# MANAGEMENT OF HAWKWEED (*HIERACIUM* SPP.) IN WILD BLUEBERRY FIELDS ON PRINCE EDWARD ISLAND

by

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# DEDICATION

This research thesis is dedicated to the Almighty God, the ONE who is, who will and who is to come. HE has been my pillar and fortress. HE lifts me when I am down. Without HIM, I would never have got to this point. I am eternally grateful. Thank you Lord!

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# ABSTRACT

Hawkweeds (*Hieracium* spp.) are a persistent problem in lowbush blueberry fields on Prince Edward Island (PEI). In 2011 and 2012, experiments were conducted on PEI on the weed phenology, herbicide trials and the best time to spray to achieve maximum results. Two hawkweed species, *H. pilosella* and *H. caespitosum* were identified. *H. caespitosum* was the most common hawkweed species. The only herbicide which gave short term suppression on *H. pilosella* in 2011 was hexazinone (Velpar) applied at 1920g a.i/ha sprayed in the spring. A fall application of dicamba (Banvel) sprayed at 1104g a.i/ha or an application of clopyralid (lontrel) applied at 151.2 g a.i/ha effectively managed *H. caespitosum* over the season and the most effective control was obtained when applications were made in the bolting stage.

## LIST OF ABBREVIATIONS AND SYMBOLS USED

GDD growing degree days

ai active ingredient

$^0$C degree Celsius

cm centimeter

$\chi^2$ chi-square

DAS days after spraying

ml millilitres

ha hectare

g grams

kg kilogram

m metre

km kilometre

L litre

NA not applicable

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# Chapter 1.0 Introduction

## 1.1 Introduction to the problem

Lowbush blueberry (*Vaccinium angustifolium* Ait.), also known as wild blueberry, is a perennial shrub, native to North America (Vander kloet 1978). Blueberry fields are developed from abandoned farmlands, woodlands and brushlands. The predominant lowbush blueberry producing areas are Nova Scotia, Newfoundland, New Brunswick, Prince Edward Island, Quebec and Maine, USA. From 2001 to 2005, Atlantic Canada contributed 38% of lowbush blueberry production in North America (Yarborough 2007). The province of Prince Edward Island is the third largest producer of blueberries in Atlantic Canada (C. Jordan, Personal communication). Prince Edward Island had a blueberry yield of 14.2 million pounds in 2012 (Jordan 2011) and 15 million pounds in 2013 (C. Jordan, Personal communication).

Jensen and Yarborough (2004) described weed pressure as one of the major factors inhibiting berry yield. Some of the weed species found in lowbush blueberry fields includes black bulrush (*Scirpus artrovirens* Wild), bunchberry (*Cornus canadensis* L.), hair fescue (*Festuca tenuifolia*), Lambkill (*Kalmia angustifolia* L.) red sorrel (*Rumex acetosella* L.), tickle grass (*Agrostis hyemalis*) and vetch (*Vicia cracca* L.). In a survey conducted by McCully (1988), *Hieracium* species were among the top five weed species found in Nova Scotia. Growers in Nova Scotia, New Brunswick and Prince Edward Island has observed an increase in *Hieracium* populations within commercial fields. The growers assume that dense *Hieracium* reduce blueberry yields, compete with the blueberry, and interfere with harvest operations. An incident of *Hieracium* seed head contaminating frozen blueberry products has been reported (N. Boyd, personal communication).

*Hieracium* species occur over a wide geographic area. In Argentina, *Hieracium pilosella* L., a species that also occurs in Nova Scotia blueberry fields, recently invaded northern grasslands of Tierra del Fuego Island in Southern Patagonia (Cipriotti et al. 2010) and also a great concern to pastoral farmers in areas such as central Otago and the McKenzie basin of the south Island (Duncan et al. 1997; Hunter 1991; Scott 1985). They have also been documented as a threat to the Peace and Fort Nelson Forests Districts also in northeastern British Columbia (Giroday and Baker 2006). In Idaho, United States of America, *Hieracium* species have been known to inhabit moist grasslands (Callihan and Miller 1994) and has taken over pastures and mountain meadows because of their mat forming growth (Callihan et al. 1989b) and are of little nutritive value to wildlife and livestock. Forage grass production on pasture and rangeland is reduced greatly because of *Hieracium* species (Shinn and Thill 2003). They also have the ability to displace desirable native species and cause a reduction in biodiversity (Shinn and Thill 2003). *Hieracium* species have been declared noxious in North South Wales (NSW) under the NSW Noxious Weeds Acts 1993 and in New Zealand as Class 1 weeds (Burton and Dellow 2005).

No herbicide products have been registered for *Hieracium* control in lowbush blueberry fields but hexazinone (Velpar, DuPont Canada) is a registered broadleaf herbicide that provides short-term suppression. An increase in *Hieracium* population has become a concern to growers because dried flower stalks interfere with harvest operations (C. Jordan, Personal communication). Therefore, the overall objective of this research is to develop an integrated weed management plan that includes: 1) Understanding the biology of *Hieracium* species in blueberry fields using a temperature-based growth

models; 2) Evaluation of both spring and fall herbicides for control of *Hieracium* species and; 3) Evaluation of various herbicides and doses in a controlled environment to determine the impact of spraying before the emergence of flower buds or after flower bud emergence.

## 1.2 The blueberry plant

The blueberry is a flowering plant in the genus Vaccinium (McIssac 1997). It is a native perennial shrub with an approximate height of 10 cm (Vander Kloet 1978). It is a low growing, deciduous shrub with broad to elliptic shaped leaves that are glossy blue-green in summer that turn red to purple in the fall (Hall et al. 1979). Buds are brownish red on stem axels. The flowers are white and bell-shaped, and 5 mm long (Hall et al. 1979). Blueberry plants grow in either wooded or open areas with well-drained acidic soils with a pH between 4.5 and 5.5 (Kinsman 1993). The fruit has a sweet taste when mature with variable acidity (Hall et al. 1979). Lowbush blueberries are a nutritious treat and a good source of Vitamin C and dietary fibre. They are cultivated commercially in Canada and the United States.

Prince Edward Island is an attractive blueberry producing area because the fields are relatively level and rock free making crop management much easier (Prouse 1996). Lowbush blueberries grow in most areas, however, commercial production center on areas that have a high natural density of lowbush blueberry plants. They are Tignish, Woods Island, Mount Stewart and Souris area (Prouse 1997). Lowbush blueberries on Prince Edward Island are not planted but developed from existing stands, which spread *via* rhizomes and are managed on a two-year cycle. The first year is known as the vegetative (sprout) year and growers encourage ramet growth. The second year is known as the

reproductive (crop) year and blueberry plants flower and produce berries that are harvested in late July through August. The majority of the Island crop (99 percent) is shipped to three major processors. They are Wymans, Oxford Frozen Food and Rainbow Farms and approximately one percent of the crop is sold locally as fresh product (Prouse 1996).

## 1.3 Weeds in blueberry fields

Most commercial lowbush blueberry fields in Atlantic Canada were developed from old pastures, hayfields or woodlots (Hall 1955). Weeds in blueberry fields include surviving woodland species, annuals, perennial grasses and a composite of species found on abandoned farmland (Jensen and Yarborough 2004). Weeds may compete with blueberry plants for available resources (Kinsman 1993) and can act as alternate hosts for insects and diseases, hinder harvest, and contaminate blueberry packs, reduce berry quality and interfere with the proper application of pesticides (Jensen and Yarborough 2004).

Chandler and Mason (1946) classified weeds into four categories based on their effect on the lowbush blueberry industry. The first category consisted of weeds with fleshy fruits that may adulterate the harvested blueberries. They include: *Cornus canadensis* L., *Gaylussacia baccata* (Wang) K.Koch; *Pyrola elliptica* Nutt; *Arctostaphylos uva-ursi* L. Spreng, *Vaccinum vitis–idaea* L., *Ross spp*. and *Aronia arbutifolia* (L) Ell. The second category consisted of weeds with wind borne seeds, which can spread and compete with the blueberry plants. They include *Apocynum androsaemifolium* L, *Solidago spp*., *Epilobium augustifolium, Asclepias spp*., *Hieracium spp*., *Aster spp*. and *Salix spp.,* Category three consisted of weeds forming dense masses, which crowd out the blueberry fields. They include: *Diervilla lonicera* Mill., *Kalmia angustifolia* L., *C. canadensis* L.

and *Pyrola spp*. The fourth category includes plants such as *Alnus spp*. *Betula spp*., *Comptonia peregrina* (L.) Coult and *Salix spp*., which are woody weeds usually occurring in new cleared lands.

## 1.4 Hawkweed description

Hawkweeds (*Hieracium* spp) grow in pastures, abandoned lands, lawns and gardens. The genus *Hieracium* is divided into three subgenera. They are chionoracium, (formerly subgenus stenotheca) hieracium and pilosella. The subgenus pilosella is entirely European in origin and represents most of the invasive species in the Pacific Northwest. They include *H. pilosella* L., *H. caespitosum* Dumort, *H. aurantiacum* L., *H. flagellare* Weld. (Pro sp.), *H. praeltum* Vill.ex Gochnat., *H. gronovii* L., *H. piloselloides* Vill. (Wilson et al. 2006). Invasive *Hieracium* species, unlike their native counterparts, reproduce sexually as well as asexually *via* vegetative propagation such as rhizomes, stolons and in some species, buds on the roots (Wilson and Callihan 1999) which allows them to colonize bare ground quickly. Native species to British Columbia reproduce only by seeds (Giroday and Baker 2006). *Hieracium* species are low growing establish and spread quickly by inter-connected underground rhizomes and surface stolons enabling them to outcompete native vegetation for available nutrients and moisture (Giroday and Baker 2006). They can grow in acidic soils, soils with low organic matter content. Some invasive *Hieracium* species form dense mats by stoloniferous reproduction. They have a competitive advantage over other plants as they have high aluminum tolerance (Boswell and Espie 1998). They also exhibit allelopathic effects on adjacent native vegetation by releasing toxic root exudates into the soil (Wilson and Callihan 1999). The seed stage is very important for establishment of new populations at long distances from the parent

population and regeneration of the population after an event that kills the parent population such as the application of herbicide (Jacobs 2007).

*Hieracium pilosella* L. and *Hieracium caespitosum* Dumort found in wild blueberry fields on Prince Edward Island are invasive species which belong to the sub genus pilosella. Macoun (1890) reported *H. pilosella* L found on Prince Edward Island was from Europe and came as seed contaminants. *H. pilosella* L and *H. caespitosum* Dumort were found along roadsides, back of dykes, dump sites, abandoned grasslands, meadows and borders of fields.

### 1.4.1 Description of *Hieracium pilosella* L.

Mouse ear hawkweed is a stoloniferous plant with an extensive underground root mass. All plant parts exude a milky juice when broken. The flowering stems are hairy and erect and the basal leaves are also hairy elliptic to oblanceolate and about 10 to 75 mm long. Leaves on flowering stems are either few or absent (Nawrocki 2011) and are green having white bristles on the upper side and white color with soft bristles on the underside. Flower heads are usually borne singly or, less commonly, in groups of twos or threes at the end of stems. The florets are yellow, strap shaped 8 to 13 mm long and often red tinged on the lower surface (Nawrocki 2011).

Achenes are cylindrical and 1.5 to 2 mm long. A pappus composed of 30 or more bristles that are 4 to 5 mm long are found in each achene (Nawrocki 2011) and dispersed by wind (Makepeace 1985).

They reproduce sexually by achenes and vegetatively from stolons (Makepeace 1985). Stolon production occurs simultaneously with floral initiation. After flowering, plants die and stolons decay after the rooting of daughter rosettes. The first generation of plants arise

from seeds but the maintenance and expansion of a population is primarily dependent on vegetative production (Makepeace 1985; Winkler and Stocklin 2002). A plant population expands *via* outward growth of stolons and gaps are formed in the center when the parent plants die (Makepeace 1985). Figure 1.1(a-e) shows the different parts of *H. pilosella*.


b


c



**Figure 1.1** *Hieracium pilosella* (a) rosettes (b) roots (c) flower heads borne in groups of two's (d) flower borne singly (e) achene with pappus

### 1.4.2 Description of *Hieracium caespitosum* Dumort

Meadow hawkweeds are stoloniferous perennial plants (Callihan and Miller 1999). The plant exudes a milky sap when damaged (Callihan and Miller 1999). The leaves,

stems, and stolons are hairy (Callihan and Miller 1999). The plant has a basal rosette and a flower stem produces 5 to 40 yellow leaves arranged in a flat-topped cluster (Evans 2007) and leaves are approximately 4 - 25 cm long (Giroday and Baker 2006). There is usually one or two small leaves on the flowering stem. Meadow hawkweed has a shallow root system and underground creeping stems called rhizomes. New plants also grow from buds on the rhizomes (Stone 2011). Achenes of meadow hawkweeds are about 1.5 to 2 mm long (Stone 2011).

Figure 1.2 (a-c) shows the rosettes, roots and flowers of *H. caespitosum*


**Figure 1.2** *Hieracium caespitosum* (a) rosettes (b) roots (c) flowers

## 1.5 Hawkweed management

### 1.5.1Chemical management

*Hieracium caespitosum* can be temporarily suppressed using 2,-4 D which is a member of the phenoxy family of herbicides that include Aminopyralid (Milestone), Clopyralid (Transline), Dicamba (Clarity) and Picloram (Tordon) (Jacobs 2007). An

application of 2, 4 - D is most effective at 1.68-2.24 kg/ha (0.68-0.90 kg a.i. $ha^{-1}$) early in the growing season when plants are in the rosette stage (Jacobs 2007). Aminopyralid at 0.28 to 0.42 kg/ha is effective in the bolting stage of the plant development (Jacobs 2007). Clopyralid applied at 1.68 kg/ha (360 g a.i. ha-$^{1}$) and Picloram applied at 1.12 to 2.24 kg/ha can suppress *Hieracium* population for up to six years. Dicamba at 4.48 kg/ha provides good control when applied to rosettes (Jacobs 2007). Glyphosate applied at 4.48 kg/ha will also control *Hieracium* species (Jacobs 2007). The addition of a surfactant in the spray solution will raise the efficacy of all herbicides by increasing adherence to the hairy stems and leaves (Jacobs 2007). Although research has been carried out on the control of *Hieracium* species using clopyralid on non-agricultural fields (Lass and Callihan 1992), the efficacy of these herbicides in managing *Hieracium* population in blueberry fields is unknown. Therefore, an evaluation of different herbicide that have different chemistries and modes of action is needed.

### 1.5.2 Physical management

The perennial buds of *Hieracium* species are at the soil surface. Hand pulling may be effective if rosettes and stolons are removed and may be practical where it can be repeated on small patches where there are competitive desirable plants in a community (Jacobs 2007). However, this method is not likely to be adopted on large acreages. Tillage alone will spread stolons and rhizomes. Tillage equipment used on sites with *Hieracium* species should be cleaned before use on weed-free areas to prevent weed spread (Jacobs 2007). Neither hand pulling nor tillage is a viable option in wild blueberry production because of the large expanse of land and lowbush blueberries are not cultivated but rather grown from existing stands. *Hieracium* species are not problematic in cultivated fields

because crop competition and herbicidal control of weeds prevents its invasion in these areas; however, in blueberry fields crop rotation is not possible due to the perennial nature of the crop.

### 1.5.2.1 Pruning

Pruning is a biennial practice in lowbush blueberry fields. It is an operation necessary to encourage and rejuvenate the growth of blueberry stems from the underground rhizome buds. If blueberry plants are not pruned after harvesting, there is a decrease in crop yield (McCully 1988).

### 1.5.2.2 Thermal and mower pruning

Pruning with fire may reduce the incidence of insects, diseases and weeds. The heat may kill insects overwintering on or near the surface of the soil. Pruning with fire also reduces small coniferous trees and some weeds that spread *via* seeds. Seeds on the weed stalk and on the soil surface may be burned, especially in the fall and as a result fewer weeds are recruited the following season (DeGomez 1988). Burning also encourages the growth of blueberry stems and floral buds (McCully 1988).

Pruning with mowers is less expensive, it increases the organic matter content on the soil surface and blueberry stems are mowed to the ground level. Mowing during or before the bud stage of flowering plants can prevent viable seed production (McCully 1988). Although lowbush blueberry fields are mowed after the berry harvest, low-growing rosettes of *Hieracium* species are not cut. Mowing may encourage the further spread of *Hieracium* species by spreading seeds within and between fields.

