THE INTRODUCED PLANTS PRESENT IN THE CHURCHILL MANITOBA REGION IN 2013 AND POSSIBLE FACTORS THAT CAN EXPLAIN THE REDUCTION IN SPECIES DIVERSITY FROM THE LAST SURVEY IN 1989.

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A THESIS SUBMITTED TO
THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTERS OF SCIENCE

GRADUATE PROGRAM IN GEOGRAPHY
YORK UNIVERSITY
TORONTO, ONTARIO

June 2014

Abstract

The number of introduced plants species in Churchill Manitoba has fallen from 104 to 36 between the sampling periods of 1989 and 2013 despite continued climate warming which is predicted by theory to allow for easier establishment of new species in harsh environments. My work suggests that introduced plants are, in general, favouring warmer, ameliorated sites, with higher average soil nutrition that have been disturbed by human activities. This work has found two novel and important differences from the 1989 survey in that continuous disturbance is no longer required for introduced species to persist, and one introduced plant, *Taraxacum officinale,* has begun growing in two undisturbed locations. Climate warming as well as the invasional meltdown hypothesis can explain these two new observations. The decline in introduced species diversity can in large part be explained by the removal of barley from grain shipments to the Churchill grain elevator, although the study was confounded by a low precipitation summer which could have impacted the number of introduced species that germinated and grew in 2013. The drop in introduced species diversity despite a warming climate is evidence that many of the plants recorded as occurring in Churchill were ecologically doomed populations only kept in existence through constant seed subsidies from the grain elevator.

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Introduction

My study asks whether the number of different introduced vascular plant species present in Churchill Manitoba in 2013, and their distribution has changed since the last survey in 1989. Furthermore I ask if select biotic and abiotic variables can explain the observed present day distribution of introduced plants.

1.1 What is an invasive/introduced species?

Because the literature on invasive species contains many different terms for the phenomenon of invasion I will define how my work uses different terms and the definitions I ascribe to.

The definition of what is an 'invasive', 'alien', 'naturalized', 'introduced', and 'exotic' species is an ongoing debate in the scientific community that has been unresolved since perhaps 1882 (Rejmanek 2002). Species invasion is defined in both popular and scientific literature as "organisms that cause significant and unwanted ecological, economic or human health impacts" (Ruiz and Carlton 2003, pg preface XI). Two problems with this common definition is that it does not indicate how an invasive species is ecologically different from a non-invasive one. The definition also requires a subjective assessment of the species' perceived harm to human interests. As an example of the problematic ambiguity, livestock in North America are non-native species that damage native ecosystems (Fleischner 1994), but are beneficial to human economic interests and so are not considered invasive despite qualifying ecologically.

The following is perhaps the most comprehensive definition currently available for species invasions:

“A biological invasion consists of a species’ acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population.” (Valery et al. 2008, p. 1349)

This definition however, requires expansion. By not referring to whether a species is occurring within or outside its historical range, the definition does not consider species invasion as a biogeographical phenomenon (Wilson et al. 2009) which theory and evidence suggest it often is (Callaway & Ridenour 2004). The term biogeographical is used because the species is itself not necessarily invasive but instead becomes invasive when introduced into a certain community in a particular place and time. Thus, according to theory, invasion is not purely a species trait but the result of a species X environment X community interaction. Recent experimental work supports this claim (Radford 2013, Jeschke et al. 2012)

Also, Valery et al.’s (2008) definition does not address species that have been brought into a new ecosystem, are able to establish, but have not yet, or do not, achieve ecological dominance. Species that follow such patterns are referred to in scientific literature most commonly as introduced (Lonsdale 1994), or naturalized (Richardson et al. 2000). The word ‘introduced’ conveys that the species is new to an area and some human action brought it. The state of being ‘naturalized’ occurs when a species has existed in the landscape long enough to become fully integrated into the ecosystem.

Problematically though, introduced species can become invasive, existing in low abundance for a time before becoming ecologically dominant. Or conversely, introduced species can achieve ecological dominance for a short time after introduction but eventually reach a stable equilibrium at greatly reduced population levels (Strayer et al. 2006) so whether a species is labeled invasive or introduced can purely be a function of when the observation was made and any designation may not hold true for future classifications.

The last term to be clarified is the difference between native colonizers, also called successional species (Connell 1977), versus introduced or invasive species. The difference is in the comparison of each species' historical range. A species establishing outside its historic range is introduced or invasive which is different than a 'native' species occurring inside its historic range but into a site it had previously been absent from. Both species can have similar temporal occurrences, such as immediately after a forest fire, but the term colonizer should be reserved for native species to avoid confusion. The clarification is necessary because 'colonizer' has been used in literature to describe both species invasions (Williamson 1996) and the difference between early and later community successional species (Connell 1977). To avoid any confusion this work defines ecological communities as "a collection of species occurring in the same place at the same time" (Fauth et al. 1996). The definition covers the differences between similar ecosystems with differentiation in species presence/abundance such that the same patch of land viewed at different points along a post disturbance succession would be considered different communities because each species may not be present at all time steps.

