected at Onslow on October 17th and 18th, 2012 and at Great Village on October 23rd-25th, 2012 in plots that were not mowed, mowed at peak height each year, at seed set each year and all of these plots mowed at this time but with the addition of a second mowing each year. All biomass and root samples were dried at 50 °C for approximately 72 hours and weighed. Root samples were weighed separately.

2.5 Data Collection

Five height measurements and an above ground biomass sample were collected randomly just prior to mowing on the day the plots were mowed. Height was measured using a metre stick and biomass was collected in a 50 cm by 50 cm quadrat and was later dried and weighed. Growth stage was also observed and classified as: peak height, floral bud, bloom, seed set, seed maturity I or seed maturity II. The growth stage was classified based on the stage of the majority of the plants in the plot. Umbels were also counted in

the plots that were mowed for the second time. These variables were used to help define the time of mowing in addition to the dates and GDD. The dates and GDD at the time of each mowing at Onslow and Great Village for both years are provided in Table 2.1.

The biomass samples collected on the day of mowing and one month after mowing were separated into three groups: wild chervil, grass and miscellaneous plants, except in 2011 where miscellaneous plant species were grouped with the grasses due to their low levels. Biomass samples collected in the fall were separated into four groups: wild chervil, grasses, miscellaneous plants and legumes. All samples were dried and weighed.

Ten random root samples were collected from each of the plots of the treatments mentioned in section 2.4. The number of rootlets on each root was counted and rootlets with and without a tap root were counted separately. The diameter of the parent root was also measured. The root samples were washed, dried and weighed separately.

2.6 Data Analysis

Hobo® Pro V2 logger (Onset Computer Corporation) weather stations were set up approximately 1 m from the ground at each mowing site in a control treatment plot to record air temperature. Growing degree days were calculated starting on April 1st in 2011 and 2012 using a base development temperature of 0 ºC with the following formula:

Cumulative GDD = $\sum (T_{average} - T_{base})$

where $T_{average}$ is the average daily air temperature and T_{base} is the temperature below which many plants do not develop. T_{base} is 0°C in this case. A biofix date of April 1st was used.

Daily temperatures in April of each year were collected from the Environment Canada weather station located at Debert, Nova Scotia, the closest weather station to Onslow and Great Village. Hobo® Pro V2 loggers were set up in the field on May 1st and used to measure hourly data for the remainder of the season.

Data were analyzed using the PROC MIXED command in SAS v. 9.3 (SAS Institute Inc., Cary, NC). Growth stage before mowing and frequency of mowing were fixed effects and block was a random effect. Means were separated using Tukey adjusted means comparison at the 5% level. The statistical model used was for each site:

$$Y_{ijk} = \mu + \rho_i + \alpha_j + \gamma_{ij} + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk}$$

Where Y_{ijk} is the variable of interest; μ is the overall mean; ρ_i is the effect of the i^{th} block (i=1-4); α_j is the effect of the j^{th} number of main plot treatments (mowing times) (j=1-6); γ_{ij} is the main plot error; β_k is the effect of the k^{th} number of sub plot treatments (mowing frequency) (k=1-2); $\alpha\beta_{jk}$ is the effect of the interaction between main and sub plot treatments and ε_{ijk} is the random effect of error.

Assumptions including independence, normality of residuals and constant variance were tested and verified using PROC UNIVARIATE analysis and by plotting residual*predicted values. One to four outliers were removed from a number of data sets to meet assumptions. These outliers were determined through examining the normal probability plot. Any values that were not plotted within the pattern (an approximate straight line) of the whole plot were considered outliers. The datasets from which outliers were removed included:

- grass biomass collected before mowing, Onslow, 2011
- wild chervil biomass collected one month after mowing, Onslow, 2011

- wild chervil and grass biomass collected before mowing, Great Village, 2011
- grass biomass collected in the fall, Great Village, 2011
- wild chervil biomass and height measurements collected before mowing, Onslow, 2012
- wild chervil biomass collected in the fall, Onslow, 2012.
- wild chervil and grass biomass collected before mowing, Great Village, 2012
- wild chervil biomass collected in the fall, Great Village, 2012
- grass biomass collected one month after mowing, Great Village, 2012.
- miscellaneous plant species collected one month after mowing and in the fall, Great Village, 2012
- diameter of the parent roots measured at root sampling, Onslow and Great Village, 2012

Log and square root transformations were also used, where required, to meet assumptions but actual means are presented. The subroutine pdmix800.sas (Saxton 1998) was utilized to provide letter groupings. For data which still failed to meet these assumptions, a Proc Npar1way Kruskal-Wallis test was done.

2.7 Results and Discussion

2.7.1 Wild Chervil Growth and Development

Growth stage at the time of mowing had little impact on wild chervil growth and development. There were few or no significant differences in height and biomass as the plants reached their maximum growth stage before a second mowing was applied. At Onslow in 2011, wild chervil heights had a significant mowing time by mowing frequency interaction and wild chervil biomass had a significant mowing frequency effect but mowing had no effect on grass biomass (Table 2.2). At Great Village, wild chervil heights had a significant mowing time by mowing frequency interaction and grass biomass had a significant mowing time effect but there was no effect on wild chervil biomass (Table 2.2). As expected, height tended to increase, though not always significantly, as the season progressed and then decreased late in the season. Regrowth from plants mowed later in the season tended to be shorter with less biomass before the second mowing. There were no umbels that grew (or regrew) after mowing. Similar trends were observed at both sites.

At Onslow in 2012, wild chervil heights and biomass had significant mowing time by mowing frequency interactions. Mowing had no effect on grass or miscellaneous plant species biomass (Table 2.3). Umbels grew after mowing at the peak height and floral bud stages and one per plot grew after mowing at bloom (Table 2.3). At Great Village, wild chervil heights, biomass and grass biomass had significant mowing time by mowing frequency interactions (Table 2.3). Mowing did not have an effect on miscellaneous plant species biomass (Table 2.3). Umbels grew on the wild chervil plants

after mowing at the peak height and floral bud stages (Table 2.3). Trends in height and biomass observed were similar at each site and to those observed in 2011.

Generally, the wild chervil plants recovered to similar heights and biomass regardless of the growth stage at the time of mowing; however, wild chervil plants mowed later in the summer did not recover as much. Wild chervil height and biomass was less overall in Great Village but results were similar to those at Onslow. Umbels grew on the wild chervil plants after mowing at the peak height and floral bud stages at both sites in 2012. These results correspond with the hypothesis that mowing at the peak height and floral bud stages would cause the greatest regrowth and development after mowing in regard to height, biomass and flowering. The findings are similar to those of van Mierlo and van Groenendael (1991) who found that mowing at the floral bud stage resulted in inflorescence development from axillary buds while diminishing the potential for vegetative reproduction.

2.7.2 Plant Description

In control plots, wild chervil plants began to grow a basal rosette in April from crown tissue. Rosettes did not overwinter and new leaves grew in the spring. Plants in the vegetative stage grew up to 50 cm tall (Figure 1.2 A). The plants grew an average of 23 cm per week until flowering when plant growth slowed dramatically. Figure 1.2 B shows the flower buds that formed before flowering began. Wild chervil plants began to flower in early June, peaking in mid-June, and lasting until early July. (Figure 1.2 C1, C2). Flowering plants grew up to 2 m tall with stems approximately 2 cm in diameter. Seeds began to set in early July, matured and turned dark brown by early August (Figure 1.2 D, E1, E2). As seeds matured, wild chervil plants began to senesce, regardless of

frost, while newly emerging plants continued to grow into late fall. Plants emerging from seed and from vegetative reproduction were difficult to distinguish; however, rootlets were attached to the main taproots of the plants and were observed throughout the season (Figure 1.2 F).

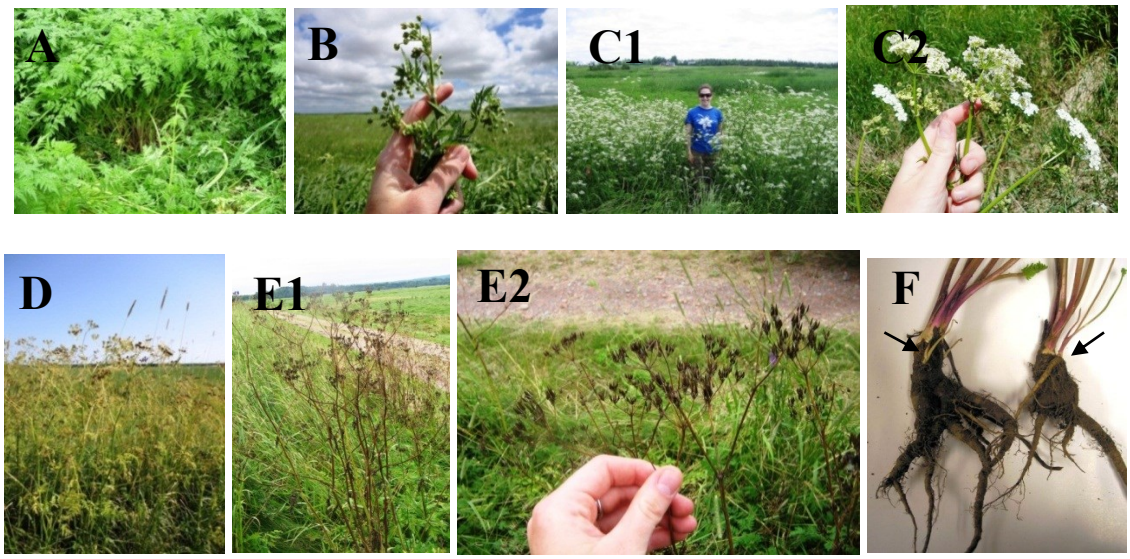

Figure 1.2. Wild chervil in (A) the vegetative, (B) floral bud, (C1)/ (C2) bloom (D) seed set and (E1)/(E2) seed maturity growth stages as well as (F) wild chervil undergoing vegetative reproduction (photos taken by Eileen Beaton).

Table 2.1. Dates and GDD when the first and second mowing occurred at Onslow and Great Village, 2011/2012.

		Onslow				Great Village			
		2011		2012		2011		2012	
Mowing	Stage	Date	GDD[d]	Date	GDD	Date	GDD	Date	GDD
First[a]	Unmowed	N/A[d]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Peak height	May 25	345	May 25	345	May 25	346	May 24	449
	Floral bud	June 1	453	June 1	453	June 1	460	May 31	536
	Bloom	June 16	643	June 16	643	June 16	652	June 14	721
	Seed set	July 6	970	July 6	970	July 6	982	July 3	1055
	Seed maturity I[c]	July 29	1387	July 29	1387	July 29	1400	July 17	1337
	Seed maturity II[c]	Aug 9	1641	Aug 2	1460	Aug 9	1602	July 31	1606
Second[ab]	Mowed	N/A	N/A	May 25	345	N/A	N/A	May 24	449
	Peak height	Aug 2	1515	June 28	940	Aug 2	1474	June 29	974
	Floral bud	Aug 12	1638	July 11	1197	Aug 12	1655	July 11	1214
	Bloom	Aug 17	1734	Aug 2	1625	Aug 17	1751	Aug 2	1642
	Seed set	Aug 22	1837	Aug 16	1932	Aug 22	1852	Aug 23	2088
	Seed maturity I	Aug 25	1893	Aug 31	2219	Aug 25	1908	Sept 7	2350
	Seed maturity II	Aug 31	2008	Sept 4	2277	Aug 31	2021	Sept 13	2451

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Abbreviation: GDD, growing degree days; N/A, not applicable.