### 1.5.3 Cultural methods

#### 1.5.3.1 Grazing

Grazing animals eat the flower heads of *Hieracium* species, but the rosettes are not usually eaten, therefore, grazing may have a similar effect as mowing (Jacobs 2007).

#### 1.5.3.2 Mulching

Current management practises in lowbush blueberry fields such as biennial pruning with fire will increase the vigor of aerial portions of existing plants but may hinder rhizome development and death of young seedlings. Smagula and McLaughlin (1985) in a study attributed the slow growth of blueberries into bare patches to temperature, moisture content of the soil, impact of frost heaving, light intensity and pruning techniques. With this information, Smagula and Goltz (1988) conducted a study using mulch on bare spots in lowbush blueberry fields. They observed mulching increased the growth and rhizome spread of the plants. However, the disadvantages include cost to purchase mulches and its application in fields, difficulty to stabilise the mulch under windy or dry conditions and possibility of hindering the teeth of harvesters and rakes (Chiasson and Argall 1996). The use of mulches to reduce the spread of *Hieracium* species in lowbush blueberry fields has not been documented.

#### 1.5.3.3 Fertility

Lowbush blueberry fields originating from hardwood or mixed forests are richer in soil fertility compared to the fields from softwood forests. This is due to the nature of the decomposing material and the fact that the base soils of the hardwood forest is higher in more nutrients. Blueberry fields originating from abandoned hayfields tend to be richer than those abandoned from pastures since the hay fields tend to have richer soils and they

benefitted from better field management and typically were plowed more often thereby distributing the organic pad throughout the soil profile (Argall et al. 1998). Using fertilizers high in nitrogen will suppress the growth of *Hieracium* species growing in grasslands, since grasses tend to thrive much better in environments with high nitrogen concentrations. However, the ability to improve blueberry fields with fertilizer is a bit difficult because many weed species will respond to fertilizer (Argall et al. 1998).

## 1.6 Integrated weed management

Integrated weed management is the adoption of different management tools to help reduce a pest population to an acceptable level using biological, mechanical or chemical methods.

Most weeds in lowbush blueberry fields are perennials with similar growth pattern as the blueberry. As a result some production practices that promote blueberry yields such as pruning and fertilization will also promote the development of weeds. Chemical or cultural practices that suppress some weed species could actually encourage others. Also, excessive weed control could result in long term bare ground, which can lead to soil erosion or impair blueberry clone expansion (Anonymous 2012). Therefore, it is important to develop an integrated approach using both cultural and chemical methods (Wu 2010).

### 1.6.1 Herbicides

Herbicides used within lowbush blueberry fields are either selective or non-selective. At the appropriate application rates, selective herbicides will control specific weeds without injuring blueberry plants significantly. The survival of perennial plants is due to the abundance of carbohydrates in the root and rhizome system (Becker and

Fawcett 1998). With the development of above ground photosynthetic structures, there is movement of carbohydrates down to the underground structures. Chemical control is an acceptable way to control weeds in most blueberry fields. Perennials with creeping roots or rhizomes are the most difficult to control because they are able to withstand many herbicide applications and readily recover. Consequently, repeated treatments are often needed to successfully manage them (Ross and Lembi 1999). Regrowth of weeds is also possible due to late season or intermittent germination times or poor herbicide application timing and techniques (McCully 1988). Thus, effective management of perennial weeds occurs at the seedling and early vegetative stages before they start to form reproductive structures (Ross and Lembi 1999).

If application rates higher than the recommended rates are applied then they are no longer selective and can cause severe crop injury. Non-selective herbicides such as glyphosate will kill both weeds and crops. Herbicides for blueberries can also be applied either as pre-emergence (applied before the emergence of blueberry plant) or post-emergence (applied after blueberry plant has emerged) (Anonymous 2012). The use of tank mix of herbicides has proven to be effective in managing perennial weeds. *Cornus canadensis*, a weed in lowbush blueberry fields with extensive underground rhizome system cannot be effectively controlled using a single application of registered herbicides such as Amitrol, Asulam, Atrazine, 2,4 -D, dicamba, hexazinone and Terbacil (McCully 1988). Therefore, herbicide screening was carried out using 15 different herbicides applied in tank mixes at various rates, timings and formulation to evaluate the best control. Amitrol when applied at mid-summer and late fall application at rates between 1.25 to 8.0 kg (a.i) / ha provided very poor control (Jackson 1981). Tank mixes of amitrol + atrazine

(1.25 + 2.5 kg (a.i) / ha to 5.0 + 5.0 kg (a.i) / ha gave a treatment control between 10 to 60 % without any blueberry phytotoxicity and amitrol + hexazinone (2.5+ 1.25 kg (a.i) / ha to 2.5+2.5 kg (a.i) / ha gave a treatment control of 0 to 50 % with the best control being 2.5 kg (a.i) / ha of atrazine and 1.25 kg (a.i) / ha of hexazinone applied in late June. Also no crop injury or yield increases were observed at these rates. This herbicide screening show that tank mixes (herbicides having different modes of action) could be another viable option to control weeds with rhizomatous roots in blueberry fields such as *Hieracium* species.

### 1.6.2 Biological control

*Hieracium* species found in New Zealand where originally from the United Kingdom. They have spread rapidly and are now weeds in the native grasslands. Since these grasslands are used for grazing, the "Hieracium control trust "requested the Environmental Risk Management Authority (the Authority) ERMA to permit the release of *Macrolabis pilosellae* (Binne) (Diptera: Cecidomyyiidae), *Cheilosia urbana* (Meigen) and *Cheilosia psilophthalma* (Becker) (Diptera: Syrphidae) to biologically control hawkweeds. The approval to release these insects were based on these decisions:

(1) The risk of these insects interbreeding with native insects is insignificant. (2) The possibility of insects competing with or displacing already existing natural enemies of either the target or non- target plants was not possible (Barratt and Moeed 2005). Although this is a developing method of hawkweed management in New Zealand on non-agricultural fields, a transfer of this knowledge to lowbush blueberry fields could possibly help control its spread.

# Chapter 2.0 Meadow (*Hieracium caespitosum* Dumort) and Mouse ear (*Hieracium pilosella* L.) hawkweed development in lowbush blueberry fields


## Abstract

Temperature is an important environmental factor in predicting weed development in agricultural fields. A two year study was conducted in 2011 and 2012 to develop phenological models on leaf number, emergence of flower buds, flowering and length of primary stolons of *H. pilosella* and *H. caespitosum*, perennial weed species found growing in lowbush blueberry fields using base temperatures between 0-1$^0$ C. Leaf number of *H. pilosella* was modelled with an exponential decay and leaf number rapidly declined throughout the summer months of 2011 and 2012. In 2011 and 2012, *H. pilosella* flower buds peaked at 401 and 560 GDD respectively. Also in 2011 and 2012, flowering peaked at 582 GDD and 583 GDD using a Gaussian model. Maximum primary stolon emergence was predicted at 343 GDD and 510 GDD in 2011 and 2012 respectively using a Gompertz model. Leaf number of *H. caespitosum* was modelled using a logistic model in 2011 and 2012. Primary stolon emergence could not be modelled because of insufficient data. A Gaussian model predicted flower buds of *H. caespitosum* peaked at 726 and 922 GDD in 2011 and 2012 respectively. Flowering of *H. caespitosum* peaked at 1197 GDD in 2011 and 1149 GDD in 2012 using a Gaussian model. With the different phenological stages of both species modelled, this could enhance our ability to properly maximize herbicide application because it is the only viable weed management option, however validation of these models is important.

## 2.1 Introduction

Hawkweed species have become established in bare patches within lowbush blueberry fields on Prince Edward Island (PEI). *Hieracium caespitosum* and *Hieracium pilosella* are commonly found growing on coarse textured soils (Whiteside 1965). Both species have similar growth characteristics. *H. caespitosum* produces adventitious root-buds and stolon production *via* vegetative production (Stone 2011). However, *Hieracium pilosella* undergoes vegetative reproduction exclusively to maintain its population (Bishop et al. 1978). These stolon lengths range from 10 – 30 cm (Makepeace 1985; Bishop and Davy 1985) and are capable of producing daughter rosettes that root adventitiously to become independent plants. Daughter rosettes can also develop from axillary buds of the parent rosette without a stolon (Bishop and Davy 1985). Both species are a major concern to blueberry growers (C. Jordan, Personal communication).

The first step toward the development of an integrated weed management program for hawkweeds is to understand their growth, development and reproduction. This includes the life cycle, emergence patterns and seed production. Biological knowledge should enable increased efficacy of chemical and mechanical control methods (Webster and Cardina 1999) by knowing the optimal application timing which results in a decrease in chemical use and cost of production (Zavalloni et al. 2006). Furthermore, understanding weed growth and development not only within their environment but also how they change the environment of an associated crop is necessary (Schreiber 1982).

Air temperature is an important factor influencing the phenological phases of perennial plants when resources are not limiting. Therefore, using a measure of cumulative heat such as growing degree days (GDD), to measure time of weed emergence enables

comparisons between sites at different altitudes and during different years (Snyder et al.1999). The lowest temperature at which development occurs is known as the base temperature. Base temperature can be $0^0$C for crops such as brussel sprouts, cabbage and parsley, $5^0$C for peas, forages and $10^0$C for corn, soybeans and tomatoes (Edey 1977). Growing degree days can be calculated by subtracting base temperature from the average daily air temperature (Robles et al. 2003).

Thermal time models have predicted emergence of a variety of annual species but little information is known for perennial weed species (Wu 2010). Examples of thermal models for perennial species include hemp dogbane (*Apocynum canabinum* L.) in tillage systems (Webster and Cardina 1999), Canada thistle (*Cirsium arvense* L.) in common wheat (*Triticum aestivum* L.) (Donald 2000) and Johnson grass (*Sorghum halepense* L.) in corn (Sattore et al. 1985).

Wu (2010) developed a growth model for spreading dogbane (*Apocynum androsaemifolium* L.), a perennial weed in blueberry fields, using growing degree days (GDD). In his study, initiation of flower buds and flowers were between 486 to 535 GDD and maximum number of flowers per plant was reached at 750 GDD. This provides growers an estimation of the ideal time to spray the weeds and also prevent the unnecessary use of herbicides. Studies on the biology and ecology have been carried out on hawkweed species in the United States of America, Canada and New Zealand on non-agricultural fields (Wilson et al. 1997). However, there is no published research on the biology of *Hieracium* species in lowbush blueberry fields. Therefore, the development of a thermal time model for various hawkweed developmental stages of *H. pilosella* and *H. caespitosum*

would be a valuable tool and assist with the development of an effective integrated weed management plan.

## 2.2 Objective

The objective of this study was to estimate the base temperature for emergence and model the different phenological stages of hawkweed growth in the vegetative and reproductive year in lowbush blueberry fields using growing degree days (GDD).

## 2.3 Materials and methods

In this study, an established rosette with an independent root system was considered an independent plant (Makepeace 1985). This established criterion was adopted from other studies on *Hieracium* species (Reader 1978; Thomas and Dale 1974) and each offspring of the mother rosette will be called a daughter rosette. Six 0.5×0.5 m quadrats were randomly and permanently placed at two sites, Mt. Stewart ($46^0$ 22'N, $62^0$ 52'W) and Caledonia ($46^0$ 1'N, $62^0$ 43'W). All quadrats were placed where both *Hieracium* species and blueberry stems were found growing together in the early spring of 2011 and data were also collected in the spring of 2012 at the same location. Each site was independently analysed because of the different species found in lowbush blueberry fields and experimental design was completely randomised (CRD).

### 2.3.1 Data collection

Five rosettes were selected randomly within each quadrat and were labelled. Data collected were divided into two categories vegetative growth which includes (1) number of leaves on mother rosettes, (2) length of primary stolons growing from mother rosettes, (3) number of daughter rosettes from primary stolons, (4) number of daughter rosettes from axillary buds, (5) length of secondary stolons from daughter rosettes, (6) number of

secondary stolons and reproductive growth includes: (7) number of flower buds on mother rosettes, (8) number of flower heads on mother rosettes and (9) timing of achene dispersal were collected. Data were collected weekly throughout the months of May - September of 2011 and 2012.

### 2.3.1.1 Air and soil temperature

Onset (USA) Hobo U23 pro V2 external temperature data loggers were used to monitor hourly air and soil temperature throughout the months of May - September of 2011 and 2012 on each site for two years. Temperature sensors were placed 75 cm above ground and the soil probes were 2.5 cm below the soil surface at both sites. Temperature readings began on May 26 2011(Julian day 146) and May 17 2012 (Julian day 138) at both Caledonia and Mount Stewart sites in both years. The biofix date was set at April 1 for calculation of GDD's because plant growth rarely occurs prior to this date in Atlantic Canada. Air temperature data for Caledonia was collected at the Environment Canada station in Charlottetown ($46.29^0$N, $63.13^0$W, elevation 48.8 m) and Mount Stewart site was collected at St Peter's Environment Canada station ($46.45^0$N, $62.58^0$W, elevation 29.7 m).

## 2.3.2 Model description

Total number of leaves, flower buds, flower heads and length of primary stolons on mother rosettes collected from five labelled rosettes in each quadrat on each day of data collection was divided by the maximum number achieved to determine the percent of all characteristics of interest. Number of primary stolons, number of daughter rosettes from primary stolons, axillary buds and number of secondary stolons from daughter

rosettes was only counted and averaged in each quadrat. Total number of flowers in each quadrat was also averaged.

GDD was calculated by subtracting the base air temperature from the average daily air temperatures. Models developed will relate plant development to temperature rather than calendar days to avoid reducing accuracy in years with unusual weather conditions. (Wu et al. 2013) GDD was calculated using the equation:

$$GDD = \Sigma (T_{aver.} - T_{base}) \quad (1)$$

Where $T_{aver.}$ is the average daily air or soil temperature, and $T_{base}$ is the base temperature below which biochemical reactions do not occur (Hacault and Van Acker 2006).The use of air temperature for the accumulation of growing degree days is widely used by researchers and also these data are accessible to growers therefore, air temperature was used in this study.

### 2.3.3 Determination of base temperatures to predict growth stages of hawkweed species in lowbush blueberry fields

Data obtained from the growth pattern of hawkweed species were expressed as percent of maximum emergence. The base air temperatures for different growth stages of hawkweed species was determined by iterating a series of base temperatures from 0 to 5 C in $1^0$ C intervals (Izquierdo et al. 2009) against different non-linear models until the best fit was obtained between percentage total number of leaves, percent total number of flower buds, percent total number of flowering buds and length of primary stolons on mother rosettes using cumulative GDD as the independent variable. The criteria for best fit were based on the model with the lowest RMSE (Root Mean Square Error) value and highest $R^2_{Adj}$ value (White et al. 2012). Non- linear regression was run using Sigma plot version 12 statistical software.

### 2.3.4 Statistical analysis

Total number of leaves, flower buds, flowers and length of primary stolons on mother rosettes were analyzed separately for each site and plotted as functions of GDD. Percent of maximum leaves on *H. pilosella* was modelled using an exponential decay, single parameter of the form:

$$Y = ae^{-bx}$$

Where *Y* is the percent of maximum leaves, *a* is the initial GDD for leaves found on wild blueberry fields at the beginning of the season, *b* is the rate of decline of leaves over the season.

Percent of maximum flower buds on *H. pilosella* (Y) was related to cumulative GDD with a Weibull, four parameter model:

$$Y = a\left(\frac{c-1}{c}\right)^{(1-c)/c}\left[\frac{x-x0}{b}+\left(\frac{c-1}{c}\right)^{\frac{1}{c}}\right]^{c-1} e\left[\frac{x-x0}{b}+\left(\frac{c-1}{c}\right)^{\frac{1}{c}}\right] c+\frac{c-1}{c}$$

Where *Y* is the percent of maximum flower buds, *a* is the theoretical percent of maximum flower buds, *b* is the location parameter, $X_0$ is the growing degree day at which flower buds begin to decrease and *c* is the shaped parameter.

Percent of maximum flower buds on *H. caespitosum* (Y) was related to cumulative GDD with a Gaussian, three parameter model:

$$Y = a*\exp(-.5*((x-x0)/b)^{\wedge}2)$$

Where Y is the percent of maximum flowers, a is the theoretical percent of maximum flowers, b is the location parameter and x0 is the initial growing degree day for X.