1.2 Introduced/invasive plant minimum requirements

For a plant to be able to be successfully introduced some broad criteria must be fulfilled. First, the environment must be within the physiological limits of the species. Thus, areas of harsh climate are predicted to be less affected by introduced species as it is less likely that a species will be able to survive. Climate is perhaps the most important factor limiting plant growth at the scale of landscapes(Pearson and Dawson 2003). It follows logically that edaphic conditions can be important at smaller spatial scales. If the soil lacks a required nutrient or has a toxic excess, and/or is unsuitable for rooting the plant will not be able to establish despite the climate being within the species habitable tolerance. For example a garden tomato that grows and produces mature fruit but cannot grow in any soils other than a carefully tended garden would not be considered established in the area.

The other major condition required for a plant to be successfully introduced in an area is the ability to form a self-propagating population (Staniforth and Scott 1991). I propose that should a population only survive through an external propagule source, continually subsidized by human activities, that species would not be considered established even if found in the landscape because cessation of the seed subsidy will cause that species to die out. Most introduced plant species can have their pollination needs met with generalist pollinators (Bartomeus et al. 2008) or can asexually reproduce either through self-fertilization, clonal reproduction, or expansion by vegetative growth (Kleunen 2007, Rambuda & Johnson 2004). An introduced specialist plant without its specialist pollinator will not be able to form a self-sustaining population because it will not be able to set seed.

Being able to survive the environment and propagate does not, however, separate colonizing species from introduced ones. How a species is able to successfully invade a region following introduction, especially with examples of invasive species with non-invasive sister taxa (Burns 2004, Muth 2006), is the ongoing, unresolved, investigational focus of invasion ecology. Invasive plants do tend to have common traits, tending toward fast growth and competitive advantages (Graebner et al. 2012). The excellent meta-analysis by Kleunen et al. (2010) found that the “performance related traits” such as physiology, leaf area allocation, shoot allocation, growth rate, size and fitness were significantly higher for invasive plant species occupying the same range as non-invasive plants (Kleunen et al. 2010, p 235); invasive plants are generally able to outgrow non-invasive neighbours.

Additionally, invasive plants tend to have originated in more variable environments as compared to related taxa (Pysek et al. 2009). A generalist species that occupies a larger range will have adaptations suited for a larger variety of climatic and community stresses as compared to a specialist species whose adaptations are focused on a narrower set of climate and community. A broader set of adaptations translates into a greater probability of being invasive in a novel range because the species may, by chance, already possess the traits it needs to prosper (Thompson et al. 1995).

An important concept when studying invasive species are realized and fundamental ecological niches (Connell 1961). The fundamental niche is the territory a species will occupy and resources it will consume in the absence of predators or competitors. The realized niche is the territory and resources used by the same species if predators, competitors and other species interactions are present and is typically smaller than the fundamental niche. In the case of facilitation the realized niche may expand beyond the fundamental niche due to positive species interactions (Callaway 1995).

1.3 Introduced and Invasive species and the Arctic

The historic, purveying, opinion in ecology was that Arctic environments were not at risk from introduced plants because of “great distances from source populations, relative lack of agriculture, low levels of human disturbance, and cold climates” (Carlson & Shepard 2007, p. 117). ‘Cold climate’ is a complex term that encapsulates cold temperatures, generally low amounts of precipitation, and a short growing season. All three conditions are growthlimiting and ones that native Arctic plants have had to adapt to (Bliss 1962, 1971). Introduced species from southerly climates were predicted to be unable to cope with an environment that was outside their range of tolerance. However, if the harsh climate was ameliorated, introduction would become more likely (Hellman 2007). The increased number of introduced species found in the Arctic (McBean et al. 2005, Smith et al. 2012 Usher et al. 2005) can be seen as evidence that climate change has begun to cause changes in Arctic plant communities. In Churchill

Manitoba previous researchers found all introduced plants within areas that had been modified through disturbance and inputs by the towns population and its industry (Staniforth and Scott 1991). The two locations with the most introduced plants were the dump (now decommissioned) and the grain elevator with no introduced plants found growing in areas undisturbed by human activity (Staniforth and Scott 1991).

Introduced plants are not unknown in the Arctic as they have been found in association with human settlements and areas under constant human disturbance (Rose & Hermantuz 2004, Staniforth & Scott 1991, Wein et al. 1992). The tight association of introduced plants with human areas demonstrates that human habitats are not comparable to climatically similar undisturbed areas. Plant community membership, microclimate effects from landscape modification, and soil chemistry are examples of attributes and conditions that would distinguish human disturbed and undisturbed sites. I propose that If the landscape and climate around a human disturbed area supporting an introduced plant colony sufficiently ameliorates due to climate change then it might be possible for those introduced plants to escape into undisturbed terrain.