Table 2.2. Chervil height and biomass and grass biomass at the first and second mowing at Onslow and Great Village, 2011.

		Onslow			Great Village		
		Height	Biomass		Height	Biomass	
Mowing	Stage	Chervil	Chervil	Grass	Chervil	Chervil	Grass
		cm	g m^{-2}		cm	g m^{-2}	
First[a]	Un-mowed	N/A[e]	N/A	N/A	N/A	N/A	N/A
	Peak height	56 de[d]	432 abc	62 a	31 cd	38 a	73 b
	Floral bud	104 c	478 abc	12 a	52 bc	170 a	200 b
	Bloom	155 a	610 a	83 a	104 a	65 a	196 b
	Seed set	159 a	597 ab	37 a	102 a	61 a	243 b
	Seed maturity I[c]	153 a	593 ab	100 a	101 a	147 a	341 ab
	Seed maturity II[c]	130 b	262 abc	91 a	76 ab	92 a	636 a
Second[ab]	Mowed	N/A	N/A	N/A	N/A	N/A	N/A
	Peak height	.	233 abc	65 a	.	76 a	161 b
	Floral bud	61 de	225 abc	29 a	38 cd	32 a	153 b
	Bloom	67 d	200 abc	63 a	36 cd	74 a	162 b
	Seed set	62 d	389 abc	64 a	34 cd	83 a	408 ab
	Seed maturity I	45 de	111 c	37 a	30 cd	28 a	72 b
	Seed maturity II	39 e	125 bc	45 a	24 d	23 a	.
	SEM[d]	0	18	5	1	8	17
	Effect	*P*-value					
	Main	*<.0001*	*0.1541*	*0.6642*	*<.0001*	*0.8983*	*0.0007*
	Sub	*<.0001*	*<.0001*	*0.3677*	*<.0001*	*0.0675*	*0.6499*
	Main*sub	*<.0001*	*0.2432*	*0.4361*	*0.0002*	*0.1212*	*0.0473*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included more vegetative chervil plants.
[d]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[e]Abbreviation: N/A, not applicable; SEM, standard error of the mean.

Table 2.3. Chervil height and biomass, and grass and miscellaneous plant species biomass the same day as the first and second mowing along with number of umbels before the second mowing at Onslow and Great Village, 2012.

		Onslow					Great Village				
		Height	Biomass			umbels	Height	Biomass			umbels
Mowing	Stage	Chervil	Chervil	Grass	Misc.[g]		Chervil	Chervil	Grass	Misc.	
		—cm—	——————g m^{-2}——————				—cm—	——————g m^{-2}——————			
First[a]	Unmowed	N/A[g]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Peak height	57 d[d]	241 d	3 (1)[e]	0 (0)	-	46 c	142 bcd	73 bc	27 a	-
	Floral bud	89 c	655 abc	0 (0)	0 (0)	-	71 b	135 bcd	72 bc	55 a	-
	Bloom	135 b	794 ab	13 (13)	0.4 (0)	-	118 a	367 ab	84 bc	46 a	-
	Seed set	154 a	951 a	27 (26)	0 (0)	-	119 a	254 bc	34 bc	34 a	-
	Seed maturity I[c]	153 ab	595 abcd	0 (0)	0 (0)	-	124 a	596 a	132 b	32 a	-
	Seed maturity II[c]	88 c	388 bcd	43 (40)	0.1 (0)	-	69 b	93 cd	291 a	71 a	-
Second[ab]	Mowed	61	188.3	2.4	0	-	48	165.6	55.4	44	-
	Peak height	80 c	282 cd	0 (0)	0 (0)	113 (27)	74 b	71 cd	28 bc	73 a	47 (17)
	Floral bud	38 d	189 d	0 (0)	0 (0)	37 (12)	27 d	35 cd	43 bc	87 a	8 (5)
	Bloom	44 d	237 d	4 (4)	0 (0)	1 (0)	28 d	93 cd	26 bc	8 a	0 (0)
	Seed set	45 d	166 d	2 (1)	0 (0)	0 (0)	27 d	45 d	21 c	21 a	0 (0)
	Seed maturity I	47 d	236 d	6 (4)	21 (21)	0 (0)	33 cd	80 cd	19 c	26 a	0 (0)
	Seed maturity II	44 d	271 cd	42 (24)	0.7 (1)	0 (0)	29 d	113 cd	25 bc	31 a	0 (0)
	SEM[g]	1	17	N/A	N/A	N/A	0	3	3	4	N/A
	Pr > Chi-Square	*N/A*	*N/A*	*0.2133*	*0.1169*	*0.0008*	*N/A*	*N/A*	*N/A*	*N/A*	*0.0012*
	Effect[f]	——————————————————————————*P*-value——————————————————————————									
	Time	*<.0001*	*0.0187*	*N/A*	*N/A*	*N/A*	*0.0021*	*0.1447*	*0.0011*	*0.3035*	*N/A*
	Frequency	*<.0001*	*<.0001*	*N/A*	*N/A*	*N/A*	*<.0001*	*0.1447*	*<.0001*	*0.7579*	*N/A*
	Time*frequency	*<.0001*	*<.0001*	*N/A*	*N/A*	*N/A*	*<.0001*	*0.0040*	*<.0001*	*0.1359*	*N/A*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[e]Means within a column with no letters were analyzed using a Proc Npar1way Kruskal-Wallis test; SEM are provided in brackets.
[f]Effects included mowing time and mowing frequency.
[g]Abbreviaion: N/A, not applicable; SEM, standard error of the mean; Misc., miscellaneous.

2.7.3 Regrowth Following Mowing

Mowing had little effect on wild chervil regrowth one month after mowing and in late fall. There was often no additional benefit in mowing twice. At Onslow in 2011, wild chervil regrowth had a significant mowing time by mowing frequency interaction one month after mowing and mowing frequency was significant in late September. Grass regrowth had a significant mowing frequency effect one month after mowing but no significant effects were found in late September (Table 2.4). In Great Village, wild chervil had a significant mowing time by mowing frequency interaction one month after mowing and mowing frequency was significant in early October (Table 2.5). Mowing had no effect on grass regrowth one month after mowing but had a significant mowing frequency effect in early October (Table 2.5).

At Onslow in 2012, wild chervil regrowth had a significant mowing time by mowing frequency interaction one month after mowing but no significant effects were found in early October (Table 2.4). Mowing tended to have no impact on grass regrowth one month after mowing or in early October (Table 2.4). At Great Village, mowing had no effect on wild chervil biomass one month after mowing but a significant mowing time by mowing frequency interaction was found in early October (Table 2.5). Mowing did not have an effect on grass regrowth one month after mowing or in early October (Table 2.5).

There were few differences in miscellaneous plant species and legume biomass at Onslow and Great Village in 2012. At Onslow, mowing tended to have a marginal effect on miscellaneous plant species biomass. Biomass was low in most cases one month after mowing except when mowing occurred at bloom with a second mowing as well as in

early October except when mowing occurred once at bloom (Table 2.6). At Great Village, biomass had a significant mowing time by mowing frequency interaction one month after mowing and in early October (Table 2.6). The least amount of biomass was found after the later mowings. At Onslow, mowing did not impact legume biomass (Table 2.7). At Great Village, legume biomass tended to be greatest in late fall after any of the regimes with only one mowing (Table 2.7).

There were high levels of variability in the results of this experiment and similar trends were observed at both sites and years. Mowing mostly had no effect on wild chervil and grass regrowth, especially in late fall of both years, and few effects on miscellaneous plant species and legume biomass. These results correspond with the hypothesis that mowing at different growth stages either once or twice per season would not cause a difference in biomass one month after mowing and in late fall. Results of this study were similar to that of Hansson and Persson (1994) where there were no differences among mowing regimes when wild chervil was mowed once or twice and at different growth stages. Likewise, Darbyshire et al. (1999) and Rosef and Bele (2008) and Parr and Way (1988) did not find any differences in control when wild chervil was mowed at different growth stages. Averill et al. (2008) had similar results as well when evaluating mowing on pale swallow-wort (*Vincetoxicum rossicum*) control over 2 years. They found no difference in mowing once or twice and furthermore, no benefit in mowing at all.

Other researchers have shown that adequate management of weeds through mowing requires more than 2 years. Tipping (2008) conducted a 6 year experiment to evaluate plumeless thistle and musk thistle control and reported that the best management

was achieved when mowed once at the bloom and senescence stage, respectively. Despite tillage and cattle grazing being shown to be effective management options for wild chervil by Miller and D'Auria (2011) and Rosef and Bele (2008), respectively, these would not be viable options in this case because cattle would likely damage the dykes.

Table 2.4. Chervil and grass biomass (g m^{-2}) 1 month after mowing and in the fall at Onslow, 2011 and 2012.

		Chervil				Grass			
		2011		2012		2011		2012	
Mowing	Stage	1 month after	Late September	1 month after	Early October	1 month after	Late September	1 month after	Early October
		g m^{-2}							
First[a]	Unmowed	-	112	-	157	-	31	-	17
	Peak height	254 a[d]	280 a	223 abc	170 a	486 a	25 a	2 (1)[e]	15 (11)
	Floral bud	123 abc	316 a	125 bcd	161 a	35 ab	5 a	0 (0)	0 (0)
	Bloom	56 c	259 a	98 cd	182 a	21 ab	32 a	20 (19)	48 (44)
	Seed set	132 abc	198 a	97 cd	175 a	9 ab	2 a	13 (8)	37 (22)
	Seed maturity I[c]	132 abc	215 a	129 bcd	156 a	43 ab	37 a	20 (16)	51 (30)
	Seed maturity II[c]	183 abc	267 a	172 abcd	131 a	86 ab	6 a	29 (23)	31 (14)
Second[ab]	Mowed	-	-	-	232	-	-	-	1
	Peak height	191 abc	298 a	112 bcd	187 a	26 ab	9 a	8 (4)	1 (1)
	Floral bud	240 ab	240 a	155 bcd	266 a	5 b	5 a	0 (0)	0 (0)
	Bloom	201 abc	201 a	301 a	174 a	12 b	12 a	16 (21)	1 (1)
	Seed set	190 abc	185 a	247 ab	152 a	24 ab	24 a	1 (0)	1 (1)
	Seed maturity I	70 bc	70 a	91 cd	82 a	58 ab	54 a	24 (14)	24 (14)
	Seed maturity II	116 abc	116 a	63 d	82a	5 ab	5 a	18 (23)	23 (23)
	SEM[g]	8	13	7	10	0	1	N/A	N/A
	Pr > Chi-Square	N/A[g]	N/A	N/A	N/A	N/A	N/A	*0.2270*	*0.1730*
	Effect[f]	*P*-value							
	Time	*0.1278*	*0.0738*	*0.0385*	*0.1414*	*0.0498*	*0.1393*	N/A	N/A
	Frequency	*0.5877*	*0.0275*	*0.1934*	*0.8214*	*0.0145*	*0.9803*	N/A	N/A
	Time*frequency	*0.0027*	*0.4786*	*<.0001*	*0.3630*	*0.4522*	*0.0866*	N/A	N/A

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[e]Means within a column with no letters were analyzed using a Proc Npar1way Kruskal-Wallis test; SEM are provided in brackets.
[f]Effects included mowing time and mowing frequency.
[g]Abbreviation: N/A, not applicable; SEM, standard error of the mean.