Percent of maximum flowers on *H. caespitosum* (Y) was related to cumulative GDD with a modified Gaussian four parameter model:

$$Y = a*\exp(-0.5*\text{abs}((x-x0)/b)^{c})$$

Where Y is the percent of maximum flowers, a is the theoretical percent of maximum flowers, b is the location parameter, x0 is the initial growing degree day for X and c is the shaped parameter.

Percent of flowers of *H. pilosella* (Y) was related to cumulative GDD with a Gaussian, four parameter model:

$$Y = y0 + a*\exp(-0.5*((x-x0)/b)^{2})$$

Where *Y* is the percent of maximum flowers, y0 is the initial value for y, *a* is the theoretical percent of maximum flowers, x0 is the GDD at the percent of maximum flower buds and *b* is a location parameter (White et al. 2012).

Percent maximum of leaves on *H. caespitosum* (Y) was related to cumulative GDD with a logistics three parameter model:

$$Y = \frac{a}{1+\left(\frac{x}{x0}\right)}b$$

Where *Y* represents maximum number of leaves *a* is the upper asymptote, $X_0$ is the point of inflection and *b* represents the growth rate.

Percent maximum length of primary stolons on *H. pilosella* (Y) was related to cumulative GDD with a Gompertz, three parameter model:

$$Y = a*\exp(-\exp(-(x-x0)/b))$$

Where *Y* represents maximum number of stolons *a* is the asymptote, $X_0$ is the point of inflection and *b* represents the growth rate.

## 2.4 Results and discussion

### 2.4.1 Modelling the vegetative growth of *H. pilosella* at Mount Stewart

#### 2.4.1.1 Leaves on mother rosettes (percent of maximum)

Rosettes were already established in lowbush blueberry fields in the vegetative (2011) and reproductive year (2012) with reddened leaves. On my first day of data collection in 2011, we observed an average of 11 leaves per rosette at 277 GDD (May 26) which increased to 12 leaves at 444 GDD (June 3). This was followed by a decline in leaf number and death of mother rosettes occurred at 1407 GDD (August 3) after daughter rosettes had emerged and were established in the soil (Figure 2.1). In 2012, 12 leaves per rosette at 242 GDD (May 17) was also observed followed by a decrease in leaf number with only 5% of mother rosettes surviving past August 16 (1746 GDD). Competition from blueberry plants may have inhibited the growth of stolons and the establishment of daughter rosettes which may have slowed leaf senescence.

Values predicted by the exponential model was close to the observed values indicating the model is a good predictor and temperature is an important factor for rosette development in blueberry fields (Figure 2.1). The relationship between leaves on mother rosettes and GDD both in the vegetative and reproductive year indicate mother rosettes were already rooted in the soil at 305 and 285 GDD respectively. Parameter estimates a and b of the exponential decay model for both years are shown in Table 2.1. White et al. (2012) observed 50% of blueberry ramet emergence occurred at 406 GDD in the vegetative year of lowbush blueberry fields in Nova Scotia, this shows blueberry ramets emerge after hawkweed rosettes are actively growing. Rate of leaf decay (b) for both years was the same in 2011 (0.004) and 2012 (0.003) (Figure 2.1). A complete death of mother rosettes was predicted at 1150 GDD in 2011. However, in 2012, not all mother rosettes died. A

characteristic of *H. pilosella* is they die after flowering and this was observed by Jenkins (1991) who described the rosettes as monocarpic. Bishop and Davy (1985) also observed the death of rosettes originating *via* sexual reproduction or clonal growth after flowering and death of stolons after daughter rosettes are firmly rooted in the soil.

Because rosettes of hawkweed species already found in blueberry fields require a minimal amount of cumulative GDD for active growth, the use of GDD could improve our ability to understand the timing and application of hexazinone (Velpar) in the spring to manage these weed species in the vegetative year and help reduce the population because growers rely predominately on herbicides for weed management.

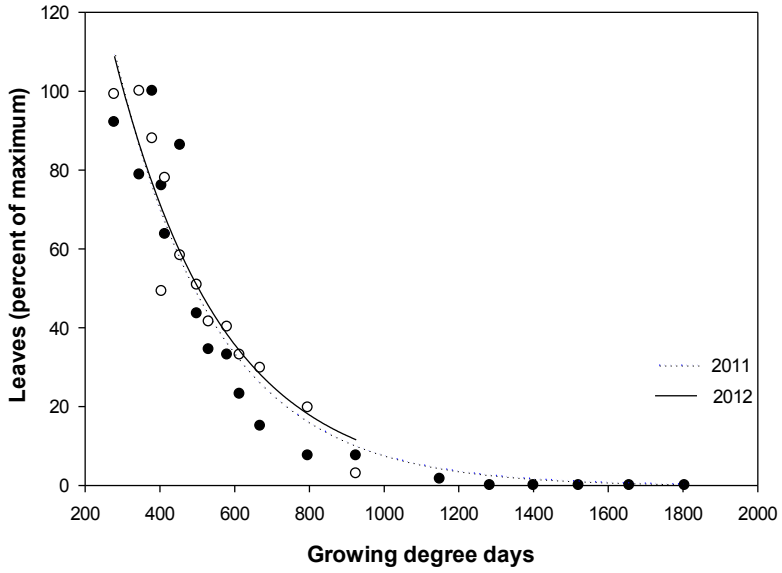


Figure 2.1 Leaves (percent of maximum) of *H. pilosella* in relation to cumulative growing degree days (GDD) ($T_{base} = 1^0$ C) at Mt. Stewart 2011(vegetative year) and 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

Table 2.1 Parameter estimates and 95% Confidence interval (CI) for percent of maximum leaves and percent of maximum length of primary stolons for *H. pilosella* in 2011 and 2012.

| Model | Year | Equation | $T_{base}$ | Parameter estimates a | b | Xo | $R^2_{Adj}$ | RMSE* | P value |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% CI | | | | |
| percent of maximum leaves | 2011 | Exponential decay | $1^0$ | 305.2±136.3 | 0.004±0.0017 | - | 0.89 | 10.94 | <0.0001 |
| | 2012 | | | 28±23.8 | 0.003±0.0008 | - | 0.89 | 9.00 | <0.0001 |
| percent of maximum length of primary stolons | 2011 | Gompertz | $1^0$ | 84± 6.5 | 96±45.5 | 343±34 | 0.86 | 8.18 | <0.0001 |
| | 2012 | | | 87±24.5 | 346±308 | 510±173.5 | 0.80 | 11.39 | <0.0001 |

*Root Mean Square Error

### 2.4.1.2 Length of primary stolons from mother rosettes (percent of maximum)

The temperature base was iterated as described above (Section 2.3.3) until the best fit was achieved between growing degree days versus length of primary stolons using the Gompertz model. Izquierdo et al. (2009) developed a model to understand the pattern of seedling emergence of corn poppy (*Papaver rhoeas*) in cereal fields using the Gompertz model. The model predicted emergence began at 247 GDD after sowing and 95 % of total emergence was at 524 GDD. Similarly, White et al. (2012) related Gompertz model to predict lowbush blueberry tip dieback in blueberry fields in Nova Scotia. Study showed tip dieback initiation began at 692 GDD and 95% of total tip dieback was at 1626 GDD in the vegetative year. In our study, parameter estimates a, b and $X_0$ of the model are described in Table 2.1. The model predicted growth rate of primary stolons was faster and maximum length was reached at 343 GDD in the vegetative year. In the reproductive year growth rate of stolons was slower and maximum length of stolons was predicted at 510 GDD (Figure 2.2). A rapid increase in growth of primary stolons with an average number of twelve and a maximum length of 7.1cm was observed in 2011 compared to 2012, were primary stolon growth was slower and an average of two primary stolons with a maximum length of 4.9 cm averaged across quadrats was observed. I speculate that the number and length of primary stolons was higher in the spring of 2011 because this field was mowed in the fall of 2010, which removed the canopy and thus reduced the competitive ability of the blueberries. Studies have shown that rosettes of *H. pilosella* have more rapid stolon growth after mowing (Callihan et al. 1997). In a study by Makepeace (1985) on the biology of mouse ear (*H. pilosella*) and kings devil hawkweed (*H. floribundum*), stolon production was higher in

mouse ear hawkweed. Also studies have shown these species can reach a maximum stolon length of 30 cm (Bishop and Davy 1985).

Primary stolon production in both years began shortly after the emergence of flower buds. This similar developmental pattern was also observed by Roche (1992). Because thermal heat is a major requirement in hawkweed growth, a similar temperature base of $1^0$C could be responsible for initiating primary stolons and flower bud emergence within a short timing interval. Another feature of *Hieracium* species that was visually observed in lowbush blueberry fields is when rosettes had no flower buds, they did not produce stolons which caused an increase in rosette size. This growth characteristic was also observed by Yeung and Peterson (1972). In Figure 2.1, the model used indicated hawkweed rosettes were already established in blueberry fields at 305 and 285 GDD in 2011 and 2012 respectively. These results show that primary stolons emerged after rosettes were actively growing and before the emergence of blueberry ramets. Therefore, rosettes should be sprayed around 305 GDD with hexazinone in the vegetative year because stolon and flower bud both have a close emergence window.

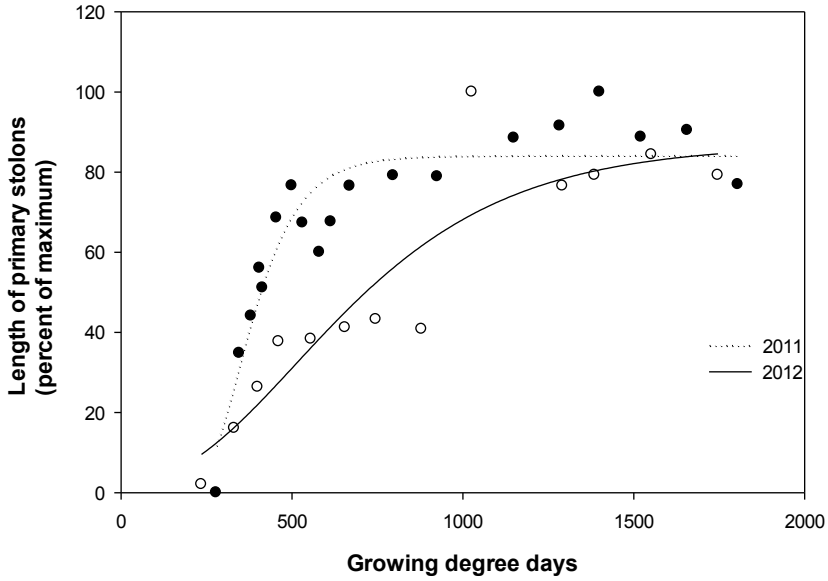


Figure 2.2 Length of primary stolon (percent of maximum) of *H. pilosella* in relation to cumulative growing degree days (GDD) ($T_{base} = 1^0C$) at Mt. Stewart 2011(vegetative year) and Mt. Stewart 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

Table 2.2 Parameter estimates and 95% Confidence interval (CI) for percent of maximum flower buds and percent of maximum flower heads for *H. pilosella* in 2011 and 2012.

| | | | Parameter estimates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model | Year | Equation | $T_{base}$ | a | b | c | $X_0$ | $Y_0$ | $R^2_{Adj}$ | RMSE* | P value |
| | | | | | 95% CI | | | | | | |
| percent of maximum flower buds | 2011 | Weibull | $1^0$ | 96±23 | 172±37.5 | 1.0±0.22 | 363±52.4 | - | 0.96 | 4.29 | <0.0001 |
| | 2012 | | | 108±59.3 | 921±(-1130) | 5.6±6.9 | 560±30 | - | 0.97 | 5.63 | <0.0001 |
| percent of maximum flower heads | 2011 | Gaussian | $1^0$ | 97.5±8.5 | 65.4±7.1 | - | 582±6.4 | 1.1±1.1 | 0.97 | 4.33 | <0.0001 |
| | 2012 | | | 92.1±27.9 | 103.4±36.2 | - | 583±32.3 | -0.73±1.2 | 0.83 | 10.9 | 0.0002 |

* Root Mean Square Error

### 2.4.1.3 Production of daughter rosettes from primary stolons and axillary buds

Daughter rosettes are usually found at the tip of stolons. Once established the stolons die and daughter rosettes become independent plants. In the vegetative (2011) and reproductive (2012) year there was an average of nineteen and two daughter rosettes across the six quadrats respectively. Also in the vegetative and reproductive year, an average of two and twelve daughter rosettes were found growing from axillary buds (found at the base of mother rosettes without a stolon) across the six quadrats respectively. Kroon et al. (1987) used a model to understand the effect of mowing rosettes of *Hypochaeris radicata* a perennial grassland species in Netherlands at different intervals. It was observed that mowing these species twice across the season increased the number of flowering stalks which also maximised seed production. However, the number of axillary buds produced for vegetative production was reduced. Although this research findings is similar to growth of *H. pilosella* in the vegetative year, it is unclear if production of daughter rosettes *via* axillary buds help to maintain their population in the reproductive year in lowbush blueberry fields.

### 2.4.1.4 Production of secondary stolons from daughter rosettes

The term "secondary stolons" was used for stolons growing from the base of daughter rosettes. They were observed towards the end of the season in 2011 and this further supports the idea that *H. pilosella* increases its population *via* vegetative spread. An average of four secondary stolons with an average length of 5 cm were found in the blueberry fields. In 2012, no secondary stolons were observed on labelled plants this could be as a result of the decrease in number of primary stolons which resulted into a low number of daughter rosettes produced in the reproductive year. Wilson et al. (1997) reported that a

single generation can be completed in four months. Our data suggest a single generation can be completed in three months on Prince Edward Island and as many as three generations may occur in any one growing season.

### 2.4.2 Modelling the reproductive growth of *H. pilosella* at Mount Stewart

#### 2.4.2.1 Number of flower buds (percent of maximum)

Growing degree days was plotted against number of flower buds using the Weibull model. Wu et al. (2012) described flower bud formation in spreading dogbane (*Apocynum androsaemifolium*) in lowbush blueberry fields using a Weibull model. First visible flower buds was observed at 385 GDD. In our study, model predicted flower buds peaked at 363 GDD in 2011 and at 560 GDD in 2012 (Figure 2.3). Model parameter estimates a, b, c and $X_0$ are shown in Table 2.2. In addition, maximum number of flower buds produced across site was 10 and 5 for 2011 and 2012 respectively. With maximum primary stolon length at 343 GDD in 2011 and 510 GDD in 2012, vegetative and reproductive structures began emergence at the same base temperature of $1^0$C and both developmental patterns are probably not mutually exclusive.

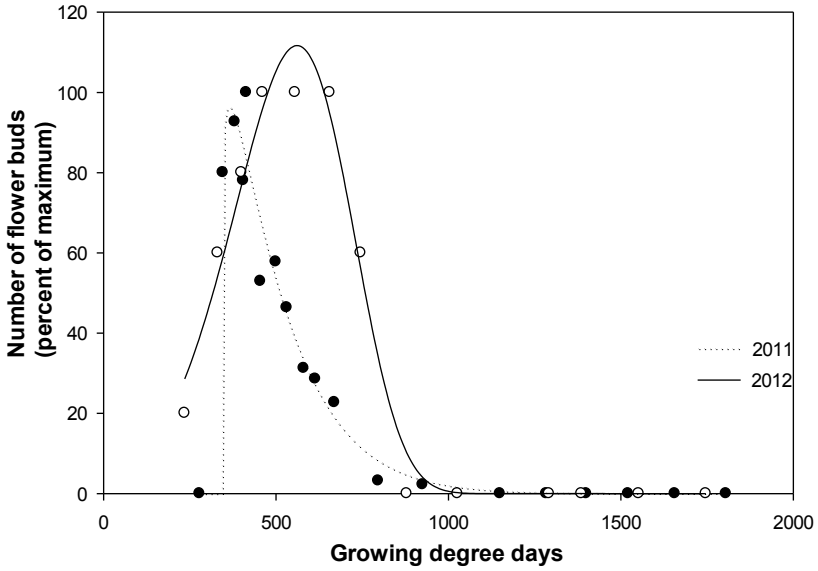


Figure 2.3 Number of flower buds (percent of maximum) of *H. pilosella* in relation to cumulative growing degree days (GDD) ($T_{base} = 1^0$ C) at Mt. Stewart 2011(vegetative year) and Mt. Stewart 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

### 2.4.2.2 Flower heads (percent of maximum)

Number of flower heads versus growing degree days was modelled using a Gaussian model. Parameter estimates a, b, $X_0$ and $Y_0$ are discussed in Table 2.2. The model predicted 97 % of flowering peaked at 582 GDD in 2011 and 92 % at 583 GDD in 2012. (Figure 2.4). Visual count of flower heads from mother rosettes across site was higher in 2011 compared to 2012 (data not shown), this can be attributed to the removal of competition from the blueberry ramets by pruning. In 2012, blueberry stems were fully grown and getting set to bear fruits and could "possibly" be competing with *H. pilosella* for resources. The results obtained from my study concur with the research conducted by Jacobs (2007) who observed flowers on hawkweed species in late May and peak flowering in mid – June.