In the last 10 years, the absolute association of introduced plants with human modified areas in the north appears to be giving way and allowing species to escape into the wild as demonstrated by self-sustaining populations occurring in areas not directly modified by human activities. For example, *Melilotus alba*, *Melilotus officinalis* (Conn et al. 2008), and *Phalaris arundinacea* (Carlson & Sheppard 2007) have escaped into the Alaskan landscape. In the boreal forest of Gros Morne National Park, Newfoundland, Canada, *Cirsium arvense* has been found wild and is altering the recruitment of *Abies* *balsamea* (Humber and Hermanutz 2011). In each case, the researchers determined that warming climate has allowed the introduced species to spread into the Arctic landscape. If climate change has increased the average temperature and total precipitation, and if introduced species are temperature and precipitation limited, an increase of both would be predicted to cause an increased ability to establish new populations or expand existing populations.

1.4 Invasion theory and climate

Invasion ecology has several theories to explain how some species are able to introduce/invade while others cannot. The most successful theories (Jeschke et al. 2012) are the novel weapon hypothesis (NWH) (Callaway & Aschehoug 2000), enemy release hypothesis (ERH) (Maron and Vila 2001), and invasional meltdown theory (IMT) (Simberloff & Von Holle 1999). The NWH states that an ecological community that has no experience (ecologically naïve) with a particular competitive strategy or adaptation cannot resist invasion from species that possess those have unprecedented means and/or methods to compete.

The enemy release hypothesis (ERH) states that a species moved from its original range into a tolerable new one will experience an increase in its realized niche due to a loss of predators, competitors and pathogens (Maron and Vila 2001). This new niche can even expand past the fundamental niche of the original range by access to new spaces and resources. For example the loss of a predator would free energy and resources that could go toward survival and reproduction. Kambo and Kotanen (2014) have found evidence for invasive plants profiting from enemy release by showing decreased herbivory at plant species' cold limited margin. There is some evidence that the 'climate envelope' (the range of climatic conditions the species can tolerate) for introduced species can expand if brought into a new range or environment (Broennimann et al. 2007), as predicted by the enemy release hypothesis. However, recent work suggests that such an expansion does not routinely happen for terrestrial plants introduced into a new area (Petitpierre et al. 2012) because most plants simply cannot exist outside their established environmental envelopes. The theory that a climate envelope will not meaningfully change between a native range and a new range is called niche conservatism (Pysek et al. 2009).

The IMT states that once an ecosystem becomes hospitable to an introduced species it is likely that more species will continue to successfully establish both due to the existence of a suitable environment but also by profiteering from the ecological disruption caused by prior invasion(s). An example for the IMT was found when introduced deer reduced the cover of native tree species which facilitated the growth of non-native trees (Relva and Simberloff 2010)

1.5 Soil Chemistry: is it limiting?

"[R]ealistic predictions of the future distribution of vegetation with respect to climate must emphasize the indirect effects of climate on resource supply."(Chapin et al. 1995, p. 709)

Bliss (1962) reported that plant growth in the tundra is generally nitrogen, limited as cold temperatures limit nitrogen mineralization. Nitrogen limitation in the tundra is different from more southerly terrestrial plants which tend to be phosphorus limited in accoCCAnce with the Redfield ratio of 106 moles C to 16 moles N to 1 mole P (Knecht and Goransson 2004). The Redfield ratio was originally used to describe marine phytoplankton but holds well enough in terrestrial systems to be used as a benchmark (Knecht and Goransson 2004)

The biologically available nutrients nitrate, ammonium, phosphorus, potassium, calcium, magnesium, iron, and also soil pH are all essential, and can be limiting, for plant growth. Deficiencies or excesses in any supply will cause decreased body condition (such as wilting), reproductive failure, and or death (Schulze et al. 2006).

Although each compound can be limiting, each species has its own uptake/saturation tolerances and limits. A long term field experiment in Iceland (Thorvaldsson et al. 2008) has shown that the commonly weedy species *Taraxacum officinale* and *Poa pratensis*, as well as others, generally respond well to fertilization but there is no one nutrient that will always benefit all species. Even within the same species the response to nutrients can be confounded by other variables. Tilman et al. (1999) found that the population of *T.officinale* in a temperate climate city park increased in number with the addition of potassium, while Cavieres et al. (2008) found a negative association between the presence of *T.officinale* and soil postassium in a high altitude study site when comparing between microhabitats offered by two different cushion plants.

Because introduced species are usually generalists who favour quick growth strategies (see section 1.2 on the general traits of introduced species) it is predicted that they would generally favour soils with easily accessible but not excessive nutrient pools (Daehler 2003). Thus, if distinct microsites harbour introduced plants in a landscape while visually similar neighbouring patches do not, a possible explanation could be that the soils that introduced plants are growing in are more nutrient rich.