Table 2.5. Chervil and grass biomass (g m^{-2}) 1 month after mowing and in the fall at Great Village, 2011 and 2012.

		Chervil				Grass			
		2011		2012		2011		2012	
Mowing	Stage	1 month after	Early October	1 month after	Early October	1 month after	Early October	1 month after	Early October
		g m^{-2}							
First[a]	Unmowed	-	71	-	168	-	99	-	31
	Peak height	32 a[d]	56 a	72 ab	59 ab	107 a	85 ab	40 a	58 a
	Floral bud	33 a	59 a	31 ab	67 ab	79 a	124 ab	30 a	46 a
	Bloom	64 a	30 a	19 ab	60 ab	82 a	208 a	25 a	103 a
	Seed set	25 a	91 a	55 ab	81 ab	66 a	116 ab	11 a	40 a
	Seed maturity I[c]	57 a	76 a	87 ab	94 a	74 a	58 b	28 a	18 a
	Seed maturity II[c]	31 a	31 a	72 ab	60 ab	104 a	104 ab	37 a	35 a
Second[ab]	Mowed	-	-	-	21	-	-	-	9
	Peak height	38 a	47 a	112 a	79 ab	60 a	40 b	29 a	28 a
	Floral bud	31 a	31 a	12 b	55 ab	66 a	66 ab	22 a	32 a
	Bloom	24 a	24 a	42 ab	52 ab	104 a	24 b	26 a	29 a
	Seed set	75 a	34 a	38 ab	38 ab	66 a	56 b	23 a	23 a
	Seed maturity I	38 a	38 a	39 ab	20 b	66 a	61 ab	17 a	14 a
	Seed maturity II	30 a	30 a	33 ab	18 ab	.	30 b	25 a	10 a
	SEM[f]	2	3	4	2	5	7	2	0
	Effect[e]	*P*-value							
	Time	*0.8524*	*0.6973*	*0.0458*	*0.9061*	*0.9143*	*0.3341*	*0.9297*	*0.1450*
	Frequency	*0.8903*	*0.0175*	*0.3207*	*0.0008*	*0.5265*	*0.0006*	*0.2935*	*0.0486*
	Time*frequency	*0.0260*	*0.4550*	*0.1072*	*0.0103*	*0.6203*	*0.0807*	*0.6552*	*0.2611*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[e]Effects included mowing time and mowing frequency.
[f]Abbreviation: SEM, standard error of the mean.

Table 2.6. Miscellaneous plant species biomass (g m^{-2}) 1 month after mowing and in the fall at Onslow and Great Village, 2012.

		Onslow		Great Village	
Mowing	Stage	1 month after	Early October	1 month after	Early October
		g m^{-2}			
First[a]	Unmowed	-	0	-	2
	Peak height	0.8 (0)[e]	0 (0)	34 a[d]	20 bc
	Floral bud	0 (0)	0 (0)	24 ab	24 bc
	Bloom	0 (0)	12.7(0)	5 bc	19 bc
	Seed set	0 (0)	0 (0)	2 c	6 c
	Seed maturity I[c]	5.9 (6)	0 (0)	6 bc	4 c
	Seed maturity II[c]	4.1 (4)	0 (0)	15 abc	10 c
Second[ab]	Mowed	-	0	-	5
	Peak height	6.3 (4)	0 (0)	6 bc	49 ab
	Floral bud	0.5 (0)	0 (0)	32 ab	63 a
	Bloom	19 (19)	0.4 (0)	8 abc	22 bc
	Seed set	0 (0)	0 (0)	15 abc	15 c
	Seed maturity I	0.6 (1)	0.6 (1)	3 c	2 c
	Seed maturity II	0.7 (1)	0 (0)	4 bc	3 c
	SEM[f]	N/A	N/A	1	1
	Pr > Chi-Square	*0.0497*	*0.0409*	N/A	N/A
	Effect[g]	*P*-value			
	Time	N/A[f]	N/A	*0.0043*	*<.0001*
	Frequency	N/A	N/A	*0.2764*	*0.0026*
	Time*frequency	N/A	N/A	*0.0026*	*0.0076*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[e]Means within a column with no letters were analyzed using a Proc Npar1way Kruskal-Wallis test; SEM are provided in brackets.
[f]Abbreviation: N/A, not applicable; SEM, standard error of the mean.
[g]Effects included mowing time and mowing frequency.

Table 2.7. Legume biomass (g m^{-2}) in late fall at Onslow and Great Village, 2012.

Mowing	Stage	Onslow	Great Village
		g m^{-2}	
First[a]	Unmowed	95	0.3
	Peak height	0 (0)[d]	18.9 (3)
	Floral bud	31 (31)	3.9 (2)
	Bloom	0.08 (0)	5.9 (3)
	Seed set	24.4 (24)	16.6 (12)
	Seed maturity I[c]	2 (2)	12.7 (6)
	Seed maturity II[c]	27.5 (25)	1.2 (1)
Second[ab]	Mowed	28	3
	Peak height	0 (21)	24.7 (8)
	Floral bud	0 (0)	8.9 (8)
	Bloom	0 (0)	3.6 (2)
	Seed set	0 (0)	3.7 (3)
	Seed maturity I	7.6 (6)	4.3 (4)
	Seed maturity II	0.7 (1)	0.27 (0)
	Pr > Chi-Square	*0.6637*	*0.0087*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Seed maturity I was an area of mostly chervil plants with mature seeds; seed maturity II included additional vegetative chervil plants as well.
[d]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

2.7.4 Vegetative Reproduction and Root Biomass

Numbers of rootlets with or without a tap root on the wild chervil plants were between 0 to 1 at Great Village and 0 to 2 at Onslow in all plots including the unmowed control. There were no significant differences in root biomass and parent root diameter at either site; values were similar to that of the unmowed control (Table 2.8). These results correspond to the hypothesis that mowing at different growth stages either once or twice per season would not affect rootlet growth and root biomass. Generally, mowing did not have an impact on vegetative reproduction and root biomass, and there was no major benefit in mowing twice. These results are similar to that of Darbyshire et al. (1999) who found no differences in rootlet growth after mowing at different growth stages.

On the other hand, Hansson and Persson (1994), Hansson (1994) and van Mierlo and van Groenendael (1991) all found differences in vegetative reproduction among mowing times evaluated.

Table 2.8. Root biomass and parent root diameter in late fall at Onslow and Great Village, 2012.

Mowing	Stage	Onslow		Great Village	
		Root biomass	Parent root diameter	Root biomass	Parent root diameter
		——g——	—mm—	——g——	—mm—
First[a]	Unmowed	3	11	4	10
	Peak height	5 (1)[c]	13 (1)	3 (0)	11 (1)
	Seed set	4 (1)	12 (1)	4 (0)	10 (1)
Second[ab]	Peak height	3 (0)	12 (1)	3 (0)	9 (1)
	Seed set	3 (0)	11 (1)	2 (1)	9 (1)
	Pr > Chi-Square	*0.4622*	*0.3056*	*0.6363*	*0.7924*

[a]The main plot represented the timing of the first mowing and sub-plot was the presence or absence of a second mowing.
[b]The second mowings occurred when chervil stopped or slowed dramatically after being mowed at the growth stages listed.
[c]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM are provided in brackets.

2.8 Conclusion

Mowing did not provide adequate wild chervil control during this experiment. Wild chervil continued to grow on the dykes regardless of the mowing regime evaluated; however, mowing at the peak height and floral bud stages caused inflorescence development of axillary buds in 2012 at each site. Mowing once at the floral bud stage may be an optimal regime for inflorescence development of axillary buds and minimizing vegetative reproduction; however, aboiteau superintendents would need a broad time frame to achieve adequate control with mowing alone, despite the frequency. Herbicides used alone or in combination with mowing may be a better option with more rapid impact to provide long-term control of wild chervil on NS dykes.

CHAPTER 3.0: CHEMICAL CONTROL

3.1 ABSTRACT

Herbicides are an effective management strategy for control of many perennial weeds; however, there are currently no effective herbicides registered for use on wild chervil. Herbicides, tank mixes and application times were evaluated in field studies conducted during 2011 and 2012. Aminocyclopyrachlor + metsulfuron-methyl, aminocyclopyrachlor + chlorsulfuron, aminopyralid, aminopyralid/ metsulfuron- methyl and diflufenzopyr/ dicamba were all evaluated for their ability to control wild chervil. Different application times were evaluated with aminocyclopyrachlor + metsulfuron-methyl as well. Applications occurred when wild chervil was in the floral bud, bloom, or the seed set stage and in early fall. Spraying in early fall was also evaluated in combination with mowing at bloom; however, mowing did not provide any additional control. Aminocyclopyrachlor + metsulfuron-methyl, aminopyralid/ metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron gave the best control and aminocyclopyrachlor + metsulfuron was most effective when sprayed at the floral bud and bloom stages. HPLC/UV analysis was performed to quantify herbicide translocation in roots of wild chervil plants. Herbicide residue was only found in the roots of wild chervil plants sprayed at bloom; therefore, we conclude that spraying at bloom may provide better long term control.

3.2 Introduction

Dykes need to be well maintained in order to protect adjacent lands from flooding caused by heavy rainfall and high tide events. Grass species are typically grown on the dykes to provide stabilization and reduce soil erosion. Wild chervil is a problematic weed on NS dykes that out-competes these grasses and needs to be managed. An effective herbicide for wild chervil management that causes minimal grass injury is needed to incorporate into an effective management plan. Jeffrey and Robison (1990), Stachler and Kells (1997), and Miller and D'Auria (2011) reported that glyphosate effectively managed poison hemlock, wild carrot and wild chervil. Regardless, non-selective herbicides, such as glyphosate, are not viable options for use on dykes because they kill grasses which are an essential component of the dyke system.

Herbicide efficacy varies with growth stage of the plant at the time of application. For example, Kyser and DiTomaso (2013) evaluated a number of herbicides on Dalmatian toadflax (*Linaria dalmatica*) at the vegetative stage and in the fall when plants had senesced. They found that the greatest and most consistent long-term management was with aminocyclopyrachlor (280 g ae ha^{-1}) when applied in the fall. Maximum translocation to below ground structures in many creeping perennials tends to occur at the early floral bud stage or in late summer or fall as plants senesce. Given this knowledge, Wu et al. (2013) were able to estimate when these stages occurred with spreading dogbane in lowbush blueberry fields through relating GDD to spreading dogbane growth and development. They concluded that herbicides should be applied between 486 and 535 GDD when spreading dogbane is in an early floral bud stage. Boyd and White (2010) evaluated control of goldenrods (*Solidago spp.*) when mesotrione (101 g ha^{-1}) was applied at different growth stages with or without a pre-emergent application of hexazinone (1920 g ha^{-1}). They found that management of goldenrods was greatest when mesotrione was applied before bloom with a pre-emergent application of hexazinone.