Similarly, Thomas and Dale (1975) and Stergios (1976) noted that the number of flower buds produced, number of flowers, quantity of seeds produced and length of stolons were all highly density dependent. This meant most flowering rosettes growing in patches are usually found at the edge of the patch because intraspecific competition is low compared to the centre of patches where density is highest. I observed this to be true because hawkweeds growing with blueberry plants had little to no flower heads compared to those growing in bare patches in lowbush blueberry fields. This shows hawkweed growth is rapid when there are no other plants within its environment. Similarly, Jenkins (1991) observed a higher number of flower production in newly colonised sites resulted in a greater number of rosettes compared to densely populated sites. Wu et al. (2013) predicted the flowers of spreading dogbane (*Apocynum androsaemifolium*), a perennial weed in lowbush blueberry fields bloomed between 535 to 741 GDD in the reproductive year. In a similar study, White et al. (2012) developed a model on lowbush blueberry flowering in Nova Scotia and predicted the maximum percent of open flowers was 552 and 565 GDD at two different sites in the reproductive year. Although hawkweed begins flowering before both spreading dogbane and blueberry plants and ceases after blueberry plants have completed the blooming stage in the reproductive year, it is unclear whether hawkweed flowers are an important source of pollen for honeybees, which pollinate the blueberry flowers in the reproductive year. Also emergence of both vegetative and reproductive organs suggests these weeds can begin rapid growth in a lowbush blueberry field when optimum temperature is reached.

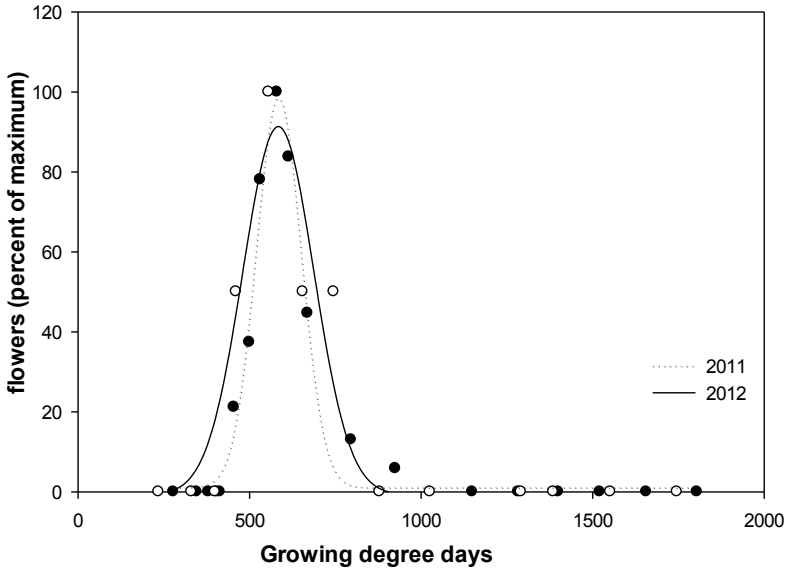


Figure 2.4 Flowers (percent of maximum) of *H. pilosella* in relation to cumulative growing degree days (GDD) ($T_{base} = 1^0$ C) at Mt. Stewart 2011(vegetative year) and 2012 (reproductive year) in lowbush blueberry fields on Prince Edward Island.

### 2.4.2.3 Achene production

At the end of flowering, a visual observation of achene with pappus (tiny hairs) was observed on leaves of rosettes around August 3(1407 GDD) in 2011 and July 12 (1129 GDD) 2012. Makepeace (1985) on Eastern South Island in New Zealand compared the reproductive attributes *via* achene production of two hawkweed species *H. pilosella* and *H. praealtum* on two separate trial sites dominated with *Festuca novae - zelandiae* and grown on shallow soils. It was observed achene production was of minor importance in contributing to the population despite the presence of young seedlings emerging at wet periods. Winkler and Stocklin (2002) designed a simulation model on the interspecific competition between clonal grasses and *H. pilosella* in North West Switzerland. In a plot disturbed by cattles and other environmental factors, it was observed grasses grown in a more fertile soil region displaced *H. pilosella*. On the other hand when grasses could not

be maintained on poor soils, *H. pilosella* persisted *via* vegetative growth. It was only in a narrow boundary region could they both coexist. However, in the absence of clonal grasses, *H. pilosella* covered the plots which had both low and high soil fertility *via* achene production. The study concluded seeds of *H. pilosella* are more important for long distance spread. A visual observation show *Hieracium* species are mostly found growing in bare patches surrounded by blueberry plants and this could also mean production of rosettes via achene is limited or reduced. Similarly, Epsie (1994) observed *H. pilosella* produced a lot of seeds after flowering however, about 1 in 230000 seeds germinated, this shows *H. pilosella* maintains its population vegetatively *via* stolons.

### 2.4.3 Modelling the vegetative growth of *H. caespitosum* in Caledonia

#### 2.4.3.1 Leaves on mother rosettes (percent of maximum)

A visual observation showed number of leaves on established rosettes in lowbush blueberry fields increased from 8 at 336 GDD (May 26) to 10 at 502 GDD (June 7) in the vegetative year (2011) and 7 leaves were found on rosettes at 331 GDD (May 17) in the reproductive year (2012). At the end of the season, about 15% of leaves were still found on mother rosettes at 1807 GDD in 2011 and 25 % of leaves on mother rosettes at 1784 GDD in 2012. Growing degree days was plotted against percent of maximum number of leaves using a logistic model and parameter estimates a, b and $X_0$ of the model are described in Table 2.3.

Rate of leaf decay was slower in 2011 (b=1.7) than 2012 (b=2.5) (Figure 2.5) and this show a change in temperature is also responsible for leaf development and a gradual decline of leaves for both years over the season. Death of mother rosettes was slower in 2011 even though the fields had been previously punned compared to *H. pilosella* which had a faster death rate of mother rosettes across the season. In 2012, a visual observation

show hawkweed rosettes seem to be shaded by the presence of blueberry stems in the quadrats which prevented sunlight thus reducing photosynthesis. Lawson et al. (2006) used a logistic model to express the emergence timing of volunteer Canola in spring wheat fields in Manitoba, Canada. Using a $T_{base} = 5^0$ C, 50% of Canola seedlings had emerged at 90 and 132 GDD in 2003 and 2004 respectively. Although these weed species are annual plants, emergence development is dependent on minimal temperature. Blueberry growers have a short window to control *H. caespitosum* in blueberry fields because blueberry ramet emergence begin after *H. caespitosum* are actively growing, therefore an application of clopyralid which is a registered herbicide product for blueberry fields should be sprayed shortly after rosettes are actively growing in the vegetative year.

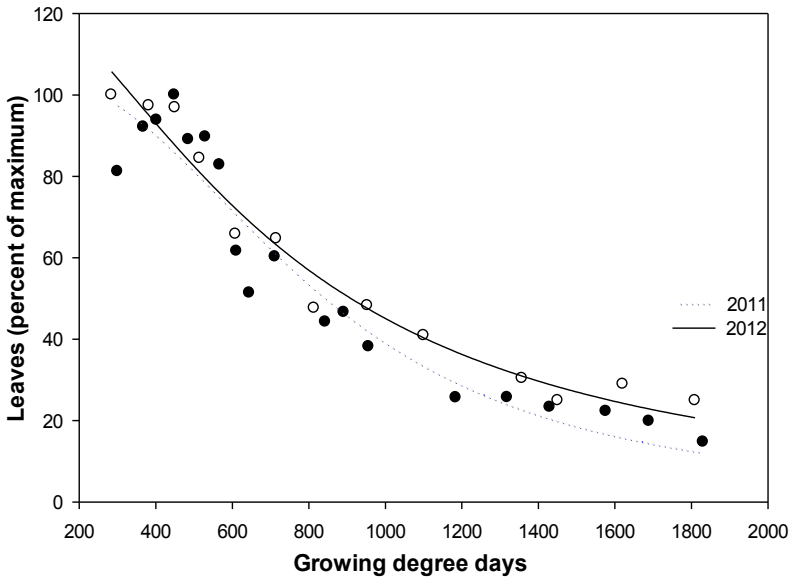


Figure 2.5 Leaves (percent of maximum) of *H. caespitosum* in relation to cumulative growing degree days (GDD) ($T_{base} = 1^0$ C) in Caledonia 2011(vegetative year) and Caledonia 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

Table 2.3 Parameter estimates and 95% Confidence interval (CI) of percent of maximum leaves, percent of maximum flower buds and percent of maximum flowers for *H. caespitosum* in 2011 and 2012.

* Root Mean Square Error

| | | | Parameter estimates | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | Year | Equation | $T_{base}$ | a | b | c | $X_0$ | $R^2_{Adj}$ | RMSE* | P value |
| | | | | | 95% CI | | | | | |
| percent of maximum leaves | 2011 | Logistic | $1^0$ | 105.6±24.5 | 2.5±1.05 | - | 806.4±204.2 | 0.91 | 7.89 | <0.0001 |
| | 2012 | | | 127±36.1 | 1.7±0.6 | - | 710.7±278.9 | 0.96 | 4.75 | <0.0001 |
| percent of maximum flower buds | 2011 | Gaussian | $0^0$ | 90±16.4 | 248±66.2 | - | 762±55.4 | 0.83 | 13.75 | <0.0001 |
| | 2012 | | | 107±27.8 | 198±60 | - | 871±62.2 | 0.83 | 14.59 | 0.0002 |
| percent of maximum flower heads | 2011 | Gaussian | $0^0$ | 99.7±0.25 | 220.6±0.8 | 9.9±0.5 | 1197±0.5 | 1.0 | 0.1 | <0.0001 |
| | 2012 | | | 107.5±51.55 | 130.4±128.9 | 1.9±2.0 | 1149±46.2 | 0.99 | 2.2 | <0.0001 |

### 2.4.3.2 Length of primary stolons from mother rosettes

A model could not fit the emergence and length of primary stolons in blueberry fields because of the low number of primary stolons that emerged from the base of labelled mother rosettes. Primary stolon production in *Hieracium caespitosum* was slower and stolons were short, inconspicuous and low in number. Espie (1994) also observed the species is also less stoloniferous when compared with *H. pilosella* in grazing fields in New Zealand. In 2011, an average of three stolons with a maximum length of 3.4 cm across the six quadrats were observed and two stolons with a maximum length less than 1 cm across site in 2012. Three out of the six quadrats had about 75% of blueberry stems growing and this could be responsible for hawkweed's slow growth. In comparison, primary stolon length of *H. pilosella* was higher for both years, this is a major difference between both species.

### 2.4.3.3 Production of daughter rosettes from primary stolons and axillary buds

One and two daughter rosettes were observed in 2011 and 2012 from primary stolons across sites respectively. Similarly, in the vegetative and reproductive year, daughter rosettes from axillary buds were four and five in number across the six quadrats respectively. This could probably mean *H. caespitosum* increases its population *via* axillary buds, rhizomes and adventitious root buds found on fibrous roots (Wilson et al. 1997). In comparison, a higher number of daughter rosettes was recorded in the reproductive year via axillary buds in *H. pilosella*, therefore these species may alternate daughter rosette formation using axillary buds when in close proximity with other plant or plants in the same environment. Daughter rosettes in this study are responsible for the

start of a second generation. Secondary stolons were not observed in either 2011(vegetative year) or 2012 (reproductive year).

### 2.4.4 Modelling the reproductive growth of *H. caespitosum* in Caledonia

#### 2.4.4.1 Flower buds (percent of maximum)

A Gaussian model was used to plot growing degree days against percent of maximum for flower buds and parameter estimates a, b and $X_0$ are described in Table 2.3. The model predicted 90 % of flower buds peaked at 762 GDD and 100% flower buds peaked at 871 GDD in 2011 and 2012 respectively (Figure 2.6). Emergence of flower buds took a longer period of time compared with *H. pilosella* because each inflorescence have between 6 – 25 flower buds compared to *H. pilosella*, which has one flower bud and at most two.

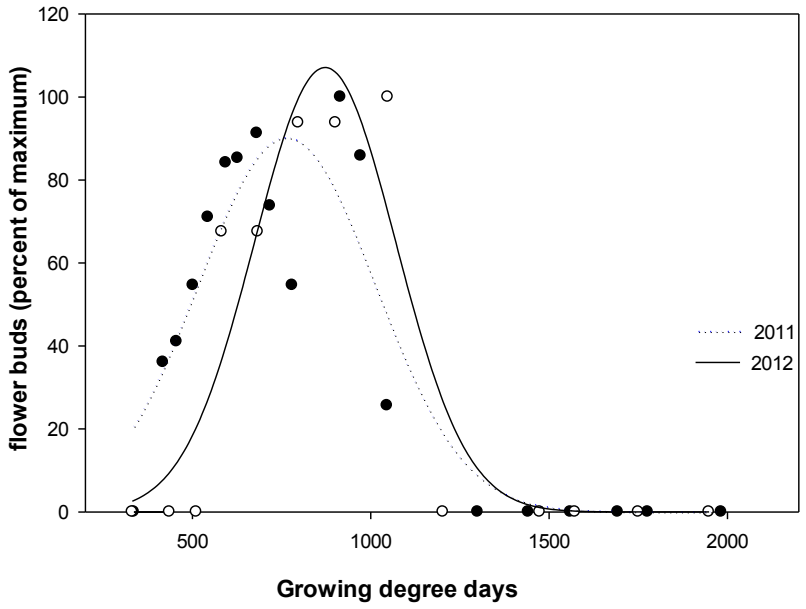


Figure 2.6 Flower buds (percent of maximum) of *H. caespitosum* in relation to cumulative growing degree days (GDD) ($T_{base}$ = $0^0$C) in Caledonia 2011 (vegetative year) and Caledonia 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

### 2.4.4.2 Flower heads (percent of maximum)

Growing degree days was plotted against percentage of maximum flower heads using a Gaussian model. Parameter estimates a, b, c and $X_0$ are described in Table 2.3. The model predicted flowering began around 402 and 337 GDD in 2011 and 2012 and peaked at 1197 GDD in 2011 and 1149 GDD in 2012 (Figures 2.7). Flowering was also observed in September and this shows that these hawkweed species flower twice in a year. This was also reported by Jacobs (2007). White et al. (2012) predicted flowering of blueberry plants began between 376 and 409 GDD and maximum flower bloom in two different fields at 552 and 565 GDD in the reproductive year.

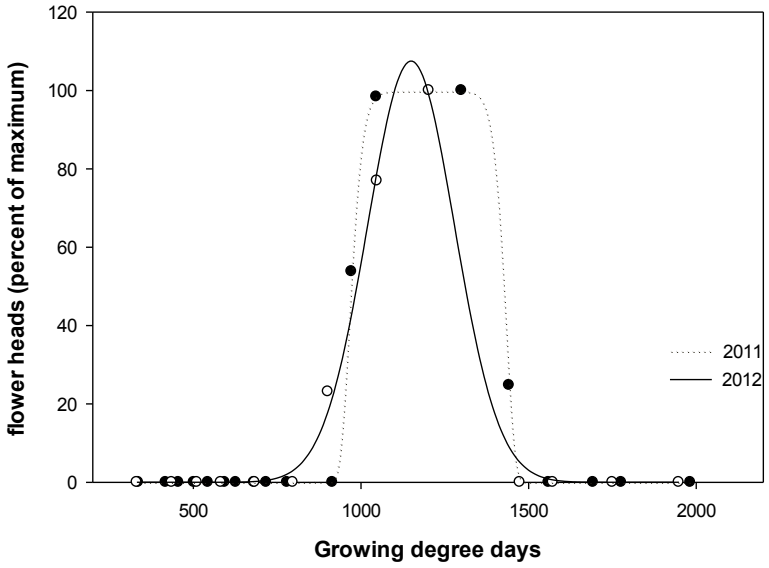


Figure 2.7 Flower heads (percent of maximum) of *H. caespitosum* in relation to cumulative growing degree days (GDD). ($T_{base} = 0^0C$) in Caledonia 2011 (vegetative year) and Caledonia 2012 (reproductive year) in a lowbush blueberry field on Prince Edward Island.