1.6 Churchill, MB area and history

With the combination of ameliorated conditions and the likely absence of natural predators, an area undergoing climate change may be more likely to be invaded by new plant species. A place like Churchill, MB, is at even greater risk of plant invasions because introduced seeds are constantly being brought into the area as contaminants in grain shipments carried by the local railway to the associated grain elevator, which imports hundreds of thousands of tons of grain every year for international export via the port. In Churchill before it is loaded onto a ship the imported grain is cleaned of the husk (screened) and any other unwanted materials such as the seeds of non-agricultural plants. The screenings, a mix of compostable vegetable matter and introduced species seeds are then dumped. It is these screenings that are the primary source of introduced plant seeds in Churchill. Thus, introduced plant propagules are present, and constantly being reintroduced, waiting for the right conditions to germinate and establish local populations.

The Churchill Manitoba human population has decreased from several thousand to today's current population of around 800 (Statistics Canada 2012) due to the closure of its military base in 1979 ("Town of Churchill FAQ", 2013). The intensity of anthropogenic disturbances has declined in Churchill since the base closure. As far back as 1955 researchers have noted that military activity was a cause of major disturbance in the Churchill area (Ritchie 1956, Walker 1969) and its absence in the landscape has caused a drastic decrease in anthropogenic disturbance. However, despite the drop in human population between 1959 and 1989 there has been an increase in the number of introduced vascular plant species (Staniforth & Scott 1991). If disturbance has decreased but more introduced species are occurring, climate is the likely driver for introduced species establishment.

The primary source of introduced species in Churchill is the railway and the associated grain elevator that feed the port. Between 1979 and 1989 only wheat and barley were brought into Churchill via train for international export (Canadian Grain Commission 1979-1989) and Staniforth and Scott (1991) found that between 1971 and 1989, 59.5% of the total tonnage was barley (Staniforth and Scott 1991) . The high proportion of barley was considered important by Staniforth and Scott (1991) because they found that barley had a higher instance of weed seed contamination as compared to wheat crops (Thomas and Wise 1987 cited through Staniforth and Scott 1991).

1.7 Special history of the old dump

The old Churchill town dump ,which was closed in 2005, had the most introduced species in 1989 (Staniforth and Scott 1991), which is not a surprising result as the area was under constant disturbance and had a constant seed supply from grain screenings (discussed in section 1.4). The dump was shuttered in 2005 as a means to reduce summertime human/polar bear conflict as the animals would flock to the dump to eat the composting grain. Since the dump was closed in 2005, and its subsequent reclamation through the addition of soil to cap landfill pits, the disturbance regime has ended as well as the seed supply so any species remaining are either from a still persistent seedbank or are the offspring of existing/previous individual plants. The dump thus provides a setting where introduced species were at great advantage, benefitting from enriched soils from the screenings compost, no pre-existing plant community to compete with, and the raised topography (from being a filled land fill) that reduces the chances of water inundation which can drown roots and reduce nitrogen mineralization (Bliss 1962).

Introduced plant seeds escape the grain elevator when the imported grain is cleaned ('screened') of the outer husk and any other unwanted material such as the seeds of non-agricultural plants. The screenings are then dumped into composting heaps. The original dumping location was the old Churchill landfill until 2005 when it was closed. Alternative dumping locations that have been used are on port owned land, adjacent to the grain elevators, an illegal dumping operation that occurred south of the community gun range and lastly at the new town dump site. As of 2013 the new dump site is not fully operational. It was determined by previous work that grain screenings were both a source and an incubator for introduced plant seeds by offering “warm, moist, nutrient-rich substrates for germination and growth” (Staniforth and Scott 1991, p. 819). From the 1989 survey 18 species were deemed established, see Table 1.8.1, as evidenced by their ability to set seed and increase their distribution outside immediate points of seed source, the grain screenings and associated dumpsites. A complete list of plants found by Staniforth and Scott can be found in Appendix 2.1. I have excluded two species (*Taraxacum laevigatum,* the native dandelion species, and *Populus tremuloides* , trembling poplar) from considerations of the introduced species present in 2013 because both are native to northern Canada and have latitudinal ranges extending far more northerly that Churchill, MB. The reason for this discrepancy is that Staniforth and Scott were recording ‘weedy’ species which was a classical definition for introduced/invasive plants but not a robust one as it did not make a strong enough distinction between native and introduced plants.

Table 1.7.1 The established weeds of Churchill as determined by Staniforth and Scott 1991.