Herbicide movement from foliage to root tissue is necessary to achieve adequate control of perennial weed species; therefore, it is important to know when a herbicide is most likely to translocate to the root system. Price et al. (2002) found that translocation to below ground structures was highest in late fall with most perennial species including Japanese knotweed. Other than growth stage, translocation is impacted by environmental conditions such as temperature and relative humidity. Wills (1976) reported that the greatest herbicide translocation in common cocklebur plants in a greenhouse study occurred under the highest temperature (35 ° C) and soil moisture (14%) and RH (35%).

As far as the author is aware, there has been no published research on herbicide movement in wild chervil.

Few studies have been conducted to identify herbicides that provide long-term wild chervil control in NS. For this reason, field trials were established in 2011 and 2012 on natural populations of wild chervil existing on dykes in Colchester County, NS where grasses were the only other abundant plant. The effects of herbicides recommended by DuPont were evaluated in field trials for their ability to provide wild chervil control. Different herbicide application timings of the tank mix aminocyclopyrachlor + metsulfuron-methyl were evaluated for their ability to control wild chervil and to translocate into the root system. Mowing combined with herbicide application was also evaluated. All dykes had been mowed annually in mid to late summer prior to experimental set up and were sprayed with aminopyralid once 3 years prior. The following hypotheses were tested: 1) aminocyclopyrachlor + metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron will both cause the greatest wild chervil foliage damage and reduction in ground cover; and 2) applying aminocyclopyrachlor + metsulfuron-methyl when wild chervil is in the floral bud stage will cause the greatest foliage damage and herbicide translocation from the foliage to the root.

3.3 Materials and Methods

3.3.1 Data Collection and Equipment Used in the Herbicide Screening and Application Timing Trials

Growth stage and ground cover measurements of wild chervil were recorded before spraying (and mowing) and ground cover measurements were recorded in late fall. Growth stages were classified as vegetative (Figure 1.2 A), floral bud (Figure 1.2 B), bloom (Figure 1.2 C1, C2), seed set (Figure 1.2 D), seed maturity I or seed maturity II

(Figure 1.2 E1, E2). Ground cover was measured randomly in each plot using a 50 cm by 50 cm quadrat with cross hairs placed 10 cm apart. One biomass sample was collected from each plot in the herbicide application timing trial once in the fall and in the following spring using a 50 cm by 50 cm quadrat. In the 2011 Timing trial, wild chervil and grass were separated and any plant species other than wild chervil and grass were combined with the grasses due to the small amounts of these species. Samples were collected in the fall and spring from Site 1 on October 11th, 12th, 2011 and May 11th, 2012 and from Site 2 on October 13th, 2011 and May 11th, 2012. In the 2012 Timing trial, wild chervil, grass, legumes and other miscellaneous plant species were separated. Samples were collected in the fall and spring from Site 1 on October 8th, 2012 and May 28th, 2013 and from Site 2 on October 5th, 2012 and May 27th, 2013. The samples were dried at 50°C for approximately 72 hours then weighed.

Wild chervil damage and grass injury were visually evaluated 7-14, 21-35, 42-56 and 365 days after treatment (DAT) using a categorical scale relative to the untreated control, with a score of 1 representing no wild chervil damage or grass injury and a score of 10 representing complete wild chervil damage or grass injury (Figure 3.1). Damage symptoms of wild chervil included discoloration of the plants and/or bending/twisting of plant stems while that of the grass included discoloration. All herbicides were applied under low wind conditions with a hand-held 2 m boom with a CO_2 pressurized sprayer equipped with XR8002VS Teejet nozzles and calibrated to deliver 200 L ha^{-1} at a pressure of 228 kPa.

Figure 3.1. Wild chervil and grass in trial plots where (A) chervil is rated 3, (B) chervil is rated 8, (C) grass is rated 2 and (D) grass is rated 8 (photos taken by Eileen Beaton).

3.3.2 Herbicide Screening

In 2011, a herbicide screening trial was established in Masstown, Nova Scotia (45°21'58"N 63°26'50"W), hereafter referred to as 'Screening Site 1', on a dyke, and was repeated on another section of the same dyke approximately 1 km away (45°22'2"N 63°27'37"W), hereafter referred to as 'Screening Site 2'. All herbicides were applied once when wild chervil was in bloom (Table 3.1). Screening Site 1 was sprayed on June 10th and Screening Site 2 was sprayed on June 8th, 2011. All treatments were arranged in a randomized complete block design with four replications. Individual plots were 6 m by 4 m. Growth stage and two ground cover measurements were recorded in each plot

before spraying and ground cover measurements were recorded in mid-summer, July 27th (48 DAT), late summer, August 22nd (74 DAT) and late fall, October 27th (140 DAT).

Table 3.1. Herbicide treatments applied to the screening trial established in Masstown, 2011.

Common name	Trade name[a]	Rate g ai ha^{-1}	Surfactant
Aminocyclopyrachlor + metsulfuron-methyl	MAT-28 SG[b] Escort WG	66 22	Merge 1% v/v
Aminocyclopyrachlor + chlorsulfuron	MAT-28 SG Telar DF	66 27	Merge 1% v/v
Aminopyralid	Milestone LS	206	Agral 0.5% v/v
Aminopyralid, present as potassium salt/ metsulfuron- methyl	Clearview WG	121 22	Agral 0.2% v/v
Sodium salt of diflufenzopyr/ sodium salt of dicamba	Overdrive WG	126 325	Agral 0.2% v/v

[a]Abbreviations: SG, soluble granule; WG, wettable granule; DF, dry flowable; LS, liquid solution.
[b]Aminocyclopyrachlor does not have a trade name; however, the code name is listed.

3.3.3 Herbicide Application Timing

In 2011, a herbicide timing trial was established in Masstown, N.S. on a dyke (45°21'54"N 63°26'53"W), herafter referred to as '2011 Timing Site 1', and was repeated on another section of the same dyke approximately 1 km away at (45°21'59"N 63°27'30"W), hereafter referred to as '2011 Timing Site 2'. The tank mix aminocyclopyrachlor + metsulfuron-methyl was applied when wild chervil was in bloom, in seed set, in early fall or in early fall combined with a mowing when wild chervil was in bloom. All treatments were arranged in a randomized complete block design with four replications. Individual plots were 6 m by 2 m. In 2012, a similar trial was established in Masstown, N.S. on a dyke (45°21'58"N 63°26'46"W), hereafter referred to as '2012 Timing Site 1', and was repeated on another section of the same dyke approximately 1 km away at (45°21'56"N 63°27'18"W), hereafter referred to as '2012 Timing Site 2'. The only difference between the 2011 and 2012 Timing trials was that there was a

treatment added in 2012 where the tank mix was sprayed when wild chervil was in the floral bud stage. Herbicide application dates for these trials can be found in Table 3.2.

Table 3.2. Herbicide application and mowing dates for the herbicide timing trials conducted in 2011 and 2012.

	Herbicide application/mowing dates	
Herbicide application time	2011	2012
Floral bud	-	May 24
Bloom	June 9	June 8
Seed set	July 20	July 4
Early fall	September 9	September 13
early fall/mowing at bloom	September 9/ May 31	September 13/June 8

3.3.4 Herbicide Root Translocation

Root sample collection and preparation

Root samples were collected from the 2012 Timing Site 1. Samples were collected from the plots 7 DAT, when wild chervil was in the floral bud stage and also when wild chervil was in bloom. Collection took place on May 28th and June 12th, 2012, respectively. Root samples were also collected from control plots on August 10th, 2012. All root samples were collected randomly within plots and approximately 100 g of roots were collected from each plot. The number of root samples collected was related to the wild chervil density in the plot. If there was high wild chervil density in a plot, then approximately five samples were collected, whereas if the density was low, approximately two samples were collected. Any plant material remaining above the root crown was removed. The roots were cut to 10 cm lengths (starting at the top of the root crown), washed, bagged and stored at -20°C. Three 1 g root samples were used for analysis per plot. The root tissue was taken from vertical segments of the roots for each sample. The root pieces were placed in a centrifuge tube and used for the analyte extraction procedure.

Reagents

Herbicide standards of aminocyclopyrachlor (98.4%) and metsulfuron-methyl (98.9%) were obtained from DuPont (Wilmington, DE, USA). Stock solutions of 100 μg mL^{-1} of aminocyclopyrachlor were prepared in methanol and 100 μg mL^{-1} of metsulfuron-methyl were prepared in acetonitrile and stored at 5°C. Deionized water was obtained from a Millipore water purification system. Bond Elut ENV (500 mg, 6 mL capacity) solid-phase extraction (SPE) cartridges were purchased from Agilent Technologies (Mississauga, ON, Canada) and HyperSep Strong Anion Exchanger (SAX) SPE cartridges (1000 mg, 6 mL capacity) were purchased from Thermo Scientific (Bellfonte, PA, USA).

Apparatus and elution parameters

A high performance liquid chromatograph (Waters, Milford, MA, USA) with two solvent pumps (Model 515), a 'Rheodyne' manual injector with a 20 μL loop, and a single wavelength UV absorbance detector (Model 2487) was used to detect and quantify the aminocyclopyrachlor and metsulfuron-methyl in the root samples. A stainless steel analytical column, Luna Phenyl-Hexyl with 100 Å pore size (150 mm x 4.6 mm 3 μm; Phenomenex Inc., Torrance, CA, USA) was used. The mobile phase used for the detection and quantification of aminocyclopyrachlor consisted of a mixture of (A) 0.1% formic acid in deionized water and (B) methanol at a flow rate of 1.0 mL min^{-1} which was applied in the following gradient elution: 95% A: 5% B initially, then to 41% A: 59% B at 5 min, then to 1% A: 99% B at 8 min remaining constant until 10 min, then to 95% A: 5% B at 10.1 min and remaining constant until 22.5 min. The mobile phase used for metsulfuron-methyl consisted of a mixture of (A) 0.01% v/v formic acid in deionized

water and (B) 0.01% v/v formic acid in methanol at a flow rate of 1.0 mL min^{-1} which was applied in the following gradient elution: 50% A: 50% B initially, then to 20% A: 80% B at 20 min, then to 10% A: 90% B at 20.1 min and remaining constant until 23 min, then to 50% A: 50% B at 23.1 min and remaining constant until 28 min. Before using, the mobile phases were filtered through a 1.2 µm membrane purchased from Micron Separations, Inc. (Westboro, MA, USA) and degassed using helium. Both analytes were detected at 219 nm and all injections were carried out at room temperature.

Analyte Extraction

Aminocyclopyrachlor was extracted from the root samples by adding 3.5 mL 0.15 M ammonium acetate, shaking and leaving to stand for 10 min followed by the addition of 8 mL acetonitrile, homogenizing for four min and centrifuging for 15 min at 3000 rpm. The supernatant was decanted and set aside while 10 mL of 70:30 (v/v) acetonitrile / 0.15 M ammonium acetate was added to the solid pellet. The sample was homogenized centrifuged and the supernatant was decanted. Both supernatants were combined and 5 mL 0.1 M hydrochloric acid were added and made up to 25 mL with deionized water.