### 2.4.4.3 Achene production

At the end of flowering, achene (tiny black seeds with hairs) attached to them was observed on leaves of rosettes around 1693 GDD (August 17) in 2011 and 1589 GDD (August 1) 2012. These seeds are responsible for rosettes growing at a distant from mother rosettes. *H. praealtum* (King devil hawkweed) found growing in Canterbury, New Zealand has a similar growth form with *H. caespitosum.*

## 2.5 Conclusion

Based on the different phenological growth stages of hawkweed species using different base temperatures, weed management decision should consist of either monitoring or early scouting of wild blueberry fields for these weed species and herbicide application in the spring of the vegetative year or fall application after harvesting of blueberries and mowed fields in the reproductive year. Two hawkweed species found in lowbush blueberry fields on Prince Edward Island are *H. pilosella* and *H. caespitosum* with similar growth and emergence pattern such as number of leaves on rosettes declining over the season, emergence of flower buds initiating stolon emergence and production of daughter rosettes, however, there mode of reproduction is different depending on the cycle of the blueberry field. *H. pilosella* is a highly stoloniferous plant in the vegetative year and in the reproductive year it reproduces vegetatively mostly *via* axillary buds. An application of 1920 g a.i/ ha of hexazinone (Velpar) in the spring of the vegetative year could be applied. *H. caespitosum* did not produce many stolons or axillary buds and this could mean it reproduces *via* other vegetative means. Also secondary stolon production was not observed in *H. caespitosum* in 2011 and 2012. We observed rosettes without flower buds had a slower decline therefore, it is important to spray in the fall of the crop year after

fields have been mowed using an application of 1104 g a.i/ ha  dicamba (Banvel). Also in the vegetative year before the production of flower buds, an application of 151.2 g a.i/ ha clopyralid (Lontrel) could also be used. To develop a model for blueberry growers, more data should be collected in other parts of Prince Edward Island to see if the results are consistent with the two sites used for the study and the need to have these models validated as this would enable other growers in North America with similar weed problem know when to actually spray their fields and avoid blueberry damage.

# Chapter 3.0 Management of Meadow and Mouse ear hawkweed with herbicides in lowbush blueberry fields

## Abstract

Hawkweed species are a concern to lowbush blueberry growers because of their rapid spread on bare soils and perceived ability to compete, hinder harvest and reduce yields. Two herbicide screening trials were conducted in four commercial blueberry fields on Prince Edward Island to evaluate alternative herbicide options. Eleven herbicides or tank mixes were evaluated in the vegetative year in 2011. In the fall of the same year an additional trial was set up to evaluate 14 products that were applied in the fall of the reproductive year following mowing or in the following spring of the vegetative year. In 2011, an application of pyroxsulam at 0.15g a.i/ha and florasulam at 10g a.i/ha suppressed the formation of flower buds on *H. caespitosum* in Caledonia. Hexazinone applied at an application rate of 1920g a.i/ha was the only herbicide that had an acceptable control on *H. pilosella* at Mt. Stewart 1. In 2012, a fall application of dicamba applied at 1104g a.i/ha gave 100% control 257 DAS (Days after spray). The best spring treatments in 2012 on *H. caespitosum* were clopyralid applied at 151.2g a.i/ha and a tank mix of hexazinone (1920g a.i/ha ) + clopyralid (151.2g a.i/ha) which provided 40 and 45% control respectively in 2012. Mount Stewart 2 was the only site hawkweed density was marginally significant throughout the season ($P<0.05$). Herbicides applied in 2012 on hawkweed biomass was marginally significant ($p = 0.05$) in Culloden. Application of clopyralid in the spring of the vegetative year and dicamba in the fall of the reproductive year for control of *H. caespitosum* and an application of hexazinone in the spring of the vegetative year on *H. pilosella* is recommended. Further research on pyroxsulam and florasulam should be

carried out as these unregistered products have shown a potential to suppress hawkweed growth in blueberry fields.

## 3.1 Introduction

Weeds are a limiting factor in blueberry production ((McCully et al. 1991) and are managed with herbicides, mowing, hand pulling, or clipping (Anonymous 2012). Hand pulling is only viable where weed infestations are low or limited to small areas. However, perennial weeds regenerate from roots or rhizomes after a brief period of time and repeated hand pulling is necessary to achieve long term control. Clipping may be used for plant species taller than the blueberry plant. This method suppresses seed production, reduces shading, and improves berry harvest. Like hand pulling, clipping must be repeated multiple times within a season over several years to exhaust root reserves (Anonymous 2012). Therefore, growers rely predominately on herbicides for weed control due to the above mentioned limitations of physical and cultural techniques and the fact that cultural methods such as tillage are not possible due to the perennial nature of the crop.

Meadow hawkweed (*Hieracium caespitosum* Dumort) was introduced into the United States of America from Europe and inhabits grasslands and other disturbed sites (Callihan and Miller 1994). It is a creeping perennial that reproduces by stolons, rhizomes or seeds (Callihan et al. 1989b). The leaves are hairy and usually have 6-25 flowers per stalk. Mouse ear hawkweed (*Hieracium pilosella* L.), another invasive species found in blueberry fields, tends to have greater stolon production than meadow hawkweed but also has hairy and dark green leaves and it only has one to two flowers per stalk. On Prince Edward Island (PEI) both hawkweed species are common throughout the province and

form large patches in blueberry fields (Jordan 2009). Growers believe that hawkweeds hinder harvest operations, compete with blueberries and may spread throughout their field over time. Production practices used to encourage crop growth such as pruning, fertilization and irrigation also promote the development of perennial weeds. Therefore, it is necessary to develop an integrated approach which includes biological knowledge and herbicides to control perennial weeds (Wu 2010).

Currently there are 14 herbicides registered for weed control in Atlantic Canada's lowbush blueberry fields. Growers rely predominately on hexazinone (Velpar, DuPont Canada) for broadleaf weed control. This product was registered in 1984 and its widespread use has effectively managed many weed species and resulted in an increase in blueberry yields (Jensen 1985). However, it only provides short term suppression of hawkweed species in the spring of the sprout year.

In 2005, aminopyralid, clopyralid and a mixture of clopyralid and triclopyr were applied to the bolting, flowering and senescence stages of meadow hawkweed (*Hieracium caespitosum*) in Idaho. After one year of treatment, hawkweed control was greater than 95% when treated at the bolting stage. Herbicide application at the flowering stage and in the fall had greater than 80 and 30% control respectively (Wallace and Pranther 2005). Application of picloram (140g $ha^{-1}$) combined with 2, 4-D (275g $ha^{-1}$) was effectively controlled orange hawkweed (*Hieracium aurantiacum* L) during flowering in a pasture in Northern Idaho (Wattenberger et al.1979). Application of clopyralid at rates of 270, 550 and 1,100 g $ha^{-1}$ resulted in a greater than 80% chlorosis of meadow hawkweed in a northern Idaho pasture (Miller et al. 1987). In a similar experiment after 3, 4, and 5 years

of treatment, 100, 80 and 50% control was observed when plots were treated with 550 and 1100 g $ha^{-1}$ of clopyralid respectively (Lass and Callihan 1992).

Growers across Atlantic Canada report increased hawkweed density in blueberry fields (Jordan 2009). There is currently no effective management plan and a need to identify herbicide products with efficacy and crop safety. Herbicides chosen for the screening trial such as clopyralid, dicamba, 2, 4- D, aminopyralid and glyphosate have all been used in previous studies to control hawkweed species in lawns, gardens and pastures. Florasulam and pyroxsulam are unregistered products for lowbush blueberry fields but previous research suggests that they are safe on blueberry with efficacy on problematic perennial weeds (Boyd, unpublished data).

## 3.2 Objective

To identify potential herbicides or tank mixes that selectively control hawkweed species and can be safely applied in the spring of the vegetative year or the fall of the reproductive year following berry harvest and mowing.

## 3.3 Materials and methods

Field experiments were conducted in 2011 and 2012 in commercial lowbush blueberry fields located on Prince Edward Island (PEI). Experiments occurred at 4 sites and were a randomised complete block (RCBD) with four blocks. Blocking was done to account for spatial variability in the fields. Plot sizes were 2 × 6 m with a wide unsprayed buffer strip between each plot. Herbicides were applied using a $CO_2$ pressurised hand held sprayer with teejet 8002VS calibrated at 35 PSI.

### 3.3.1 Hawkweed species and soil description of trial sites

*Hieracium caespitosum* was found in Caledonia ($46^0$ 1' N, $62^0$ 47' W). Soils are coarse textured and described as loamy fine sands. The surface and internal drainage are rapid to excessive (Whiteside 1965). *Hieracium caespitosum* was found in Culloden ( $46^0$ 4' 0 N, $62^0$ 43' W). Soils are coarse - textured and sandy and porous. They are poor at holding moisture and droughty (Whiteside 1965). *Hieracium pilosella* and *Hieracium caespitosum* were found at Mount Stewart 1 and 2 ($46^0$ 22' N, $62^0$ 52' W) respectively. The soils were moderately coarse textured soils (Whiteside 1965).

### 3.3.2 Herbicide screening on hawkweed species in lowbush blueberry fields in 2011 and 2012

An experiment was set up in 2011 to evaluate spring applied herbicides. Herbicides were applied to meadow and mouse ear hawkweed rosettes prior to blueberry shoot emergence (PRE) and following blueberry shoot emergence (POST), (Table 3.1). Pre-emergence herbicides were applied on the 19th May 2011 and post emergence applied on the 10th June 2011.

A second herbicide screening experiment was set up in the fall of 2011 after berry harvest and the blueberry stems were removed with mowing to evaluate fall and spring applied herbicides (Table 3.2). Herbicides were sprayed on the 27th October 2011 when hawkweed rosettes were still green and spring herbicides were sprayed on the 17th May 2012. Herbicide treatments applied to hawkweed rosettes were at the recommended rates to avoid blueberry injury.

Table 3.1 Herbicide treatments applied in Caledonia and Mount Stewart 1 in the spring of 2011 in commercial lowbush blueberry fields.

| Trade name | Active ingredient | Application timing | Application rate (g a.i/ha) |
|---|---|---|---|
| untreated control | - | - | - |
| callisto | mesotrione | Pre | 144.0 |
| callisto | mesotrione | Post | 144.0 |
| casoron | dichlobenil | Pre | 3.2 |
| lontrel | clopyralid | Pre | 151.2 |
| lontrel | clopyralid | Post | 151.2 |
| N/A | florasulam | Pre | 10.0 |
| simplicity | pyroxsulam | Pre | 0.015 |
| ultim | rimsulfuron | Pre | 25.3 |
| ultim | rimsulfuron | Post | 25.3 |
| velpar | hexazinone | Pre | 1920.0 |

Nonylphenoxy polyethyoxyethanol was used as the surfactant

Table 3.2 Herbicide treatments applied in Culloden and Mount Stewart 2 in the fall of 2011 and spring of 2012 in commercial lowbush blueberry fields.

| Application time | Trade name | Active ingredient | Application timing | Application rate (g a.i/ha) |
|---|---|---|---|---|
| Fall | untreated control | - | - | - |
| | banvel | dicamba | Pre | 1104.0 |
| | lontrel | clopyralid | Pre | 151.2 |
| | milestone | aminopyralid | Pre | 69.6 |
| | spartan | tribenuron methyl | Pre | 30.0 |
| | tank mixes | dicamba+2,4-D | Pre | 1104.0+280.0 |
| Spring | casoron | dichlobenil | Pre | 3.2 |
| | fiesta | Iron hedta* | Pre | 142.1 |
| | lontrel | clopyralid | Pre | 151.2 |
| | round up | glyphosate | Pre | 685.8 |
| | tank mixes | florasulam+ clopyralid | Pre | 10.0+151.2 |
| | tank mixes | pyroxsulam+ clopyralid | Pre | 0.015+151.2 |
| | tank mixes | hexazinone+ clopyralid | Pre | 1920.0+151.2 |
| | velpar | hexazinone | Pre | 1920.0 |

*Hydroxyehylene diaminetriacetic acid
Nonylphenoxy polyethyoxyethanol was used as the surfactant

## 3.4 Study Parameters

### 3.4.1 Damage ratings

A visual damage rating scale of 0-100 was used in each plot where 0 is no injury, 20 is 20% of rosette damage, 40 is 40% of rosette damage, 60 is 60% of rosette damage, 80 is 80% of rosette damage and 100 is 100% complete death of rosettes (Derr 1994). Damage ratings on blueberry and hawkweed species were evaluated 12, 33, 74 and 102 days after spraying (DAS) in the spring trial 2011. Fall 2011 ratings were done in the spring of 2012 on 201, 215, 236, and 257 DAS which corresponds to spring 2012 ratings done on 14, 35, 56 and 72 DAS the spring treatments.

**Hawkweed damage rated 0**

**Hawkweed damage rated 20**

**Hawkweed damage rated 40** **Hawkweed damage rated 60**

**Hawkweed damage rated 80** **Hawkweed damage rated 100**

Figure 3.1 Damage ratings of hawkweed species using a scale of 0 -100 with pictures.

### 3.4.2 Hawkweed density

Hawkweed species were counted in each plot using two randomly placed 0.50 x 0.50 m quadrat before spraying with herbicides. Counts were done 14, 28, 54 and 419 DAS in the spring trial of 2011. For the fall trial, rosettes were counted 0, 212 and 235 DAS (in the spring of 2012) which correspond to 0, 18 and 59 days after the spring spray in 2012. Number of rosettes was counted and the average weed density for each plot was calculated and analysed using the Kruskal Wallis statistical procedure.

### 3.4.3 Above ground hawkweed biomass and blueberry floral bud count

An above ground hawkweed biomass was collected at the end of the summer in Caledonia, Culloden and Mount Stewart 2. A transect with knots every 15cm was placed diagonally across the plots and rosettes closest to the knots were cut at ground level. Clipped rosettes were bagged and dried at $60^0$ C in an oven for 48 hours and weighed. The same methodology was used to estimate blueberry floral buds per stem. Blueberry stems nearest the knot were cut at ground level, each stem measured and number of floral buds per stem counted.

### 3.4.4 Blueberry yield

A 2 m × 0.30 m area was harvested in each plot using a hand rake. Blueberries were cleaned by hand using wind to remove debris and average fresh weight of blueberries in each plot was calculated and measured in $kg/ha^{-1}$.

### 3.4.5 Statistical analysis

Data were analyzed using Chi square test. A non-parametric Kruskal Wallis statistical procedure (a one way analysis based on ranks) was used for the ratings due to

the non-parametric characteristics of the data. The PROC MIXED procedure in SAS was used to analyse aboveground shoot biomass, blueberry stem length, floral bud count and blueberry yield. All analyses were done at $\alpha = 0.05$ and tukey adjusted means comparisons were to compare treatment means.

## 3.5 Results and Discussion

### 3.5.1 Damage ratings

#### 3.5.1.1 Herbicide screening trials in Caledonia and Mount Stewart 1 2011

The two sites were analysed separately due to the presence of different hawkweed species. *Hieracium caespitosum* in Caledonia and *Hieracium pilosella* at Mt. Stewart 1. In Caledonia 12 DAS, there was a statistically significant difference between herbicide treatments ($\chi^2_{(10)} = 20.8485$, $p = 0.0222$). PRE applications of clopyralid and florasulam gave the highest percentage hawkweed damage of 40%. Based on the ranking results in Table 3.3, applications of clopyralid (pre) and florasulam ranked highest compared to the untreated control. Thirty three DAS there was a statistically significant difference between treatments ($\chi^2_{(10)} = 22.5939$, $p = 0.0062$). Clopyralid (post) had 55% of hawkweed damage followed by florasulam, pyroxsulam and rimsulfuron (post), which all had 40% hawkweed damage. Based on the ranking system, florasulam was rated the best treatment followed by clopyralid (pre-) in comparison with the untreated control which was rated a 4.5. On 74 DAS, there was a statistically significant difference between treatments ($\chi^2_{(10)} = 28.8300$, $p = 0.0013$). Florasulam had the highest percentage hawkweed damage of 40%. Pyroxsulam, rimsulfuron (pre-) and rimsulfuron (post) damaged about 30% of hawkweed rosettes. Application of florasulam had the highest ranking of 39.62 and untreated control

had the least. On 102 DAS a statistically significant difference between treatments was observed ($\chi^2_{(10)} = 27.0473$, $p = 0.0026$). Clopyralid (pre) and dichlobenil had the highest hawkweed damage of 15% (Table 3.3). None of the herbicides tested provided adequate levels of control and rosette recovery and regrowth was observed over time. Visual observation indicated application of florasulam and pyroxsulam inhibited flower bud development and this may reduce spread. None of the herbicide caused any blueberry stem damage throughout the season.