Family	Species	Common name
Asteraceae	*Crepis tectorum*	Narrowleaf Hawksbeard
	Taraxacum officinale	Common Dandelion
Amaranthaceae	*Chenopodium glaucum*	Oak-leaved Goosefoot
	Chenopodium leptophyllum	Narrowleaf Goosefoot
	Monolepis nuttalliana	Nuttall’s Povertyweed
Brassicaceae	*Camelina sativa*	Camelina
	Capsella bursa-pastoris	Shepherd’s Purse
	Descurainia sophia	Flixweed
	Erysimum cheiranthoides	Treacle Mustard
	Lepidium densiflorum	Common Pepperweed
	Neslia paniculata	Ball Mustard
	Thlaspi arvense	Field Penny-cress
Boraginaceae	*Lappula myosotis*	-
Caryophyllaceae	*Lychnis alba*	White Cockle
Poaceae	*Poa pratensis*	Kentucky Bluegrass
Polygonaceae	*Polygonum arenastrum*	Common Knotweed
Rosaceae	*Potentilla norvegica*	Norwegian Cinquefoil
Rubiaceae	*Galium aparine*	Goosegrass

The distribution of introduced species was restricted to human modified areas such as the refuse dumps, roadways and the townsite such that “no introduced species were found in the natural plant communities (salt marsh, wet tundra, dry tundra, beach ridge area, palsa area, polygon area, or in the boreal forest) “ (Staniforth and Scott 1991, pg. 816). It was also recorded that areas of previous human habitation reverted to native plant communities which led to the researchers determining that “continuous human disturbance is essential for the long-term survival of weeds in northern subarctic regions” (Staniforth and Scott 1991, p. 820)

1.8 Purpose and hypotheses

The purpose of my work was to identify all the introduced plants growing in Churchill, MB, in 2013, where those species are occurring and if the plants present have distinct soil nutrition and/or climatic requirements.

Because species cannot exist beyond their climate tolerances I suggest that minimum thresholds for heat and precipitation are important but also, the variability of species environmental tolerances could be significant predictors. The current theory is that species are more likely to establish outside their native range if that original space was large and environmentally varied (Pysek et al. 2009). The species from large ranges should have adaptations to survive a wide variety of climate and different biological communities and so should be more likely to survive in a totally new area.

My hypothesis is that the species still persisting in Churchill are more tolerant of climate extremes. Tolerance of extremes has a double meaning covering both the ability to survive harsh environmental minimum/maximum as well as persisting through conditions that deviate a great deal from the average condition across the entire species range. Based on the IMT and NWH if Churchill introduced plants have stunted native species neighbours that appear healthier without invasives the NWH would be supported.   If different introduced plants species tend to grow together in clusters, regardless of local plant community, and or the introduced species occur in areas no longer undergoing disturbance the IMT would be supported.

2. Methods

2.1 Study area climate

The climate of Churchill is Sub-arctic (Bliss and Matveyeva 1992). As calculated from Environment Canada weather station data, the average yearly precipitation is 537.4 mm. The average diurnal summer growing season (June, July and August) temperature is 10 °C while winter temperatures can drop below -50°C. Churchill's higher latitude location results in long winters and a brief summer fuelled by upwards of 18 hours per day of direct sunlight.

2.2 Vegetation

As of 1989, when the last study was conducted, 106 weedy (104 introduced see section 1.8) plant species had been observed or were recorded occurring in the Churchill area. The ratio of introduced plants to native ones (106:407) was similar to the Canadian total of 884:3269 (Staniforth and Scott 1991).

Churchill hosts 5 major vegetation community types as defined by their soil associations; sand/clay deposits, rock outcrop ridges, freshwater wetlands, plains, and gravel ridges (Johnson 1987). Each of these communities are tundra or tundra-like with high occurrences of moss, low-lying woody shrubs, and sparse/stunted tree cover. The wetland environments have increased occurrences of grasses and sedges and are more dominated by herbaceous species but woody *Salix* spp. are usually present. The distinct community types usually share common species such as *Chamerion* *angustifolium* (fireweed), *Vaccinium uliginosum* (bog blueberry), and *Salix reticulata* (snow willow) while deriving their personal character from rarer or more specialized species like *Saxifraga tricuspidata* (three-toothed saxifrage) in ledge communities or *Potentilla palustris* (marsh cinquefoil) in freshwater meadow pools; see Appendix 1 common plant communities.

2.3 Field sites

The work aimed to revisit locations originally sampled by Staniforth and Scott (1991) this included the road network of Churchill that extends from the pumphouse at the southwestern end to the Twin Lakes glacial kame at the far southeast extent. The highest priority was given to the five most invaded sites from the 1989 survey (Staniforth and Scott 1991) were the dump, grain elevator, metal dump and reclaimed barracks; see Figure 2.3.1.