The metsulfuron-methyl was extracted from the root samples by adding 9 mL 75/25 (v/v) acetonitrile / pH 7 dipotassium phosphate[1], homogenizing for 2 min at 40-50% motor speed while keeping samples in an ice bath and centrifuging for 20 min at 3000 rpm. The supernatant was decanted and set aside. This procedure was repeated with the solid pellet. The supernatants were combined and made up to 20 mL with acetonitrile. All samples from each extraction procedure were stored at -20 °C until the analyte purification procedure was conducted.

[1] The pH of dipotassium phosphate was adjusted to 7 by adding approximately 200 mL of 0.5M hydrochloric acid.

Analyte Purification

A 1 mL aliquot of each aminocyclopyrachlor extract was evaporated to approximately 0.5 mL under nitrogen gas using an evaporator with a water bath temperature set at 40°C. The extract was made up to 5 mL using 0.5% formic acid and vortexed for 10 seconds. HyperSep SAX cartridges were placed on an SPE manifold and were conditioned with 5 mL (~1 column volume) of methanol and 10 mL (~2 column volumes) of 0.5% formic acid. The extract was passed through the columns and collected in a new test tube and columns were then rinsed with 3 mL 0.5% formic acid.

Five mL of hexane was added to 10 mL of the metsulfuron-methyl extract, vortexed for 10 seconds and centrifuged for 5 min at 3000 rpm. The hexane layer was removed and discarded. Five mL of the extract was evaporated to approximately 0.5 mL under nitrogen gas using an evaporator with a water bath temperature set at approximately 30°C. The extract was made up to 10 mL with deionized water. Bond Elut ENV cartridges were placed on a SPE manifold and were conditioned with 10 mL of methanol then 10 mL of 10 mM ammonium acetate. The extracts were passed through the cartridges and the cartridges were rinsed with 5 mL 10 mM ammonium acetate.

A vacuum was used to aid flow of liquids through the manifold. The vacuum was used until the cartridges were dry (about 10 min) only when the extracts and rinsates were flowing through the cartridges. All purified analytes were stored at -20°C until HPLC-UV analysis was conducted.

Calibration

Under the previously described chromatographic conditions, calibration curves with concentration versus absorbance were constructed using standard solutions containing 100 µg mL^{-1} of each of the standards. The aminocyclopyrachlor standards were diluted to concentrations of 0.004, 0.002, 0.001, 0.0005 and 0.00025 mg mL^{-1} in methanol. For metsulfuron-methyl, standards were diluted to 0.004, 0.002, 0.001, and 0.0005 mg mL^{-1} in acetonitrile. Good linearity and correlation was achieved for both standards. The linear equation for aminocyclopyrachlor was y = 1 000 000x - 20695 and R^2 = 0.9985 while that of metsulfuron-methyl was y = 933681x – 43801 and R^2 = 0.9968. The retention times for aminocyclopyrachlor and metsulfuron-methyl were 6.2 ± 0.1 and 13.7 ± 0.7 min, respectively.

3.3.5 Data Analysis

Wild chervil ground cover and chervil, legume and miscellaneous plant species biomass data collected in fall 2012 and spring 2013 from the 2012 timing trial were analyzed using the Proc Npar1way Kruskal-Wallis nonparametric test of SAS v. 9.3 (SAS Institute Inc., Cary, NC) because residuals could not be normalized. Means and standard errors were obtained using PROC MEANS. Damage ratings were also analyzed using this test because of the categorical nature of the data.

Wild chervil and grass biomass data collected from the 2011 Timing trial as well as the grass biomass data from the 2012 Timing trial were analyzed using PROC MIXED of SAS v. 9.3 (SAS Institute Inc., Cary, NC) to determine the effect of treatment. Site, time and treatment were fixed effects and block was a random effect. Means were

separated using Tukey's adjusted means comparison at the 5% level. The statistical model used was:

$$Y_{ijkl} = \mu + \rho_i + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + \varepsilon_{ijkl}$$

Where Y_{ijkl} is the variable of interest; μ is the overall mean; ρ_i is the effect of the i^{th} block (i=1-4); α_j is the effect of the j^{th} treatment (j=1-5 in the 2011 Timing trial and 1-6 in the 2012 Timing trial); β_k is the effect of the k^{th} site (k-1-2); γ_l is the effect of the l^{th} time (l=1-2, fall and spring); $\alpha\beta_{jk}$ is the effect of the interaction between treatment and site, $\alpha\gamma_{jl}$ is the effect of the interaction between treatment and time, $\beta\gamma_{kl}$ is the effect of the interaction between site and time; $\alpha\beta\gamma_{jkl}$ is the effect of the interaction between treatment, site and time and ε_{ijkl} is the random effect of error.

Assumptions including independence, normality and constant variance were tested and verified using PROC UNIVARIATE analysis where residual*predicted values were plotted. It was necessary to remove two outliers from the 2011 Timing grass biomass data in order to meet the normality assumption. Log and square root transformations were also used as necessary to meet assumptions but actual means are presented. The subroutine pdmix800.sas (Saxton 1998) was utilized to provide letter groupings.

3.4 Results and Discussion

3.4.1 Herbicide Screening

All herbicides evaluated damaged wild chervil throughout the experiment and caused minimal grass injury. Aminocyclopyrachlor + metsulfuron methyl caused the greatest wild chervil damage 365 DAT at Screening Site 1 with a rating of 10 (Table 3.3) whereas aminopyralid/ metsulfuron-methyl caused the greatest wild chervil damage at

Screening Site 2 with a rating of 10 (Table 3.4). Aminocyclopyrachlor + chlorsulfuron also caused significant wild chervil damage with a rating of 9 at both sites (Table 3.3 and 3.4). Grass injury at both sites never exceeded a rating of 2 throughout the experiment; furthermore, all treatments caused little or no long-term grass injury (Table 3.3 and 3.4).

There were no significant differences in wild chervil ground cover at Screening Sites 1 and 2 at 48 DAT and at Screening Site 2 at 140 DAT. At 78 DAT, aminocyclopyrachlor + metsulfuron-methyl caused the greatest decrease in wild chervil ground cover at Screening Site 1 whereas aminopyralid/ metsulfuron-methyl caused the greatest decrease at Screening Site 2 (Table 3.5). At 140 DAT, aminocyclopyrachlor + metsulfuron-methyl caused the greatest decrease in wild chervil ground cover at Screening Site 1 (Table 3.4).

Aminocyclopyrachlor + metsulfuron-methyl was the most consistent and effective herbicide evaluated followed by aminopyralid/ metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron. Herbicides containing aminocyclopyrachlor + metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron are expected to be registered later in 2014 under the trade names, Navius™ and Truvist™, respectively. Aminopyralid/ metsulfuron-methyl is currently the only one of these herbicides registered and should be used until Navius™ is registered. Boyd (2010) reported effective control of wild chervil with aminocyclopyrachlor + metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron as well.

Aminocyclopyrachlor, metsulfuron-methyl, chlorsulfuron and aminopyralid, alone or in combination with other herbicides, have been effective in controlling other perennial weed species. Minogue et al. (2011) found that spraying aminocyclopyrachlor

was more effective than metsulfuron-methyl and aminopyralid in controlling kudzo (*Pueraria Montana*); however, multiple applications would be needed to provide long-term control. They found no difference in control among rates of aminocyclopyrachlor applied (140, 211 and 280 g ae ha^{-1}). Long-term control of bushkiller (*Cayratia japonica*) was achieved by spraying aminocyclopyrachlor (West et al. 2011). Spraying triclopyr-containing herbicides, such as triclopyr + aminopyralid also effectively controlled bushkiller but not in the long-term (West et al. 2011). Chlorsulfuron, metsulfuron-methyl and aminopyralid provided at least 89% control of goatsrue (*Galega officinalis*) 1 year after application and also improved grass growth (Oldham and Ransom 2011). Spraying metsulfuron-methyl + chlorsulfuron effectively controlled wild chervil followed by chlorsulfuron alone (Oswald 1986).

Picloram and 2,4-D are common group four herbicides effective in controlling perennial weed species. Picloram effectively controlled mugwort (Bradley and Hagood 2002) and goatsrue (Oldham and Ransom 2011). A tank mix of picloram + 2,4-D provided as much control of kudzu as aminocyclopyrachlor (Minogue et al. 2011). 2,4-D was most effective in controlling soft rush (Rana and Sellers 2009) and was also effective in controlling poison hemlock (Jeffrey and Robison 1990). Picloram may be an effective herbicide for wild chervil control and should be evaluated. Darbyshire et al. (1999) found effective wild chervil control using dichlorprop/ 2,4-D, clopyralid and mecoprop. These herbicides may still be effective and should be evaluated again.

Only one application of aminopyralid/ metsulfuron-methyl may be necessary for effective control of wild chervil. This herbicide can be purchased from Univar Environmental Sciences (Austin, Texas) under the trade name Clearview™ for $1925.38

per case and one case can treat 16 ha when applied at a label rate of 230 g ha^{-1}. The results from the experiment correspond with the hypothesis that aminocyclopyrachlor + metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron would cause the greatest wild chervil foliage damage and reduction in ground cover with aminopyralid/ metsulfuron-methyl also being effective.

Table 3.3. Influence of herbicide treatments on chervil damage and grass injury 14, 35, 56 and 365 DAT at Screening Site 1.

	Chervil damage				Grass injury			
Herbicide treatment	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Aminocyclopyrachlor + metsulfuron-methyl	2 (0)	5 (0)	5 (0)	10 (0)	1 (0)	2 (0)	2 (0)	1 (0)
Aminocyclopyrachlor + chlorsulfuron	2 (0)	5 (0)	6 (1)	9 (0)	1 (0)	2 (0)	2 (0)	1 (0)
Aminopyralid	3 (1)	5 (0)	5 (0)	1 (0)	1 (0)	2 (0)	1 (0)	1 (2)
Aminopyralid/ metsulfuron-methyl	3 (1)	5 (0)	6 (0)	7 (0)	1 (0)	2 (0)	1 (0)	1 (0)
Sodium salt of diflufenzopyr/ sodium salt of dicamba	2 (0)	4 (1)	5 (0)	7 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Pr > Chi-Square	*0.0095*	*0.0008*	*0.0125*	*0.0009*	*0.6926*	*0.0633*	*0.2042*	*0.1661*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represent complete kill.
[c]Abbreviation: DAT, days after treatment.

Table 3.4. Influence of herbicide treatments on chervil damage and grass injury 14, 35, 56 and 365 DAT at Screening Site 2.

	Chervil damage				Grass injury			
Herbicide treatment	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Aminocyclopyrachlor + metsulfuron-methyl	4 (0)	5 (0)	5 (0)	8 (2)	2 (0)	2 (0)	2 (0)	2 (0)
Aminocyclopyrachlor + chlorsulfuron	3 (0)	5 (0)	5 (0)	9 (0)	2 (0)	2 (0)	2 (0)	2 (0)
Aminopyralid	4 (0)	5 (0)	5 (0)	3 (1)	2 (0)	2 (0)	1 (0)	2 (0)
Aminopyralid/ metsulfuron-methyl	4 (0)	5 (0)	5 (0)	10 (0)	2 (0)	2 (0)	1 (0)	2 (0)
Sodium salt of diflufenzopyr/ sodium salt of dicamba	4 (0)	5 (0)	5 (0)	9 (0)	2 (0)	2 (0)	1 (0)	2 (0)
Pr > Chi-Square	*0.0079*	*0.0012*	*0.0161*	*0.0052*	*0.0278*	*0.0022*	*0.0481*	*0.2906*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represents complete kill.
[c]Abbreviation: DAT, days after treatment.