Table 3.3 Treatment means and ranking values of the Kruskal Wallis test for damage ratings on *Hieracium caespitosum* in response to various herbicides (12, 33, 74 and 102 days after spray) in Caledonia 2011.Values in parentheses are standard error.

| | 12 DAS | | 33 DAS | | 74 DAS | | 102 DAS | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Damage ratings | Ranking | Damage ratings | Ranking | Damage ratings | Ranking | Damage ratings | Ranking |
| untreated control | 0(0) | 17.0 | 0(0) | 4.5 | 0(0) | 4.5 | 0(0) | 6.5 |
| clopyralid (pre) | 40[b](8.0) | 33.5[a] | 25(15.0) | 33.2 | 5(5.0) | 20.62 | 15(5.0) | 10.25 |
| clopyralid (post) | 35(5.0) | 17.0 | 55(5.0) | 31.1 | 5(5.0) | 30.02 | 0(0) | 10.25 |
| dichlobenil | 25(5.0) | 33.5 | 30(5.5) | 22.3 | 25(5.0) | 23.0 | 15(5.0) | 25.50 |
| florasulam | 40(0) | 17.0 | 40(0) | 35.5 | 40(0) | 39.62 | 0(0) | 37.50 |
| hexazinone | 15(0) | 17.0 | 15(5.0) | 14.62 | 15(5.0) | 12.37 | 0(0) | 17.75 |
| mesotrione (pre) | 20 (0) | 28.0 | 15(5.0) | 18.0 | 25(5.0) | 19.0 | 10(5.5) | 25.50 |
| mesotrione(pre+post) | 20 (0) | 28.0 | 25(5.0) | 18.0 | 25(5.0) | 12.37 | 10(5.5) | 25.50 |
| pyroxsulam | 35(5.0) | 22.5 | 40(0) | 31.1 | 30(10.0) | 31.0 | 5(5.0) | 29.75 |
| rimsulfuron (pre) | 20(11.5) | 17.0 | 30(5.5) | 20.0 | 30(5.5) | 23.0 | 0(0) | 29.50 |
| rimsulfuron (post) | 20(8.1) | 17.0 | 40(0) | 19.0 | 30(5.5) | 31.0 | 0(0) | 29.50 |
| p-value | - | 0.0222 | - | 0.0062 | - | 0.0013 | - | 0.0026 |

[a] Data were analyzed for each period separately using the Kruskal Wallis test
[b] Damage ratings was assessed on a scale from 0-100

On 12 DAS on Mount Stewart 1, treatment were statistically different ($\chi^2_{(10)}$ = 31.3202, p = 0.0005). Hexazinone caused the greatest short term suppression of 80%. Application of rimsulfuron (pre-) had 50% damage on hawkweed rosettes. Based on the ranks in Table 3.4, hexazinone was ranked highest with 35.75. Rimsulfuron (pre) damaged about 50% of hawkweed rosettes. A rank value of 33.0 was shared by clopyralid (pre), mesotrione (pre) and mesotrione (pre + post). On 33 DAS treatments were significantly different ($\chi^2_{(10)}$ = 24.5771, p = 0.0062), clopyralid (post) had the highest hawkweed damage of 40 %. The ranks show rimsulfuron has the highest followed by clopyralid (pre-). At 74 DAS, treatments were not significantly different ($\chi^2_{(10)}$ = 12.0026, p = 0.2849. At 102 DAS, treatments were also not significantly different ($\chi^2_{(10)}$ = 10.4242, p = 0.4041). In our results, clopyralid only provided 40 % control of hawkweed rosettes, this results was similar in New Zealand when clopyralid was sprayed on mouse ear hawkweed (*H. pilosella*) and there was no significant difference between the control and sprayed rosettes (Smale et al.1999). This shows that clopyralid is not an effective herbicide in *H. pilosella* control. Hexazinone, a group 5 herbicide which inhibits photosynthesis at the photosystem II level controlled the growth of *Hieracium pilosella* for a short period of time but a tank mix or additional herbicide application is needed to provide long term control. This weed species is highly stoloniferous with aggressive growth and spread (Callihan et al. 1997). As a result, initiation of stolon production which is responsible for a second generation could have begun when herbicides were sprayed on rosettes. Also, blueberry fields were mowed the previous year, therefore hawkweed growth would have been rapid. During the

screening trials, herbicides applied did not damage the blueberry stems. At the end of the season, none of the herbicides provided adequate long term control.

Table 3.4 Treatment means and ranking values of the Kruskal Wallis test for damage ratings on *Hieracium pilosella* in response to various herbicides (12, 33, 74 and 102 days after spray) at Mount Stewart 1 2011. Values in parentheses are standard errors

| | 12 DAS | | 33 DAS | | 74 DAS | | 102 DAS | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Damage ratings | Ranking [a] | Damage ratings | Ranking | Damage ratings | Ranking | Damage ratings | Ranking |
| untreated control | 0(0) | 11.50 | 0(0) | 8.5 | 0(0) | 9.0 | 0(0) | 17.0 |
| clopyralid (pre) | 30[b](10.0) | 33.0 | 20(11.5) | 26.87 | 10(10.0) | 20.50 | 20(0) | 22.5 |
| clopyralid (post) | 20(11.0) | 11.5 | 40(0) | 20.75 | 0(0) | 32.0 | 0(0) | 17.0 |
| dichlobenil | 15(9.5) | 27.62 | 20(11.5) | 18 | 20(11.5) | 20.50 | 15(5.0) | 28.0 |
| florasulam | 15(9.5) | 16.87 | 15(9.5) | 18.0 | 20(11.5) | 17.25 | 5(5.0) | 28.0 |
| hexazinone | 80(0) | 35.75 | 20(20.0) | 18.0 | 0(0) | 17.75 | 25(5.0) | 17.0 |
| mesotrione(pre) | 10(5.5) | 33.0 | 30(10.0) | 15.25 | 20(11.5) | 25.50 | 20(0) | 28.0 |
| mesotrione (pre+ post) | 25(9.5) | 33.0 | 30(10.0) | 24.12 | 10(10.0) | 26.25 | 20(0) | 22.5 |
| pyroxsulam | 15(5.0) | 16.87 | 30(10.0) | 18.62 | 20(11.5) | 26.25 | 50(5.0) | 28.0 |
| rimsulfuron (pre) | 50(5.7) | 16.87 | 30(5.7) | 36.25 | 0(0) | 25.50 | 50(5.0) | 17.0 |
| rimsulfuron(post) | 15(5.0) | 11.50 | 30(10.0) | 18.62 | 10(10.0) | 26.25 | 0(0) | 22.5 |
| p-value | - | 0.0005 | - | 0.0062 | - | 0.2849 | - | 0.5412 |

a Data were analyzed for each period separately using the Kruskal Wallis test
b Damage ratings was assessed on a scale from 0-100

### 3.5.1.2 Herbicide screening trials in Culloden and Mount Stewart 2 2012

*Hieracium caespitosum* was the predominant hawkweed species at Culloden and on Mount Stewart 2. In Culloden, damage ratings 14 DAS was significantly different ($\chi^2_{(13)}$ = 47.5101, p = <0.0001). Aminopyralid, dicamba, clopyralid (fall) and dicamba + 2, 4-D all gave 100% control. About 90% of hawkweed rosettes were damaged when clopyralid and a tank mix of florasulam + clopyralid was applied in the spring. The tank mix of florasulam + clopyralid had a rank of 29.75 and clopyralid applied in the spring had a 27.5. Although glyphosate had about 75 % of hawkweed damage, it was ranked 36.75 which was second to the highest. Tribeneuron methyl and the untreated control had the least ranking of 6.0. On 35 DAS treatments were significantly different ($\chi^2_{(13)}$ = 45.1392, p = <0.0001) aminopyralid, dicamba, clopyralid (fall) and dicamba + 2, 4-D and florasulam + clopyralid had a 100% damage on hawkweed rosettes and were all ranked 44.5 except the tank mix of florasulam +clopyralid which had a rank of 35.5. On 56 DAS treatments were significantly different ($\chi^2_{(13)}$ = 44.7308, p = <0.0001). Dicamba + 2, 4-D had the highest percentage damage of 95 % followed by a tank mix of florasulam + clopyralid with about 85 % hawkweed damage. These herbicides both ranked 42.0. Clopyalid (spring) and hexazinone + clopyralid had the highest percentage hawkweed damage of 80% and ranked 32.75 and 23.5 respectively. On 72 DAS treatment types were significantly different ($\chi^2_{(13)}$ = 31.5240, p = <0.0001). Aminopyralid, clopyralid (fall), dicamba and dicamba + 2, 4-D all provided season long control and they had a ranking of 47.0, 37.5, 34.5 and 47.0 respectively (Table 3.5). These herbicides all belong to the Group 4 herbicides which are auxin mimics. Our results suggest *H. caespitosum* may be susceptible to this class of

chemicals. A similar experiment conducted in southern Alaska woodlot and hayfield also found that aminopyralid and clopyralid controlled orange hawkweed (*H. aurantiacum*) up to one year after treatment (Seefeldt and Conn 2011). Lass and Callihan (1992) in a study showed that over 50% control of hawkweed was achieved over a six year period when 0.43 liters of clopyralid was used on perennial pasture fields. No injury of blueberry stems was observed.

Table 3.5 Treatment means and ranking values of the Kruskal Wallis test for damage ratings on *Hieracium caespitosum* in response to various herbicides (14, 35, 56 and 72 days after spray) in Culloden 2012. Values in parentheses are standard errors.

| | 14 DAS | | 35 DAS | | 56 DAS | | 72 DAS | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Damage ratings | Ranking [a] | Damage ratings | Ranking | Damage ratings | Ranking | Damage ratings | Ranking |
| untreated control | 0(0) | 6.0 | 0(0) | 4.5 | 0(0) | 4.5 | 0(0) | 4.5 |
| Aminopyralid (fall) | 100[b](0) | 47.0 | 100(0) | 44.5 | 80(11.5) | 42.0 | 100(0) | 47.0 |
| clopyralid(fall) | 100(0) | 47.0 | 100(0) | 44.5 | 60(14.0) | 42.0 | 100(0) | 37.5 |
| clopyralid(spring) | 90(0) | 27.5 | 90(5.6) | 35.5 | 80(8.1) | 32.75 | 40(0) | 37.75 |
| Dicamba (fall) | 100(0) | 47.0 | 100(0) | 44.5 | 75(9.5) | 42.0 | 100(5.0) | 34.5 |
| dicamba +2,4-D (fall) | 100(0) | 47.0 | 100(0) | 44.5 | 95(5.0) | 42.0 | 100(0) | 47.0 |
| dichlobenil | 60(8.1) | 16.12 | 70(12.8) | 19.25 | 60(8.1) | 23.75 | 20(0) | 25.5 |
| Iron hedta | 35(9.5) | 16.12 | 35(9.6) | 12.75 | 35(9.5) | 12.12 | 20(8.0) | 14.5 |
| florasulam+ clopyralid | 90(5.7) | 29.75 | 100(0) | 35.5 | 85(9.5) | 42.0 | 45(5.0) | 40.75 |
| glyphosate | 75(25.0) | 36.75 | 75(25.0) | 34.5 | 50(20.5) | 32.62 | 45(5.0) | 40.75 |
| hexazinone | 40(0) | 15.50 | 50(5.60) | 13.5 | 60(8.1) | 14.75 | 20(0) | 25.5 |
| hexazinone+clopyralid | 80(2.0) | 27.5 | 80(0) | 26.5 | 80(0) | 23.5 | 40(0) | 38.0 |
| pyroxsulam+clopyralid | 85(5.0) | 29.75 | 95(5.0) | 31.0 | 75(15.0) | 37.5 | 45(0) | 34.75 |
| tribeneuron methyl (fall) | 15(15.0) | 6.0 | 15(13.0) | 8.0 | 15(15.0) | 7.62 | 0(0) | 9.62 |
| p-value | - | <0.0001 | - | <0.0001 | - | <0.0001 | - | 0.0028 |

[a] Data were analyzed for each period separately using the Kruskal Wallis test
[b] Damage ratings was assessed on a scale from 0 -100

On Mount Stewart 2, 14 DAS, treatments were significantly different ($\chi^2_{(13)} = 41.1224$, p = <0.0001). Aminopyralid and dicamba + 2, 4-D gave 100% hawkweed damage. Dicamba and dichlobenil damaged 90% and 95 % of hawkweed rosettes respectively. This shows that these herbicides suppressed hawkweed growth early in the season compared to the control which had a 0. Using the ranking scale in Table 3.6, aminopyralid was ranked highest at 50 and untreated control and tribeneuron methyl had a 7.0. On 35 DAS, damage ratings were significantly different among treatments ($\chi^2_{(13)} = 41.0336$, p = <0.0001), aminopyralid, hexazinone + clopyralid and pyroxsulam + clopyralid had a 100% damage on hawkweed rosettes and based on the ranks obtained, aminopyralid had the highest rank of 45.5. Dichlobenil and a tank mix of hexazinone + clopyralid had a rank of 41.25. The least rank was observed in untreated control and tribeneuron methyl. On 56 DAS treatments was significantly different ($\chi^2_{(13)} = 42.8283$, p = <0.0001). A tank mix of hexazinone +clopyralid had completely killed hawkweed rosettes (100%). Aminopyralid and clopyralid (spring) treatment had a 95% control. Based on the ranks, aminopyralid and hexazinone + clopyralid had a 42.0 and the least rank was observed in untreated control and tribeneuron methyl. On 72 DAS treatments were significantly different ($\chi^2_{(13)} = 44.1566$, p = <0.0001) aminopyralid had a 100% control. Dicamba and dicamba +2, 4-D had a 90% control. A 15% control was observed in glyphosate. Based on the ranks, hexazinone + clopyralid had the highest of 48.50 followed by pyroxsulam + clopyralid. The least ranked treatments were untreated control and tribeneuron methyl (Table 3. 6). Blueberry stems were tolerant to herbicides sprayed.

Results above were similar across sites. Clopyralid sprayed in the fall can also be used to control *H. caespitosum* and dicamba alone or in a combination with 2, 4 –D are recommended for control of hawkweed species. Miller and Baldwin (1999) found that smooth hawkweed (*Hieracium laevigatum*) was best controlled with clopyralid which gave a 84 % control followed by a tank mix of dicamba +2, 4-D which had an 80 % control and dicamba at 68% control. The efficacy of aminopyralid and clopyralid (spring) in the control of *Hieracium caespitosum* was fairly consistent throughout the season on this site and these results are similar to those observed by Seefeldt and Conn (2011) where orange hawkweed was controlled to about 98% using aminopyralid. However, aminopyralid can only be used in non- crop fields and pasture. Although aminopyralid was sprayed in the fall and had the best control on hawkweed rosettes in our study, this is contrary to Wallace and Prather (2009) where aminopyralid at of 1.46kg/ha and 1.96 kg/ha were applied at the early fall senescence, fall rosette, spring rosette and bolting stage. Aminopyralid spray at the fall rosette stage had the lowest control.