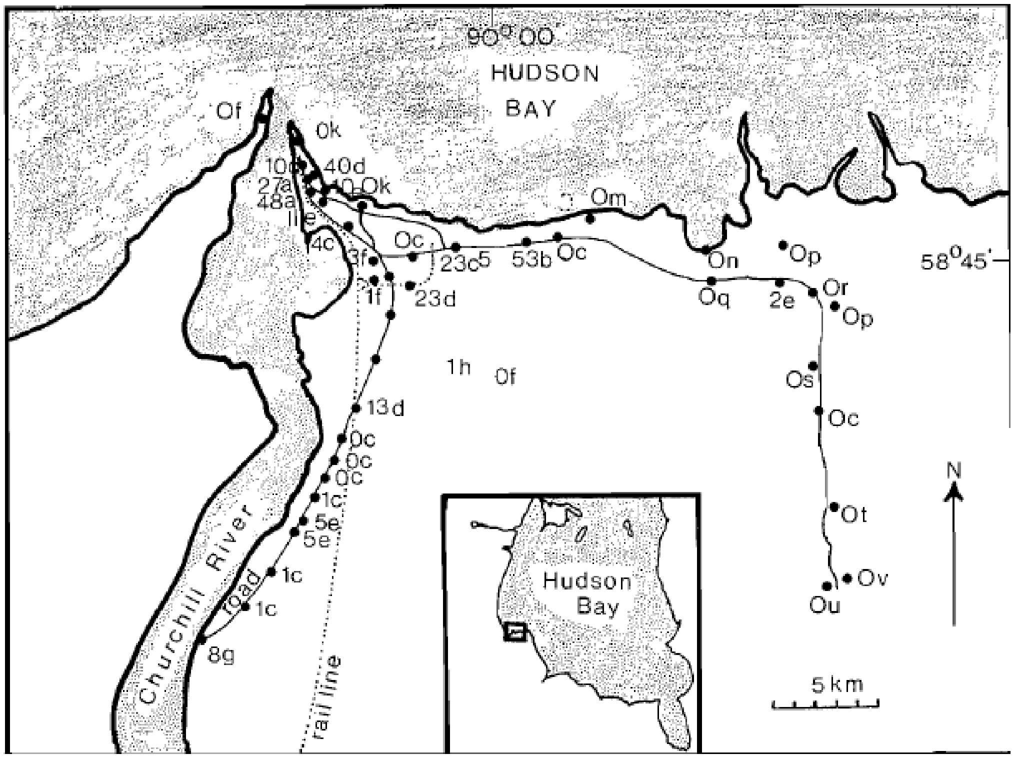


Figure 2.3.1 The sampling locations and number of species found by Staniforth and Scott (1991) The dump is 53b, the grain elevator is 47a and 40d, the metal dump is 23d and the barracks is 23c.

The grain elevator hosts 4 distinct plant communities: wetland, rock outcrop, beach and directly human modified (roads, gravel pads and dump areas). The level of invasion at each area will be recorded with percent cover methods, as discussed in section 2.4, to compare if one plant ecotype is more vulnerable to new species introduction than the others.

2.4 Measuring species quantities

My study used a simplified point-intercept method (Mueller-Dombois 1974) to calculate the frequency of species by recording every different species intercepted at the cross stitch of wires which subdivided my sampling quadrat. The method was used because counting individual plants is difficult or impossible and “frequency confounds the two parameters of density and dispersion” (Mueller-Dombois, 1974, p. 72). Cover was the chosen measure because “nearly all plant life forms, from trees to mosses, can be evaluated by the same parameter and thereby in comparable terms” (Mueller-Dombois, 1974, p. 81) and one procedure useable for comparisons of the amount of introduced species in different plant community types (see Appendix 1) was needed.

Two different quadrats were used. One had a square sampling area, 70 cm to a side, with an internal grid space defined by wires placed at 10 cm intervals. After the exclusion of the outer frame, to avoid sampling error caused by the frame matting vegetation into the quadrat that otherwise would have been excluded and thus inflating the species count, the quadrat gave 36 sampling points over 50 cm X 50 cm for a sampling area of 0.25 m^2. The other quadrat was similarly designed to the first but scaled to a square 5 m to a side with grid cross stitch every 50 cm for a total of 81 sampling points over 16 m^2. Because of the large size of the second quadrat the field equipment was actually two bars, each 1.75 m in length, strung together with 3 strings, marked and knotted at the needed increments, that was laid once then flipped over twice more to get the required sampling area. The frame sizes were chosen in accoCCAnce with Cain and Castro (1959, information retrieved from Mueller-Dombois 1974, pg 74). The large quadrat was used in areas with shrub cover taller than knee height while the smaller quadrat was used for areas without shrubs or trees which is in accoCCAnce with traditional sampling areas for particular vegetation types (Mueller-Dombois 1974)

All vascular species under the grid intersections were recorded and if no vegetation was present the land cover type was given instead; for example moss or sand. Non-vascular species, mosses and lichens, were not identified to species, and sedges were identified to genera in order to increase sampling effort. Species that occurred within the quadrat but were not recorded as occurring underneath a grid cross stitch were given the arbitrary value of 1% cover. Because multiple canopy layers are possible the total percent vegetation cover for some plots exceeded 100%.

The method described above is different from the original point-intercept sampling procedure because it does not record every instance of interception at a point; an example of which would be a single point with a shrub that has 6 intercepts with 2 more at the grass canopy layer. For my study such a location would be recorded as having 2 species. The change was made because my study was not asking if identical species had different point densities at different locations or whether the canopy structure was influenced by site. The focus of the study was to assess the biodiversity and relative proportion or different species over an area and so the procedure was simplified to decrease sampling time per plot and thus increase the number of areas sampled. The procedural simplification means that the simplifying assumption that identical species had the same average point density and canopy structure across different sites had to be made.