Table 3.5. Influence of herbicide treatments on chervil ground cover at Screening Sites 1 and 2, 48, 74, and 140 DAT.[a]

Herbicide treatment	Ground cover					
	48 DAT		74 DAT		140 DAT	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
	%					
Untreated control	50 (19)	41 (20)	31(19)	35 (16)	72 (22)	43 (23)
Aminocyclopyrachlor + metsulfuron-methyl	3 (3)	0 (0)	2 (2)	9 (9)	3 (3)	0 (0)
Aminocyclopyrachlor + chlorsulfuron	5 (4)	9 (4)	3 (3)	1 (1)	7 (1)	28 (24)
Aminopyralid	36 (13)	19 (9)	36 (11)	42 (21)	88 (5)	46 (19)
Aminopyralid/ metsulfuron-methyl	12 (9)	6 (3)	15 (5)	0 (0)	33 (14)	12 (7)
Sodium salt of diflufenzopyr/ dicamba	8 (3)	12 (6)	20 (3)	5 (3)	50 (15)	10 (19)
Pr > Chi-Square	*0.1087*	*0.0632*	*0.0468*	*0.0379*	*0.0060*	*0.2486*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

3.4.2 Herbicide Application Timing

2011

All herbicide application times evaluated in the 2011 Timing trial caused damage to wild chervil and minimal injury to grasses throughout the experiment; however, wild chervil recovered around 56-365 DAT except when herbicides were applied during bloom. At 365 days after spraying during bloom, wild chervil damage was rated 8 and 9 at 2011 Timing sites 1 and 2, respectively (Table 3.6, 3.7). Grass injury ratings were always 1 or 2 except 7 or 8 at 35 and 56 DAT when spraying occurred in early fall as well as in early fall combined with a mowing at bloom. All grass injury recovered by 365 DAT; furthermore, none of the treatments caused long-term grass injury (Table 3.6 and 3.7).

Table 3.6. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on chervil damage and grass injury, 14, 35, 56 and 365 DAT at 2011 Timing Site 1.

	Chervil damage				Grass injury			
Herbicide Application Time	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Untreated control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Bloom	3 (0)	5 (0)	6 (0)	8 (2)	2 (0)	2 (0)	2 (0)	1 (0)
Seed set	2 (0)	5 (1)	7 (1)	2 (1)	2 (0)	2 (0)	2 (0)	1 (0)
Early fall	3 (0)	8 (1)	8 (0)	3 (1)	2 (0)	5 (1)	6 (0)	1 (0)
Early fall + mowing at bloom	3 (0)	8 (0)	9 (0)	5 (1)	2 (0)	6 (1)	7 (0)	1 (0)
Pr > Chi-Square	*0.0046*	*0.0018*	*0.0026*	*0.0008*	*0.0043*	*0.0013*	*0.0018*	*1.000*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represents complete kill.
[c]Abbreviation: DAT, days after treatment.

Table 3.7. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on chervil damage and grass injury, 14, 35, 56 and 365 DAT at 2011 Timing Site 2.

	Chervil damage				Grass injury			
Herbicide Application Time	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Untreated control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Bloom	4 (0)	5 (0)	5 (0)	9 (0)	2 (0)	2 (0)	2 (0)	1 (0)
Seed set	2 (0)	5 (1)	6 (0)	4 (0)	2 (0)	2 (0)	2 (0)	1 (0)
Early fall	2 (0)	9 (0)	9 (0)	4 (1)	2 (0)	7 (1)	7 (1)	1 (0)
Early fall + mowing at bloom	2 (0)	7 (2)	8 (2)	3 (2)	2 (0)	8 (1)	8 (1)	1 (0)
Pr > Chi-Square	*0.0041*	*0.0054*	*0.0044*	*<.0001*	*0.0043*	*0.0012*	*0.0010*	*0.1359*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represents complete kill.
[c]Abbreviation: DAT, days after treatment.

Treatment significantly affected wild chervil biomass while treatment and season significantly affected grass biomass (Table 3.8). None of the interaction effects were significant for biomass; therefore, seasons and sites were analyzed together (Table 3.8). The early fall herbicide application was the only time that caused a decrease in wild chervil biomass compared to the untreated control followed by bloom (Table 3.8). None of the herbicide application times had an effect on grass biomass compared to the untreated control (Table 3.8) but grass biomass was greatest in the fall 2011, with an average biomass of 165 g m^{-2}, than in the spring 2012, where average biomass was 49 g m^{-2}. Wild chervil ground cover in the fall was lowest in plots sprayed in early fall as well as when chervil was in bloom at 2011 Timing Sites 1 and 2, respectively (Table 3.9). The damage rating, biomass and ground cover data suggest that spraying at bloom provided the greatest control of wild chervil.

Table 3.8. Influence of herbicide application time on chervil and grass biomass collected in the fall 2011 and spring 2012 from the 2011 Timing trial.

Herbicide application time	Biomass	
	Chervil	Grass
	g m^{-2}	
Untreated control	251 a[a]	116 ab
Bloom	3 ab	165 a
Seed set	63 ab	92 ab
Early fall	2 b	81 b
Early fall + mowing at bloom	10 ab	77 b
Effect	*P*-value[b]	
Season	*0.2299*	*0.0001*
Site	*0.2933*	*0.0703*
Season*site	*0.8558*	*0.2550*
Treatment	*0.0245*	*0.0142*
Season*treatment	*0.4002*	*0.1846*
Site*treatment	*0.6166*	*0.4399*
Season*site*treatment	*0.1147*	*0.4862*

[a]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[b]*P*-values are provided for the effects which were time (either fall or spring), site (2011 Timing Sites 1 and 2), treatment (herbicide application times), and combined interaction effects.

Table 3.9. Influence of herbicide treatments on chervil ground cover collected in late fall from the Timing 2011 trial.

Herbicide application time	Ground cover	
	Site 1	Site 2
	%	
Untreated control	71 (14)[a]	70 (20)
Bloom	6 (5)	0 (0)
Seed set	30 (20)	38 (13)
Early fall	0 (0)	3 (2)
Early fall + mowing at bloom	1 (1)	24 (24)
Pr > Chi-Square	*0.0042*	*0.0178*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

2012

In 2012, all herbicide application times evaluated caused damage to wild chervil throughout the experiment but caused more grass injury than in the 2011 Timing trial. Damage ratings ranged from 1-8 at 14-56 DAT for all treatments. At 2012 Timing Site 1, spraying when wild chervil was in the floral bud stage caused the greatest wild chervil damage 365 DAT with a rating of 10 (table 3.10). At 2012 Timing Site 2, spraying at the floral bud and seed set stage both caused the greatest damage with ratings of 10 (Table 3.11). Grass injury ratings ranged from 1-6 at 14-56 DAT at both sites but there were no differences in grass injury among treatments 365 DAT at either site and ratings were either 1 or 2.

Table 3.10. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on chervil damage and grass injury 14, 35, 56 and 365 DAT at Timing 2012 Site 1.

	Chervil damage				Grass injury			
Herbicide Application Time	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Floral bud	4 (0)	5 (0)	8 (2)	10 (0)	3 (0)	4 (0)	3 (1)	2 (0)
Bloom	2 (0)	4 (0)	6 (1)	9 (1)	2 (0)	3 (1)	2 (0)	1 (0)
Seed set	4 (2)	5 (0)	8 (0)	5 (2)	2 (0)	3 (0)	2 (0)	1 (0)
Early fall	3 (1)	2 (0)	2 (0)	5 (2)	2 (0)	2 (0)	1 (0)	1 (0)
Early fall + mowing at bloom	4 (1)	2 (0)	2 (0)	8 (1)	2 (0)	2 (0)	1 (0)	1 (0)
Pr > Chi-Square	*0.5314*	*0.0021*	*0.0199*	*0.0102*	*0.0481*	*0.0226*	*0.1797*	*0.1661*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represents complete kill.
[c]Abbreviation: DAT, days after treatment.

Table 3.11. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on chervil damage and grass injury 14, 35, 56 and 365 DAT at Timing 2012 Site 2.

	Chervil damage				Grass injury			
Herbicide Application Time	14 DAT[c]	35 DAT	56 DAT	365 DAT	14 DAT	35 DAT	56 DAT	365 DAT
Control	1 (0)[ab]	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Floral bud	5 (0)	7 (0)	9 (0)	10 (0)	5 (0)	6 (0)	5 (0)	1 (0)
Bloom	3 (0)	3 (0)	4 (0)	8 (1)	2 (0)	3 (1)	2 (1)	2 (1)
Seed set	2 (1)	6 (1)	8 (0)	10 (1)	3 (0)	3 (0)	2 (0)	1 (0)
Early fall	3 (1)	3 (0)	3 (0)	2 (1)	2 (0)	2 (0)	3 (1)	1 (0)
Early fall + mowing at bloom	4 (1)	3 (0)	4 (0)	8 (2)	2 (0)	2 (0)	2 (0)	2 (2)
Pr > Chi-Square	*0.0505*	*0.0035*	*0.0031*	*0.0256*	*0.0040*	*0.0262*	*0.0292*	*0.6468*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.
[b]A scale of 1-10 was used to evaluate chervil damage and grass injury; 1 represents no damage or injury and 10 represents complete kill.
[c]Abbreviation: DAT, days after treatment.

Mowing and spraying aminocyclopyrachlor + metsulfuron-methyl at different times caused few differences in wild chervil, grass, legume and miscellaneous plant species biomass. There were no differences in wild chervil biomass at either site or year; however, the lowest amounts tended to be in plots sprayed at the floral bud stage (Table 3.12, 3.13). Legume biomass tended to be highest in the control plots at both sites and years and there were no differences in miscellaneous plant species biomass at either site or year. Time and treatment significantly affected grass biomass (Table 3.14). Grass biomass was greater in the fall 2012, with an average biomass of 224 g m^{-2}, than in the spring 2013, where average biomass was 136 g m^{-2} and spraying at the floral bud stage was the only time that caused an increase in grass biomass compared to the control (Table 3.14).

Effect of herbicide timing on wild chervil ground cover was significant at both sites in the fall, 2012 (Table 3.15). Spraying when wild chervil was in the floral bud stage at 2012 Timing Site 1 and at seed set at 2012 Timing Site 2 tended to cause the greatest decrease in wild chervil ground cover. Ground cover was also low at 2012 Timing Site 2 when spraying occurred at the floral bud stage. These damage ratings and ground cover data indicate that spraying when wild chervil was in the floral bud stage achieved the greatest control.