Table 3.6 Treatment means and ranking values of the Kruskal Wallis test for damage ratings on *Hieracium caespitosum* in response to various herbicides (14, 35, 56 and 72 days after spray) in Mount Stewart 2. Values in parentheses are standard errors.

| | 14 DAS | | 35 DAS | | 56 DAS | | 72 DAS | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Damage ratings | Ranking [a] | Damage ratings | Ranking | Damage ratings | Ranking | Damage ratings | Ranking |
| untreated control | 0(0) | 7.0 | 0(0) | 7.0 | 0(0) | 7.0 | 0(0) | 7.0 |
| aminopyralid (fall) | 100[b] (0) | 50.0 | 100(0) | 45.5 | 95 (5.0) | 42.0 | 100(0) | 44.25 |
| clopyralid(fall) | 75(25.0) | 39.25 | 75(25.2) | 35.87 | 65(22.1) | 33.25 | 75(11.2) | 29.62 |
| clopyralid | 80(0) | 23.50 | 95(5.0) | 28.5 | 95(5.0) | 37.75 | 40(0) | 44.25 |
| dicamba (fall) | 90(10.0) | 47.12 | 90(10.0) | 39.25 | 80(8.1) | 36.25 | 90(5.0) | 32.5 |
| dicamba +2,4 D (fall) | 100(0) | 47.12 | 90(10.0) | 45.5 | 80(0) | 36.25 | 90(10.0) | 31.5 |
| dichlobenil | 95(5.0) | 27.25 | 90(5.7) | 41.25 | 85(5.0) | 33.5 | 45(5.0) | 35.75 |
| Iron hedta | 25(15.0) | 34.75 | 25(15.0) | 12.62 | 25(15.0) | 11.87 | 55(5.0) | 11.62 |
| florasulam+ clopyralid | 75(5.0) | 23.50 | 95(5.0) | 26.5 | 75(5.0) | 37.75 | 40(0) | 28.25 |
| glyphosate | 40(24.4) | 14.87 | 30(17.3) | 20.0 | 30(17.3) | 13.0 | 15(15.0) | 12.75 |
| hexazinone+ clopyralid | 95(5.0) | 30.62 | 100(0) | 41.25 | 100(0) | 42.00 | 45(15.0) | 48.50 |
| hexazinone | 40(0) | 23.50 | 60(0) | 16.0 | 65(5.0) | 19.37 | 40(0) | 21.75 |
| pyroxsulam+ clopyralid | 85(5.0) | 23.50 | 100(0) | 32.75 | 95(0) | 42.0 | 40(0) | 44.25 |
| tribeneuron methyl (fall) | 0(0.75) | 7.0 | 0(0) | 7.0 | 0(0) | 7.0 | 0(0) | 7.0 |
| p-value | - | <0.0001 | - | <0.0001 | - | <0.0001 | - | <0.0001 |

[a] Data were analyzed for each period separately using the Kruskal Wallis test
[b] Damage ratings was assessed on a scale from 0 -100

### 3.5.2 Hawkweed density

#### 3.5.2.1 Caledonia and Mount Stewart 1 2011

Weed density results of *H. caespitosum* on 14, 28, 59, 419 DAS were not significantly different in Caledonia (Table 3.7) although damage ratings were significantly different across the season (Table 3.3.). In Mount Stewart weed density of *H. pilosella* was significantly different on 14 and 28 DAS ($p<0.05$) (Table 3.8). On 14 DAS hexazinone ranked the highest followed by rimsulfuron (post), florasulam and clopyralid on the Kruskal Wallis ranking system. On 28 DAS hexazinone again ranked highest in hawkweed density. Regrowth of hawkweed rosettes was observed in all plots by 419 DAS (Table 3.8) Wallace et al. (2010) observed no decrease in *H. caespitosum* density 52 months after clopyralid application. Therefore, timing of herbicide application and duration of spray over the years could be crucial factors to effectively manage hawkweeds in lowbush blueberry fields.

Table 3.7 Treatment means and ranking values of the Kruskal Wallis test for weed density on *Hieracium caespitosum* in response to various herbicides (14, 28, 54 and 419 days after spray) in Caledonia 2011. Values in parentheses are standard errors.

| | Day 14 | | Day 28 | | Day 54 | | Day 419 | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Weed density ($m^{-2}$) | Ranking[a] | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking |
| untreated control | 28(16.6) | 19.7 | 17(13.5) | 20.1 | 12(6.2) | 19.1 | 18(9.2) | 22.2 |
| clopyralid(pre) | 15(3.4) | 16.2 | 2(0.8) | 17.1 | 2(1.1) | 7.7 | 12(2.8) | 17.2 |
| clopyralid(post) | 38(6.0) | 28.3 | 16(12.4) | 31 | 24(16.5) | 18.5 | 27(7.4) | 22.6 |
| dichlobenil | 8 (2.4) | 9.6 | 9(6.0) | 8.0 | 4(3.8) | 16.1 | 6(2.6) | 15.3 |
| florasulam | 39(6.8) | 30.1 | 46(10.4) | 32.5 | 18(7.6) | 37.2 | 27(4.2) | 28.5 |
| hexazinone | 32(10.2) | 31.3 | 34(9.6) | 27.2 | 37(15.3) | 31.1 | 34(10.4) | 31.1 |
| mesotrione(pre+ post) | 15(4.3) | 15.5 | 13(7.8) | 15.6 | 9(9.7) | 17.8 | 11(4.5) | 15 |
| mesotrione(pre) | 27(15.5) | 18.5 | 14(7.7) | 22 | 15(9.7) | 23.0 | 16(8.3) | 20 |
| pyroxsulam | 29(13.5) | 26.8 | 25(7.8) | 22.5 | 24(16.6) | 26.8 | 28(10.5) | 26.8 |
| rimsulfuron (pre) | 23(10.3) | 19.8 | 14(7.7) | 21 | 15(11.5) | 23 | 17(7.9) | 20 |
| rimsulfuron (post) | 36(9.0) | 31.2 | 26(12.6) | 30.5 | 35(16.5) | 26.8 | 32(9.8) | 28.5 |
| P value | - | 0.2017 | - | 0.1988 | - | 0.1142 | - | 0.6386 |

[a] Data were analysed separately for each period using the kruskal Wallis test

Table 3.8 Treatment means and ranking values of the Kruskal Wallis test for weed density on *Hieracium pilosella* in response to various herbicides (14, 28, 54 and 419 days after spray) in Mount Stewart 1 2011. Values in parentheses are standard errors.

| | Day 14 | | Day 28 | | Day 54 | | Day 419 | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking [a] |
| untreated control | 0(0) | 11.5 | 0(0) | 8.5 | 0(0) | 9 | 0(0) | 17 |
| clopyralid( pre) | 3(1) | 33 | 2(1.1) | 26.8 | 1(1) | 20.5 | 1.5(0.5) | 28 |
| clopyralid( post) | 2(1.6) | 11.5 | 4(0) | 20.7 | 0(0) | 32 | 0(0) | 17 |
| dichlobenil | 2(0.9) | 27 | 2(1.1) | 18 | 2(1.1) | 20.5 | 2(0.5) | 28 |
| florasulam | 2(0.9) | 16.8 | 2(0.9) | 18 | 2(1.1) | 17.2 | 1(0.5) | 28 |
| hexazinone | 8(0) | 35.7 | 2(2) | 42.5 | 0(0) | 17.7 | 3(0.5) | 17 |
| mesotrione( pre) | 1(0.5) | 33 | 3(1) | 15.2 | 2(1.1) | 26.2 | 2(0) | 28 |
| mesotrione( pre+ post) | 3(0.9) | 33 | 3(1) | 24 | 1(1) | 26.2 | 2(0) | 22.5 |
| pyroxsulam | 2(0.5) | 16.8 | 3(1) | 18.6 | 2(1.1) | 26.2 | 1(0.5) | 28 |
| rimsulfuron (pre) | 5(0.5) | 16.8 | 3(0.5) | 36.2 | 0(0) | 25.5 | 1(0.5) | 17 |
| rimsulfuron (post) | 2(0.5) | 11.5 | 3(1) | 18.6 | 1(1) | 26.20 | 0(0) | 22.5 |
| P-value | - | 0.0005 | - | 0.0062 | - | 0.2849 | - | 0.4041 |

[a] Data were analyzed separately for each period using Kruskal Wallis test

### 3.5.2.2 Culloden and Mount Stewart 2 2012

In Culloden, *Hieracium caespitosum* was the predominant hawkweed species and herbicides sprayed on Day 0 were not significantly different (p = 0.1086). On Day 212, effect of different herbicides were significantly different (p = 0.0017). Tribeneuron methyl significantly reduced the density of *H. caespitosum* and ranked highest in the Kruskal Wallis ranking system (Table 3.9). However, tribeneuron methyl was ranked lowest in damage ratings (Table 3.5). On Day 235 herbicide treatments were significantly different ( p = 0.0097), dichlobenil was ranked highest in hawkweed density and ranked low in damage ratings followed by glyphosate, hexazinone and a tank mix of hexazinone + clopyralid.

On Mount Stewart 2, *H.caespitosum* was found growing in fields On Day 0, herbicide treatments were significantly different (p = 0.0313), plots sprayed with Dicamba ranked highest on the Kruskal Wallis ranking system. (Table 3.10). On day 212 herbicide treatment were significantly different (p = 0.0002), glyphosate, tribeneuron methyl and Iron Hedta were ranked highest in hawkweed density. On day 235 herbicide treatments on the effect of hawkweed density were significantly different (p = 0.0046), tribeneuron methyl and glyphosate were ranked highest. The results from weed density do not correlate with the damage ratings obtained (Table 3.6). Seefeldt and Conn (2011) using aminopyralid and clopyralid on orange hawkweeds observed hawkweed density was lowest in their study, this is contrary to our results. Also it is important to note that during the collection of hawkweed density data, quadrats thrown within each plot could have fallen on bare grounds which could count as a 0 towards the weed density despite the fact that hawkweed rosettes could have been present in the plots.

Table 3.9 Treatment means and ranking values of the Kruskal Wallis test for weed density on *Hieracium caespitosum* in response to various herbicides (0, 212 and 235 days after spray) in Culloden 2012. Values in parentheses are standard errors.

| | Day 0 | | Day 212 | | Day 235 | |
|---|---|---|---|---|---|---|
| Treatment | Weed density ($m^{-2}$) | Ranking [a] | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking |
| aminopyralid (fall) | 0(0.25) | 30.2 | 1(0.5) | 16.6 | 18(7.2) | 18.2 |
| clopyralid(spring) | 0(0) | 4.5 | 0(0) | 6.5 | 2(1.1) | 13.5 |
| clopyralid(fall) | 7(6.4 | 25.8 | 0(0) | 13.6 | 18(11.2) | 13.5 |
| untreated control | 8(2.3) | 17 | 5(4.3) | 40.5 | 7(2.6) | 29.1 |
| dicamba (fall) | 0(0) | 25.3 | 1(0.7) | 6.5 | 12(5.1) | 23.1 |
| dicamba +2, 4-D (fall) | 0(0) | 34.2 | 2(0.9) | 13 | 20(6.6) | 25 |
| dichlobenil | 10(4.4) | 37.3 | 12(3.5) | 20.3 | 23(9.8) | 49 |
| Iron hedta | 5(1.6) | 17.1 | 3(1.2) | 15.1 | 7.2(2.6) | 32.8 |
| florasulam+clopyralid | 3(2.7) | 33.6 | 0(0.25) | 10.5 | 16(4.4) | 17.2 |
| glyphosate | 6(4.1) | 33 | 15(8.3) | 32 | 20(9.5) | 42.7 |
| hexazinone | 8(1.9) | 39.8 | 5(1.4) | 20.7 | 20(3.1) | 39.7 |
| hexazinone+clopyralid | 5.7(0.7) | 38.8 | 8(8.3) | 18.3 | 29(12.4) | 36.8 |
| pyroxsulam | 3(3.2) | 26.8 | 2(2) | 11.1 | 12(3.4) | 22 |
| tribeneuron methyl(fall) | 17(2.2) | 34.8 | 6(3.4) | 51 | 15(2.1) | 36 |
| P-value | - | 0.1086 | - | 0.0017 | - | 0.0097 |

[a] Data was analysed separately for each period using the kruskal Wallis test

Table 3.10 Treatment means and ranking values of the Kruskal Wallis test for weed density on *Hieracium caespitosum* in response to various herbicides (0, 212 and 235 days after spray) in Mount Stewart 2 2012. Values in parentheses are standard errors.

| | Day 0 | | Day 212 | | Day 235 | |
|---|---|---|---|---|---|---|
| Treatment | Weed density ($m^{-2}$) | Ranking[a] | Weed density ($m^{-2}$) | Ranking | Weed density ($m^{-2}$) | Ranking |
| aminopyralid (fall) | 0(0) | 20 | 1(0.5) | 12.5 | 11(4.2) | 16.2 |
| clopyralid | 1(0.45) | 26.2 | 2(1.4) | 20.7 | 16.7(7.2) | 22 |
| clopyralid(fall) | 2(2.7) | 40.8 | 4(3.7) | 21.1 | 17(7.2) | 21.6 |
| control | 9(2.7) | 22.3 | 4(3.7) | 46 | 12(4.9) | 42.8 |
| dicamba (fall) | 1(0.25) | 45.7 | 4.7(1.7) | 23.3 | 33.2(4.7) | 34.7 |
| dicamba +2, 4-D (fall) | 0(0) | 34.3 | 2(1.1) | 12.5 | 24(8.3) | 23.5 |
| dichlobenil | 10(3.4) | 29.8 | 7(2.8) | 44 | 19(7.3) | 34.5 |
| Iron hedta | 10(3.1) | 11.6 | 8(2.9) | 45.6 | 5(1.1) | 36.7 |
| florasulam+clopyralid | 0(0.25 | 30.6 | 0(0) | 16.1 | 19(5.1) | 12.5 |
| glyphosate | 9(2.7) | 22.3 | 4(3.7) | 46 | 12(4.9) | 42.8 |
| hexazinone | 3(1) | 20.8 | 5(2.1) | 31 | 13(5.9) | 34.2 |
| hexazinone+clopyralid | 3(1.8) | 14.5 | 1(0.7) | 25.3 | 10(3.7) | 17.2 |
| pyroxsulam | 0(0) | 28 | 0(0) | 12.5 | 1(1.1) | 3.7 |
| tribeneuron methyl (fall) | 17(10.1) | 24.6 | 17(6.8) | 44 | 15(4.4) | 46.5 |
| P-value | - | 0.0313 | - | 0.0002 | - | 0.0046 |

[a] Data was analysed separately for each period using the kruskal Wallis test

### 3.5.3 Hawkweed biomass

Herbicide treatments had no significant reduction on biomass of *H. caespitosum* in Caledonia (p=0.05), Mount Stewart 2 (p=0.8924) and Culloden (p=0.0509) therefore data not shown. The results obtained by Seefeldt and Conn (2011) on biomass of *H. aurantiacum* showed that aminopyralid spray also reduced its biomass this was contrary to our research findings. In our study, the dry weight of *H. caespitosum* after dicamba spray was less than dicamba + 2, 4- D. However, a study by Miller and Baldwin (1999) on smooth hawkweed (*Hieracium laevigatum*) using herbicide sprays of dicamba and dicamba +2, 4-D, recorded dry weights (g) of smooth hawkweed were 5.9 and 4.0 respectively.

### 3.5.4 Blueberry stem length, floral bud count and yield

None of the herbicides resulted in any significant difference in blueberry stem length, floral bud counts or yield.

## 3.6 Residual effects of recommended herbicides in lowbush blueberry fields

Degradation and adsorption of pesticides in soil are processes which will determine the impact on the environment. Pesticides are expected to remain on the soil surface to produce desired results and the ability to degrade into inactive materials *via* biological, chemical and or photochemical breakdown. Degradation of pesticides result in low toxicity level and adsorption ensures herbicides are retained where biological activity is expressed (Villaverde et al. 2008).

### 3.6.1 Hexazinone

The effectiveness of hexazinone depends on its residual properties. In sandy loam soils, its half-life is about 4 or 5 weeks and 5 % remaining in the following year (Jensen

and Kimball, 1987; Yarborough and Jensen 1993). Hexazinone leaches to lower levels in the soil although residue level remain high near the soil surface and this herbicide can be degraded microbiologically to a number of metabolites (Kubilus and Bushway 1998). Because hexazinone is water soluble ($33gL^{-1}$) and low sorption capacity, this further encourages its effectiveness in deep rooted perennial plants. However, this could cause contamination for ground and water surface (Jensen and Yarborough 2004). To reduce both ground and water surface contamination, best management practices were developed and they include: the use of alternative weed control strategy, granular formulation of hexazinone which could cause a reduction in leaching, proper use of calibrated and operated experiments and finally the use of low economically effective rates (Yarborough 1997a; Yarborough and Jemison 1997).

### 3.6.2 Clopyralid

Clopyralid can be found in the soil and surface water and it breaks down through microbial transformation and carbon dioxide is a transformation product. This herbicide is highly soluble in water and may leach into groundwater or as a run off in surface water. However when used according to the recommended rates and directions, it does not pose a risk to insects, small mammals, birds and aquatic organisms (Health Canada 2011).

### 3.6.3 Dicamba

Dicamba dissipates rapidly in soils with half – lives ranging from days to weeks and microbiological degradation is a major pathway under moist soil conditions. Dicamba leaches and is highly mobile in the soils therefore it has been found in rivers, ponds and farms (Menasseri et al. 2003).