2.5 Goose Creek Road individual counts

For the Goose Creek road study only the number of individual rosettes for *Taraxacum laevigatum* (native) and *Taraxacum officinale* (introduced) were counted. This was done because it was a quick method that captured the number of individuals well. I am confident that one rosette translated into one individual because of onsite exploratory excavations.

2.6 Climate envelope differences between introduced species present in 2013 and the introduced species that were present in 1989 but not in 2013

The first source of information was for updated species names and life history, annual/biennial/perennial, from the United States Department of Agriculture Plants Database. The source for species specific environmental tolerance information was Natural Resources Canada Plant Hardiness Database (Plant Hardiness 2012), metadata from species specific temperature and precipitation based models. Data were retrieved for 75 of 106 species, which includes 27 of the 36 persisting introduced species. For the full list of species with data, and those without, see Appendix 3.3. I was not able to include data for the native species of Churchill because the database did not include enough information for even common native species to generate the needed metadata.

All modeling data were generated by Natural Resources Canada using ANUSPLIN modeling software; for information on the generation and fitting of data see McKenny and Pedlar 2007a, 2007b). The meta-data retrieved from the plant hardiness site were the 19 standard variables for the BioClim model ("Bioclim" 2014); see Appendix 3.1 for variable names and descriptions. The model uses the locations of recorded occurrences of plant species to set a minimum and maximum climate envelope conditions and then calculates a Z distribution for the intervening variable space. The model outputs the minimum and maximum climate tolerances for its 19 variables but also the standard deviation. The standard deviation is useful because it allows for the climate variability of home ranges to be compared between species; a species with a higher standard deviation of its climate envelope has a more variable habitat range

For each species, and every environmental variable, I extracted the minimum and standard deviation metadata (see Appendix 3.2 for all variable data) for processing in a generalized linear model (GLM) using a binomial family distribution and the logit link function. A GLM was chosen as the method for analysis because the responding variable was a binomial presence/absence data set which cannot be assessed with a linear regression. The analysis was run with R statistical package version 3.02 using the "MASS" package for GLM's.

Models were compared using Akiake's information criteria (AIC) which is a goodness of fit test that penalizes models containing extra terms such that if two models share predictive ability but one is more parsimonious that the other the simpler model will be favoured (Akaike 1974). Model results that returned infinite confidence intervals or impossible values were outright discarded. Eight models were generated for comparison, the null, the full, one achieved through backwards selection on the full, one from the forward selection of the null, a model whose parameters were selected via stepwise selection from the full and three *a priori* models. The first *a priori* model was made using only environmental variables that were significantly different, via a 1-tailed t-test, between the absent in 2013 but present in 1989 and present in both 1989 and 2012 populations, see Table 3.6.1 for the variable list. One tailed tests were used because of the hypothesis that persistent species occur in colder, drier, more climatically variable climate envelopes.

The second *a priori* model only used variables the authors of the plant hardiness ecological species maps used to estimate species distributions (“Plant Hardiness Data”, 2014); variables 1, 5, 6, 12, 18, and 19 (see Appendix 3.1 for variable names and descriptions). Because in Churchill the wettest quarter is also the warmest, and the driest quarter the coldest, unnecessary variables were removed from the environmental minimum and standard deviation combined data set as the first step to finding the last *a priori* model, additionally for the last *a priori* model all temperature seasonality variables were removed because in model runs they tended to return infinite confidence intervals. The variables removed are numbers 4, 9, 15, 18 and 19 (see Appendix 3.1 for variable names and descriptions).Once the extraneous variables were removed a stepwise selection was performed on the now reduced model.

Additionally, I performed a statistical check on the validity of my assumption that the present species had greater tolerance for decreased temperatures, and decreased precipitation, while still having larger climate tolerances (on average) via a chi-square test. The null hypothesis is that for the 38 variables, 19 from the species climate envelope minimum values and 19 from the envelopes’ standard deviation, approximately 19 would favour those vanished species by, on average, having larger standard deviations, colder temperatures and lower precipitation. Rejecting the null hypothesis would require non-random assortment of average values favouring the persisting species.

The plant hardiness data were deemed the best source to assess if absent and persisting introduced species had different environmental requirements because it was the most complete source for the most species. I performed searches in academic and non-academic sources that yielded information on frost free days required for reproduction, minimum growth temperatures, and minimum germination temperatures but I could not locate information on more than 30 species for any one variable which, after splitting information between absent and present species, did not leave a large enough sample size to conduct meaningful analysis. The plant hardiness data were also good for giving standard deviations of the species climate envelope which gives an idea of how broad its climatic requirements are. Most academic sources did not publish similar data on their measured characteristics.