Spraying when wild chervil was in bloom in 2011 was most effective; however, spraying at the floral bud stage was evaluated in 2012 and was more effective than spraying at bloom. Fall herbicide applications were usually least effective and there was little benefit in mowing at bloom combined with spraying in early fall. Darbyshire (1999) found spraying at the bloom stage to provide effective control of wild chervil as

well. Number of rootlets per plant tended to be lowest after spraying mecoprop at full bloom. Other research on perennial weed species has shown similar results. Boyd and White (2010) reported that spraying goldenrods before bloom was optimal with a pre-emergent spraying of hexazinone. Similarly, Bradley and Hagood (2002) reported that metsulfuron-methyl provided greater mugwort control when applied at bloom rather than the vegetative stage. They also found no benefit in mowing in the spring followed by spraying 5 weeks later; however, mowing twice before spraying provided more control than spraying alone. Mislevy et al. (1999) also found more effective control of tropical soda apple when two mowings were applied before spraying with triclopyr.

On the other hand, Kyser and DiTomaso (2013) reported that aminocyclopyrachlor most effectively controlled Dalmatian toadflax when applied in the fall as opposed to the vegetative stage. Other research suggested that there was little or no difference in control among application times. For example, Ferrell et al. (2009) found no difference in blackberry (*Rubus* spp.) control in pastures when sprayed with metsulfuron-methyl in the spring or fall. Marshall et al. (2006) evaluated tall ironweed (*Vernonia altissima*) control after applying fall herbicide treatments following a midsummer mowing. They found that triclopyr-containing herbicides such as triclopyr + 2,4-D provided the greatest control; however, they did not evaluate control after herbicide application only.

The floral bud development stage may be the most effective time to spray aminocyclopyrachlor + metsulfuron-methyl considering it provided more control than spraying at the bloom stage in 2012. Only one application may be necessary for effective control as damage symptoms were noticed up to 365 DAT. These results agree with the

hypothesis that applying aminocyclopyrachlor + metsulfuron-methyl when wild chervil is in the floral bud stage would cause the greatest foliage damage.

Table 3.12. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on the biomass of chervil, legume and miscellaneous plant species at 2012 Timing Site 1 and 2 in the fall 2012.

Herbicide application time	Biomass					
	Site 1			Site 2		
	Chervil	Legumes	Miscellaneous	Chervil	Legumes	Miscellaneous
	g m^{-2}					
Control	22 (13)[a]	10 (3)	0 (0)	41 (26)	2 (2)	20 (18)
Floral bud	0 (0)	2 (0)	0 (0)	2 (2)	0 (0)	1 (1)
Bloom	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)
Seed set	3 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Early fall	29 (27)	7 (7)	5 (5)	7 (7)	0 (0)	0 (0)
Early fall + mowing at bloom	3 (2)	7 (7)	0 (0)	11 (10)	1 (1)	0 (0)
Pr > Chi-Square	*0.1847*	*0.0480*	*0.3319*	*0.3121*	*0.1781*	*0.2931*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

Table 3.13. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on the biomass of chervil, legume and miscellaneous plant species at 2012 Timing Site 1 and 2 in the spring 2013.

Herbicide application time	Biomass					
	Site 1			Site 2		
	Chervil	Legumes	Miscellaneous	Chervil	Legumes	Miscellaneous
	g m^{-2}					
Control	34 (29)[a]	2 (2)	0 (0)	27 (16)	1 (1)	0 (0)
Floral bud	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)
Bloom	3 (2)	0 (0)	0 (0)	36 (24)	0 (0)	0 (0)
Seed set	16 (10)	0 (0)	0 (0)	0 (0)	0 (0)	5 (5)
Early fall	7 (4)	1 (1)	1 (1)	32 (16)	0 (0)	1 (0)
Early fall + mowing at bloom	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	1 (1)
Pr > Chi-Square	*0.1212*	*0.3204*	*0.5231*	*0.2007*	*0.0766*	*0.4022*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

Table 3.14. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on grass biomass at the 2012 Timing Site 1 and 2 in Fall 2012/Spring 2013.

Herbicide application time	Grass biomass
	g m^{-2}
Untreated control	141 b[a]
Floral bud	245 a
Bloom	179 ab
Seed set	213 ab
Early fall	136 b
Early fall + mowing at bloom	166 ab
Effect	*P*-value[b]
Time	*0.0106*
Site	*0.1595*
Time*site	*0.8188*
Treatment	*0.0113*
Time*treatment	*0.3039*
Site*treatment	*0.1439*
Time*site*treatment	*0.9955*

[a]Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's test.
[b]*P*-values were provided for the effects which were time (either fall or spring), site (2011 Timing Site 1 and 2), treatment (herbicide application times), and combined interaction effects.

Table 3.15. Influence of mowing and aminocyclopyrachlor + metsulfuron-methyl application timing on chervil ground cover in late fall at Timing 2012 Site 1 and 2.

	Ground cover	
Herbicide application time	Site 1	Site 2
	%	
Untreated control	33 (13)[a]	18 (5)
Floral bud	0 (0)	2 (2)
Bloom	1 (1)	13 (7)
Seed set	11 (5)	0 (0)
Early fall	15 (9)	7 (3)
Early fall + mowing at bloom	39 (1)	8 (3)
Pr > Chi-Square	*0.0267*	*0.0271*

[a]Data were analyzed using a Proc Npar1way Kruskal-Wallis test; means are presented and SEM's are provided in brackets.

3.4.3 Herbicide Root Translocation

Twelve root samples were quantified for aminocyclopyrachlor and metsulfuron-methyl from plots sprayed when wild chervil was in the floral bud and bloom stages. Aminocyclopyrachlor was detected in four of the root samples from plots sprayed when wild chervil was in bloom. Amounts were 0.048, 0.022, 0.05 and 0.53 mg/g. Aminocyclopyrachlor was not detected in the root samples from plots sprayed when wild

chervil was in the floral bud stage and metsulfuron-methyl was not detected in any of the samples. In samples where analytes were not detected, analytes may not have been present, were non-detectable or below detectable limits. These results conflict with the hypothesis that applying aminocyclopyrachlor + metsulfuron-methyl when wild chervil is in the floral bud stage would cause the greatest herbicide translocation from the foliage to the root. Price et al. (2002) found that translocation of herbicides in Japanese knotweed was optimal before senescence in late fall. Herbicide translocation in wild chervil before senescence or in late fall was not quantified in this study but may cause more translocation than at bloom.

The root sampling techniques used may have had an effect on the results. On the other hand, the plants might have been sprayed but were in a different plant stage than the majority of the plants in the plot. For example, one of the root samples may have come from a plant that was in the floral bud stage while the other samples came from plants that were in bloom. One g of root was needed per sample and 3 samples were analyzed per plot; furthermore, this was not a representative root sample from each plot considering the 6 m by 2 m area of the plot and the density of wild chervil. The environmental conditions were different at each spraying which could have had an effect on herbicide translocation as well. The experiment should be repeated in a greenhouse to minimize the variables discussed that may have affected the results and more/bigger root samples should be analyzed to increase precision and accuracy.

3.5 Conclusion

Applying herbicides is an effective long-term control option for wild chervil. Aminocyclopyrachlor + metsulfuron-methyl, aminopyralid/ metsulfuron-methyl and

aminocyclopyrachlor + chlorsulfuron were the most effective herbicides evaluated in the herbicide screening trial showing symptoms of control up to 365 DAT. Aminopyralid/ metsulfuron-methyl is the only one of these herbicides registered and should be used for the time being. The most effective application times shown in the herbicide timing trials were when chervil was in the floral bud or bloom stages. There was no advantage in mowing at bloom combined with spraying in early fall. Applying herbicides at the bloom stage may provide more control as herbicide residue was only found in roots of wild chervil plants sprayed at bloom.

Further monitoring of these experiments would help determine how effective these herbicides and applications times work over a longer time period and at other locations. Other herbicides, such as picloram, could also be incorporated into screening trials to broaden herbicide options. Different spray volumes may also be evaluated to reduce herbicide use and costs.

CHAPTER 4.0: GENERAL DISCUSSION

Wild chervil is a problematic weed on Nova Scotia dykes and there are currently no effective management strategies. An integrated management plan is needed to control wild chervil; therefore, mowing and herbicides were evaluated on dykes in Onslow and Great Village, NS. Mowing did not effectively control wild chervil in the short-term. Herbicide application, on the other hand, was a more effective option, particularly when wild chervil was in the floral bud and bloom stages.

Mowing was evaluated at key growth stages of wild chervil and the results corresponded with the hypothesis that mowing at the peak height and floral bud stages would cause the greatest regrowth and development after mowing in regard to height, biomass and flowering. Height, biomass and flowering tended to be greatest after mowing at the peak height and floral bud stages. Similarly, van Mierlo and van Groenendael (1991) found that mowing at the start of flowering caused inflorescence development of axillary buds while decreasing vegetative reproduction. They believed that this was essential for control because vegetative rootlets are more persistent than seeds. More differences in wild chervil control among mowing times may have been observed if the experiment was extended. Research on other perennial species has been conducted over longer time periods. Tipping (2008), for example, evaluated mowing plumeless thistle and musk thistle over six years and found significant differences in control among mowing times.

Mowing was also evaluated at key growth stages and either once or twice. The results corresponded with the hypothesis that mowing at different growth stages either once or twice per season would not cause a difference in biomass one month after

mowing and in late fall or affect rootlet growth and root biomass. There were no major differences among mowing regimes evaluated. Level of wild chervil control was similar after all mowings and there was no major benefit in mowing twice. Mowing did not reduce chervil biomass, vegetative reproduction or root biomass.

Darbyshire et al. (1999), Hansson and Perrson (1994), and Parr and Way (1988) found no difference in wild chervil control among mowing times in regard to biomass or vegetative rootlets. Parr and Way (1988) however, found more control as mowing frequency increased. They evaluated mowing up to five times each year. Hansson and Persson (1994) and Hansson (1994) also found that mowing at bloom and as flowering plants senesced, respectively, increased vegetative reproduction. Graglia et al. (2006) evaluated mowing for control of Canada thistle and found more control as mowing frequency increased. They evaluated two, four and six mowing frequencies. This gives reason to believe that if higher mowing frequencies were evaluated for wild chervil control in this study, there may have been differences in control found.

Mowing was an ineffective control strategy for wild chervil on the dykes in the short-term; however, mowing at the floral bud stage may be optimal to increase inflorescence development of axillary buds while decreasing vegetative reproduction. More differences in control among mowing timings and frequencies may have been observed if the study was extended and more mowings frequencies were evaluated. A broad time frame would be needed to gain control of wild chervil using mowing alone. Cattle grazing and tillage were other effective control strategies for wild chervil (Rosef and Bele 2008; Miller and D'Auria 2011); however these strategies were not evaluated and may not be appropriate options in this case as they may damage the dykes.