## 3.7 Conclusion

To achieve a high level of control during the spring application, it is important for growers to scout their fields and spray herbicides on rosettes before the emergence of flower buds. The presence of flower buds on hawkweed rosettes is an indication that the initiation of primary stolons has begun which is responsible for the second generation. Hexazinone applied at an application rate of 1920g a.i/ha in the spring of the vegetative year was the only herbicide that suppressed *H. pilosella* for a short period of time. An application of clopyralid applied at a rate of 151.2g a.i/ha in the vegetative year and dicamba applied at 1104g a.i/ha applied in the fall of the reproductive year or the application of clopyralid as a single spray in the spring provided the highest level of control and reduction in the density of *H. caespitosum*. Dicamba is the recommended treatment based on lower cost of the chemical. An application of dicamba in the fall of the crop year followed by clopyralid in the spring of the vegetative year if the fall spray was ineffective will control the spread of *H. caespitosum* over a period of time.

# Chapter 4.0 Dose response of Meadow (*Hieracium caespitosum* Dumort) and Mouse ear hawkweed (*Hieracium pilosella* L.) using clopyralid and a tank mix of clopyralid + pyroxsulam in a greenhouse experiment


## Abstract

*H. pilosella* and *H. caespitosum* are perennial plants found growing in lawns, pastures, gardens and lowbush blueberry fields. A greenhouse study was carried out in two greenhouses in the summer of 2012 to determine the efficacy of different rates of two herbicide combinations (clopyralid and clopyralid + pyroxsulam) at two hawkweed growth stages (bolting and flowering) on both species. The interaction herbicide × timing × dose was significant ($p > 0.001$) in both plant species. Although there was no complete hawkweed death, the recommended application rate of 151.2 g a.i ha $^{-1}$ for clopyralid and 151.2 + 0.014 g a.i ha $^{-1}$ for the tank mix of clopyralid + pyroxsulam resulted in greater hawkweed damage when sprayed at the bolting stage compared to the flowering stage. The addition of pyroxsulam provided no additional benefit. Application rates between 37.8 – 151.2 g a.i ha$^{-1}$ of clopyralid applied on *H. pilosella* rosettes resulted in at least 80% damage whereas *H. caespitosum* had damage slightly over 70%. Additional research needs to be conducted in the field to see if the same or similar results can be obtained.


## 4.1 Introduction

Hawkweeds (*Hieracium* spp) are native to Europe and belong to the Asteraceae family. They are perennials with creeping stolons and fibrous root system. Flowers are orange or yellow and flower stems contain a milky sap when broken. They spread *via* stolons, rhizomes or auxiliary buds and grow in soils with low pH. Hawkweed species have been found growing in lowbush blueberry fields in Atlantic Canada including *H.*

*caespitosum* (Meadow hawkweed) and *H. pilosella* (Mouse ear hawkweed) found on Prince Edward Island (PEI). Growers speculate these weed species compete with blueberry stems for space, hinder harvest operations and flower heads can contaminate blueberry packs.

Studies have shown that the best group of herbicides to control these weed species on pastures and rangelands are the auxinic herbicides (group 4) which include clopyralid, dicamba, 2, 4-D and picloram ( Rinella and Sheley 2009). Application of clopyralid at rates of 270, 550 and 1,100 g ha-$^{1}$ resulted in a greater than 80% chlorosis of meadow hawkweed in a northern Idaho pasture (Miller et al. 1987). Synergism in weed control is described as two herbicides acting together and having a greater effect rather than herbicides acting individually and a tank mix of herbicides with independent modes of action rather than a single application could delay herbicide resistance (Diggle et al. 2003) and the potential of reducing the cost of herbicide application and the amount of herbicides been released into the environment (Kudsk and Mathiassen 2004). Seefeldt and Conn (2011) carried out a greenhouse experiment to evaluate the control of orange hawkweed in Alaska using different amounts (0X, 0.0625X, 0.125X, 0.25X, 0.5X and 1X) of aminopyralid, clopyralid, picloram, and tank mixes of picloram + chlorsulfuron, picloram + metsulfuron and triclopyr + clopyralid. At 13g a.i ha$^{-1}$ or higher, the application of aminopyralid reduced the biomass of orange hawkweed compared to the control at rates of 27g a.i ha$^{-1}$ and higher, the plants all appeared dead when visually evaluated. Application of clopyralid at 105 g a.i ha $^{-1}$ or greater controlled more than 50% of hawkweed and application rates of 210 and 420 g a.i ha$^{-1}$ killed all plants. At the rate of 280 g a.i ha $^{-1}$, picloram alone reduced the biomass of orange hawkweed at the highest

rate used and plants appeared visually dead. The three highest rates of triclopyr + clopyralid sprayed on plants all appeared visually dead and plant biomass ranged from 68% to 88% compared with the control.

Clopyralid, a selective herbicide and registered under the trade name Lontrel in Canada is used to control broadleaf weeds in lowbush blueberry fields. They enter the weeds through the leaves and roots and replace the natural occurring auxins which causes a disruption in the growth of plants. Pyroxsulam, a systemic herbicide registered under the name Simplicity in Canada inhibits the plant enzyme Acetolactate Synthase (ALS) which inhibit biosynthesis of amino acids however, this is not a registered product for control of weeds in wild blueberry fields but could potentially be registered if it controls or suppress the growth of these species.

## 4.2 Objective

The objective of this study was to determine the effect of clopyralid and a tank mix of clopyralid + pyroxsulam on two growth stages of *H. pilosella* and *H. caespitosum* on different days in a controlled environment.

## 4.3 Materials and methods

Two experiments were conducted in a greenhouse at Dalhousie University, Truro campus from May to August 2012. The first experiment included two growth stages (rosettes in the bolting stage and rosettes in the flowering stage) of mouse ear and meadow hawkweed that were transplanted from wild blueberry fields in Mount Stewart and Caledonia on Prince Edward Island (PEI) on 24$^{th}$ May 2012. Rosettes were grown in 4 inch pots with a surface area of 78.5cm$^2$ in a 1:1 peat: top soil mixture (Pro-Mix). A week after

plants were transplanted, they were sprayed using a handheld $CO_2$ backpack sprayer equipped with Teejet 8002VS nozzles at 35 PSI pressure.

Clopyralid and a tank mix of clopyralid + pyroxsulam at 0, 37.8, 75.6,151.2 and 302.4 g a.i $ha^{-1}$ and 0, 37.8 + 0.0035, 75.6 + 0.007, 151.2 + 0.014 and 302.4 + 0.028 g a.i $ha^{-1}$ was applied. This represents 0X, 0.25X, 0.5X, 1X and 2X were X is equal to the labeled rate. A untreated control was also included for comparison and all treatments included a non-ionic surfactant[1] (Agral 90) at 0.2% v/v to enhance uptake of herbicides. Experimental layout was a randomized complete block design with five blocks and the factors were herbicides (clopyralid versus clopyralid + pyroxsulam), growth stages (bolting stage versus flowering stage) and dose (0x, 0.25x, 0.5x, 1x and 2x). The experiment was repeated in a separate greenhouse. Plants were grown in a greenhouse and maintained at 23 C day/night temperatures with supplemental lighting in a 15/9hour day/night cycle during the experiment and watered daily. Data were collected on 8, 11, 15 and 18 DAS (days after spray). A visual damage rating scale of 0-100 was used in each pot where the value represents percent rosette damage and plants were blocked by location to reduce random variation.

### 4.3.1 Statistical analysis

Plant species were analysed separately and subjected to a three way factorial to determine if the interactions were significantly different using PROC MIXED in SAS, day was used as a repeated measure and Tukeys adjusted means for treatment separations ($\alpha$=0.05). The shoot biomass was also analysed using PROC MIXED in SAS.

## 4.4 Results and discussion

### 4.4.1The effect of different herbicides and doses on growth stages of *H. pilosella* and *H. caespitosum* in a greenhouse

#### *H. pilosella*

The results obtained from both experiments were similar therefore data from the two experiments were pooled. The herbicide × dose × growth stages interaction was significant (P <0.001), (Table 4.0). At the bolting stage, clopyralid application rates 37.8 g a.i $ha^{-1}$ to 151.2 g a.i $ha^{-1}$ caused damage between 85-88 % which was significantly higher than the control (Table 4.0). The results clearly indicate doses lower than the recommended rate effectively damaged hawkweed rosettes. Application rate of 302.4 g a.i $ha^{-1}$ had a lower hawkweed damage compared to rates between 37.8 - 151.2 g a.i $ha^{-1}$. In the flowering stage, application rate of 151.2 g a.i $ha^{-1}$ was required to achieve hawkweed damage of 51 %. Clopyralid sprayed in the bolting stage is more effective than the flowering stage.

At the bolting stage, the addition of pyroxsulam provided no added benefit (Table 4.1). In the flowering stage, an average of 60% hawkweed damage was observed at all the doses used in the experiment. Although there is no research publication on a tank mix of clopyralid and pyroxsulam to manage *H. pilosella*, a tank mix was marginally effective in suppressing hawkweed growth at the flowering stage compared to clopyralid alone.

#### *H. caespitosum*

The three way interaction effect of herbicide × dose × growth stages were significantly different (P <0.001), (Table 4.1). At the bolting stage, application rates between 37.8 – 302.4 g a.i $ha^{-1}$ had no significant difference in hawkweed damage. At the flowering stage,

the recommended application rate of 151.2 g a.i ha $^{-1}$ had a hawkweed damage of 38%. In a field experiment in Idaho, clopyralid was sprayed on 3 different growth stages (bolting, senescence and fall rosette stage) of meadow hawkweed using an application rate of 350 g a.i ha$^{-1}$. After a year of treatment, it was observed the highest control of meadow hawkweed was over 95% in the bolting stage, flowering stage was over 80 % and a poor control of less than 30% was observed in the fall spray (Wallace and Pranther 2005). Although only one application rate was used, the timing of spray on hawkweed growth stages gave similar but higher rates compared to our study. Similarly, an application rate of 0.17L ha$^{-1}$ of clopyralid were sprayed on meadow hawkweed in the spring and after 13MAT (Months after treatment), hawkweed rosettes reduced in the fields from a 30% to 6% compared to the control which increased from 27% to 36% (Wallace and Prather 2005).

Table 4.1 Percent control of clopyralid or a tank mix of clopyralid + pyroxsulam at different doses and growth stages of *H. pilosella* and *H. caespitosum* in a greenhouse experiment.

| Plant species | *H. pilosella* | | *H. caespitosum* | |
|---|---|---|---|---|
| **Growth stages** | **Bolting stage** | **Flowering stage** | **Bolting stage** | **Flowering stage** |
| **Herbicides** | | | | |
| **clopyralid** | | | | |
| **Doses (g a.i ha$^{-1}$)** | | | | |
| 0 | 0 e | 0 e | 0 h | 0 h |
| 37.8 | 85 a | 37 cd | 70 ab | 15 g |
| 75.6 | 85 a | 28 d | 76 ab | 29 f |
| 151.2 | 88 a | 51 bc | 73 ab | 38 ef |
| 302.4 | 51 bc | 52 b | 66 bc | 52 d |
| **clopyralid + pyroxsulam** | | | | |
| 0 | 0 e | 0 e | 0 h | 0 h |
| 37.8 + 0.0035 | 79 a | 64 b | 74ab | 54 cd |
| 75.6 + 0.007 | 86 a | 60 b | 69 ab | 52 d |
| 151.2 + 0.014 | 91 a | 62 b | 78 a | 43 de |
| 302.4 + 0.028 | 93 a | 64 b | 72 ab | 49 de |

For each plant species, same letters within column and across rows are not significantly different according to Tukeys (p= 0.05)

### 4.4.2 Shoot biomass

There was no significant difference between the shoot biomass of *H. pilosella* (P = 0.2578) and *H. caespitosum* (P= 0.1042) in all treatments at the end of the experiment.

## 4.5 Conclusion

The overall results indicate the best time to spray hawkweed rosettes is in the early spring or bolting stage. This theory is supported by the organizers of the King County Noxious weed control program in Australia, who believed herbicide application should be done in the spring or summer and not in the flowering period (Anonymous 2010a). A tank mix of clopyralid + pyroxsulam applied at 151.2g a.i/ha and 0.015g a.i/ha respectively tended to have a slightly higher hawkweed damage both in the bolting and flowering stage compared to a single application of clopyralid. Although this experiment was conducted in a controlled environment, results obtained from this study may not represent or reflect the results expected from a field research because of the variability in the environment.

# Chapter 5.0 Conclusion

## 5.1 Overview

Hawkweed species are found growing in pastures and gardens and have been found growing in lowbush blueberry fields. Growers speculate these weed species compete for resources and could hinder harvest operations. The overall objective of this research is to develop an integrated weed management plan that includes: (1) Understanding the biology of hawkweed species in blueberry fields using a temperature-based growth model; (2) Evaluation of both spring and fall herbicides for control of hawkweed species and; (3) Determine the effect of clopyralid and a tank mix of clopyralid + pyroxsulam on two growth stages of *H. pilosella* and *H. caespitosum* on different days in a controlled environment.

## 5.2 Overall conclusions

Hawkweeds are perennial plants and reproduce by seeds and vegetatively *via* stolons, adventitious root buds rhizomes and axillary buds. Two species found already established in lowbush blueberry fields are mouse ear hawkweed (*H. pilosella*) and meadow hawkweed (*H. caespitosum*). *H. pilosella* usually has one flower bud and a maximum of two, it increases its population exclusively by stolon production which bears daughter rosettes responsible for a second generation in the vegetative year and in the reproductive year when blueberry stem growth is higher, and it produces daughter rosettes from axillary buds. In contrast, *H. caespitosum* produces between 6-25 flower buds on a flower stalk. Stolon production is very low in both vegetative and reproductive year however, a higher number of daughter rosettes were formed in the axillary buds. Length of primary stolons from the base of *H. pilosella* rosettes was described using a Gompertz

model and maximum stolon lengths were predicted at 343 GDD and 510 GDD in 2011 and 2012 respectively. Emergence and peak of flower buds on *H. pilosella* was described with a Weibull model which predicted flower buds peaked at 363 GDD in 2011 and 560 GDD respectively. Emergence of primary stolons from the base of *H. caespitosum* rosettes could not be predicted because of the low number of stolons. Emergence and peak of flower buds on *H. caespitosum* was fitted to a Gaussian model. In 2011 and 2012, flower buds peaked at 762 GDD and 871 GDD respectively. From our greenhouse experiment, the best time to spray hawkweed rosette is before the emergence of flower buds for a spring application.

Herbicide screening trials showed hexazinone was the best herbicide for the control of *H. pilosella* in Mount Stewart 1 in the spring of the vegetative year although a regrowth of rosettes was observed in the season. In Culloden, where *H. caespitosum* was found growing, a spring application of clopyralid applied after blueberry emergence damaged about 55% of the hawkweed on trial sites. A fall application of dicamba provided excellent control in the management of *H. caespitosum* in Caledonia and in Mount Stewart 2. These results show herbicides sprayed in the fall translocate with the carbohydrate to the below ground parts and accumulates with the stored carbohydrate thus causing a delay or complete kill of perennial weeds (Qasem 2011).

To effectively manage these weed species, it is important for growers to scout their fields, an application of hexazinone or clopyralid should be sprayed in the spring of the sprout year for *H. pilosella* at 305 GDD and *H. caespitosum* at 105 GDD or an application of dicamba in the fall after fields are mowed. If *H. caespitosum* are found in small patches, they should be removed by hand or a spot spray application of dicamba to reduce their spread across the field. Lastly, equipment used in lowbush blueberry fields should be

cleaned after each use to reduce the spread by seeds into other fields where no hawkweed species are found.

## 5.3 Future direction

Hawkweed species are perennial plants and studies have shown they spread *via* seeds, although vegetative spread is the most common. Achene can spread by wind and germinate on bare sites (Wilson et al. 2006). Although no significant data were collected on these seeds, it would be important to understand their significance in lowbush blueberry fields. Flower bud emergence, flowering and emergence of primary stolons was fitted to models from only two sites both in the vegetative and reproductive year. It would be important if data from other parts of the Island are collected, improved upon and validated to ensure it can be used by not only growers on the Island but other places in North America were wild blueberry plants are grown. Additional herbicide screening trials using pyroxsulam and florasulam should be carried out to observe there efficacy in hawkweed control because these herbicides hindered the production of flower buds during the trials when applied alone.

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