Herbicides have been evaluated as another control strategy for wild chervil. Five herbicides and tanks mixes recommended by DuPont were evaluated for their ability to provide wild chervil control. The results corresponded with the hypothesis that aminocyclopyrachlor + metsulfuron-methyl and aminocyclopyrachlor + chlorsulfuron would both cause the greatest wild chervil foliage damage and reduction in ground cover. Aminopyralid/ metsulfuron-methyl, registered as Clearview^{TM} was also effective. These results are similar to that of prior research. Boyd (2010) found that aminocyclopyrachlor + metsulfuron- methyl and aminocyclopyrachlor + chlorsulfuron effectively controlled wild chervil as well. Oswald (1986) also found effective control of wild chervil with metsulfuron-methyl + chlorsulfuron and chlorsulfuron alone. Other group 4 herbicides were evaluated for wild chervil control and were found to be effective as well. Darbyshire et al. (1999) reported effective control with dichlorprop/ 2,4-D, clopyralid, dicamba and mecoprop. Miller and D'Auria (2011) also found effective control with clopyralid and glyphosate + ammonium sulfate

Aminocyclopyrachlor, metsulfuron-methyl, chlorsulfuron and aminopyrald alone or in combination with other herbicides effectively controlled other similar species. Aminocyclopyrachlor effectively controlled kudzu and bushkiller (Minogue et al. 2011; West et al. 2011) and chlorsulfuron, metsulfuron-methyl and aminopyralid effectively controlled goatsrue (Oldham and Ransom 2011). Triclopyr + aminopyralid also controlled bushkiller (West et al. 2011). Other group four herbicides have shown effective control of similar species as well. Picloram controlled mugwort and goatsrue (Bradley and Hagood 2002; Oldham and Ransom 2011) and 2,4-D controlled poison hemlock and softrush (Jeffrey and Robison 1990; Rana and Sellers 2009;).

Spraying dichlorprop/ 2,4-D, clopyralid, dicamba, mecoprop, triclopyr and picloram provided effective control of wild chervil or related species in other studies and should be evaluated for their ability to control wild chervil on Nova Scotia dykes. Spraying glyphosate has also provided effective control of wild chervil and other species. Jeffrey and Robison (1990), Stachler and Kells (1997) and Miller and D'Auria (2011) all reported effective control of poison hemlock, wild carrot and wild chervil, respectively. Glyphosate is not a good option on the dykes as it is a non-selective herbicide and would kill all plants including grasses on the dykes.

Aminocyclopyrachlor + metsulfuron-methyl was applied at different times throughout the year and mowing combined with spraying was also evaluated. Results corresponded with the hypothesis that applying aminocyclopyrachlor + metsulfuron-methyl when wild chervil is in the floral bud stage would cause the greatest foliage damage and herbicide translocation from the foliage to the root. Spraying at the bloom stage was also effective and may provide better long-term control considering herbicide residue was found in roots of wild chervil plants sprayed at this time. Darbyshire et al. (1999) reported similar results when evaluating herbicides sprayed at different growth stages of wild chervil. They found that spraying mecoprop at the bloom stage caused the greatest control of rootlet growth. Similarly, Boyd and White (2010) found effective control of goldenrods when plants were sprayed before bloom and Bradley and Hagood (2002) found effective control of mugwart when spraying occurred at the bloom stage rather than the vegetative stage.

Kyser and DiTomaso (2013), on the other hand, found more control of Dalmatian toadflax when spraying occurred in the fall rather than the vegetative stage. Wild chervil

was sprayed in the fall in this study, but these sprayings were not as effective as those earlier in the year. Herbicide translocation patterns can be species specific and be influenced by growth stage and environmental conditions. Price et al. (2002), for example, evaluated carbohydrate flow at different growth stages of Japanese knotweed and found that most of the carbohydrates were stored in the shoots in early summer and moved into the rhizomes in late summer where they were greatest before senescence in late fall. Wills (1976) also determined that environmental factors such as temperature, soil moisture and RH also affected herbicide translocation in soybeans and common cocklebur plants. Given this knowledge, carbohydrate flow into the root of wild chervil may be highest at the floral bud or bloom stages given the level of control at these times; however, environmental conditions also may have interfered with herbicide efficacy.

There was no additional benefit in mowing at bloom followed by spraying in early fall. There have been studies suggesting that combining mowing and spraying provided more weed control. Darbyshire et al. (1999), for example, found that mowing wild chervil at a pre-bloom stage followed by spraying of the regrowth caused a greater reduction in plant density than treatments that included herbicide application only. Mislevy et al. (1999), Bradley and Hagood (2002), and Renz and DiTomaso (2006) also found more effective control of similar plant species when mowing and herbicide application was combined. Other combinations of mowing and spraying may have caused more wild chervil control on Nova Scotia dykes.

There were no studies conducted to quantify herbicides in wild chervil roots or any studies that used only HPLC-UV to quantify compounds in plant roots to the author's knowledge. Aminocyclopyrachlor, however, was quantified in roots of similar species.

Bukun et al. (2010) and Bell at al. (2011) quantified aminocyclopyrachlor in roots of Canada thistle and rush skeletonweed, respectively, using LSS. Avula et al. (2011) used HPLC and UPLC to quantify compounds in blue cohosh roots and Farag et al. (2007) used HPLC-UV-MS, HPLC-MS-MS and GC-MS to identify and quantify compounds in barrel medic roots. LSS, MS or GC techniques were not available for this experiment; therefore, HPLC-UV was used. HPLC-UV sufficed for this experiment as there was no interest in compounds in the roots other than aminocyclopyrachlor and metsulfuron-methyl.

The findings of this project can be used as a reference for future studies on wild chervil management. Today, these findings are especially useful for abioteau superintendents who manage the dykes for the Nova Scotia Department of Agriculture. The results suggest that spraying aminopyrald/ metsulfuron-methyl, registered as Clearview ^{TM}, at a label rate of 230 g ha^{-1} is most effective and should be sprayed at the floral bud or bloom stages. I also suggest that mowing at the floral bud stage is most effective for inflorescence development of axillary buds and to prevent vegetative reproduction. Dykes with low to moderate chervil pressure should be sprayed and dykes with high pressure should be mowed. Spraying should not be considered unless grasses are established on the dykes to prevent bare ground after spraying. Herbicides were the most effective option in this study; however, herbicides should not be the only strategy used to control wild chervil in order to prevent resistance and ensure long-term management. Biocontrol agents and cultural control strategies such as seeding and fertilizing grasses should also be evaluated.

CHAPTER 5.0: CONCLUSION

Wild chervil is a monocarpic perennial plant growing on roadsides, dykes and dykelands throughout Atlantic Canada. Wild chervil is non-native and classified as a noxious weed in Nova Scotia due to its invasive, competitive nature. Wild chervil emerges from seed or overwintering roots in April. Flowering wild chervil plants bloom in early June, and set seed in early July. Seeds mature and turn brown by early August followed by senescence while plants in the vegetative phase continue to grow into late fall.

Wild chervil is problematic in Nova Scotia mainly on the dykes because it out-competes grasses leaving bare ground that is susceptible to soil erosion. The dyke structures were originally built by the French settlers in the 1630s to prevent flooding of dykelands, which contain some of the most fertile agricultural soils in Nova Scotia. Current practices for managing wild chervil are not effective and control strategies have rarely been studied. This project allowed for a more comprehensive evaluation of wild chervil management on Nova Scotia dykes. Mowing and herbicide applications were evaluated on dykes in Onslow and Great Village, NS in 2011 and 2012.

The main objective of this project was to develop an integrated approach to the management of wild chervil that includes mowing and herbicide applications. The first specific objective was to determine the impact of mowing timing on wild chervil growth and development. The second specific objective was to determine the impact of mowing timing and frequency on wild chervil regrowth following mowing, vegetative reproduction and root biomass. The third specific objective was to measure the efficacy of five herbicides and tank mixes recommended by DuPont. The fourth specific

objective was to determine the optimal herbicide application timing through evaluation of the impact of application timing on foliage damage and herbicide translocation from the foliage to the root.

Mowing was worthy of evaluation considering the results of prior studies. Some researchers suggested that there were no differences among mowing regimes evaluated while others noticed differences in rootlet growth. There were no differences among mowing regimes evaluated in this study. Level of wild chervil control was similar after all mowings and there was no benefit in mowing twice. Mowing did not reduce chervil biomass, vegetative reproduction or root biomass; however, mowing at the peak height and floral bud stages resulted in inflorescence development from axillary buds. Mowing at the floral bud stage, or just as flowering begins, may be the optimal time to mow wild chervil to promote seed production and decrease vegetative reproduction.

Effective herbicides were noted from previous studies. These herbicides or similar products were evaluated in this study. Herbicides provided greater control of wild chervil than mowing. Aminocyclopyrachlor + metsulfuron-methyl was the most consistent and effective herbicide tank mix and will be registered for use later in 2014. This was followed by aminopyralid/ metsulfuron-methyl, registered as Clearview^{TM}, and aminocyclopyrachlor + chlorsulfuron, also to be registered later in 2014. There were no additional benefits in mowing at bloom followed by spraying in early fall; however, other mowing and spraying times combined were not evaluated and may have provided more control. The most effective times to spray the tank mix aminocyclopyrachlor + metsulfuron-methyl was at the floral bud and bloom stages. Spraying at the bloom stage

may provide better long-term control as herbicide was found in some roots of the plants sprayed at this time.

This two year study provides knowledge about how wild chervil can be managed on Nova Scotia dykes using mowing and herbicide application. Herbicide application provided control of wild chervil in a short time period and many herbicides still provided effective control up to one year after application. Mowing, on the other hand provided no significant control of wild chervil during this study. The effects of mowing for more than two years on wild chervil control on Nova Scotia dykes is unknown. Will mowing at the floral bud stage increase inflorescence development of axillary buds while decreasing vegetative reproduction in the long-term? Are more than two mowings in a year worth evaluating considering how unrealistic this may be in practice? More time is needed to fully access mowing as a management strategy for wild chervil on NS dykes. Until then, herbicide application remains as the most effective option.

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Integrated Management Plan for Wild Chervil on Nova Scotia Dykes- A Document for Aboiteau Superintendents

Description

Wild chervil is a perennial weed that grows on dykes, roadsides and has spread into dykelands. It flowers within a few years of growth then dies. It reproduces through seed and vegetative reproduction. Wild chervil is an invasive weed that out-competes grasses leaving bare ground susceptible to erosion.

Management

Management duration and strategy for wild chervil on dykes in Nova Scotia should be site specific and modified based on wild chervil density. Colchester County has the greatest wild chervil pressure and needs to be a top priority for management. Dykes with extremely high pressure should be mowed at the floral bud stage every year to encourage flowering and to give grasses a chance to grow. Effective herbicide applications will leave bare ground that is susceptible to soil erosion. Mowing may have to be done for many years to achieve adequate grass cover before spraying can be considered an option; however, spraying may be done if grasses are seeded after spraying. Wild chervil on dykes with low to moderate pressure can be controlled with herbicides. Herbicide recommendations are stated but follow-up applications are recommended where 100% control is not achieved. The herbicides listed below have been evaluated on dykes in Masstown, N.S. and appear to cause no long-term grass injury. Photos of key growth stages of wild chervil along with the approximate dates they occur can be found in the figure at the end of the fact sheet. The floral bud and bloom stages are the most effective times to apply herbicides. These growth stages are highlighted in the figure at the end of the fact sheet.

Monitoring

- Dykes should be monitored for wild chervil pressure at least twice a year (before/after management)

Chemical Control – a long-term solution

Effective herbicides

- Clearview™ (Dow AgroSciences), registered
- Navius™ (DuPont), to be registered late 2014
- Truvist™ (DuPont), to be registered late 2014

Spraying time

- Floral bud or bloom stage ~ mid-May-early June

Physical Control- a short-term solution to prevent seed production and promote grass growth

- mow at the floral bud stage
- mowing alone is unlikely to provide adequate levels of control

May 1——————mid-May——————June 1——————July 1——

Prepared by/Photos taken by:
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