2.7 Soil and Seed Sampling Locations

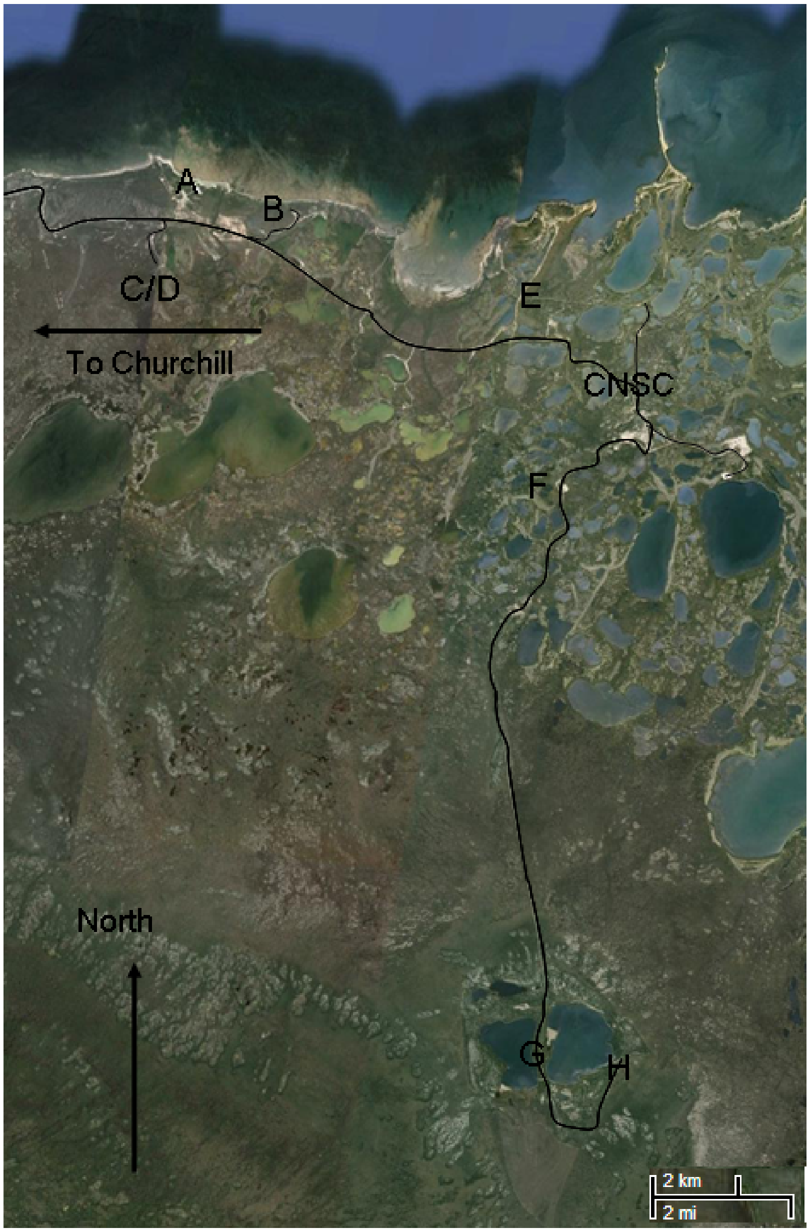


Fig. 2.7.1 Soil sampling sites, image source (https://maps.google.ca/)

I sampled soil at 8 locations. “A”, Coastal native community, a Dune community (Appendix 1) *containing Taraxacum laevigatum* , “B” Coastal Dune community(Appendix 1) (north of the “Golf Balls” derelict radar domes) containing

Taraxacum officinale, “C” & “D” Black Spruce-Larch Forest Community (Appendix 1) gun range on and off pile, respectively, from a grain screenings dump site, “E” Bird cove Lichen-Heath Community (Appendix 1) with no trees and dominant *Vaccinium uliginosium* cover , “F” Frisbee pond Black Spruce-Larch Forest Community *(Appendix 1)*, “G” Cliffords Cabin lakeside boreal forest community with dominant *Picea glauca* tree cover, “H” Twin Lakes Sandy beach also a lakeside Boreal forest community containing introduced plant species such as *Plantago major* and *Crepsis tectorum* with dominant *Picea glauca*. The black line that threads through the image shows the major roadways.

Sites B and H were chosen because they had populations of *Taraxacum officinale* that were growing outside areas of obvious human disturbance. These sites were deemed important because introduced species growing outside human disturbance was not observed anywhere else. For the coastal site the *T.officinale* patch was adjacent to the road, but extended about 50 m outward to where the beach began, there were no other tracks through the area and at all the other roadways introduced species abundance terminated within 2m of the edge of the roads’ base (road crush) material. Such a community containing a free growing introduced species was unique to my survey of the Churchill area and so it was deemed important to sample the soil nutrients at that site. To form the comparison, soil was collected at site A, west of the *T.officinale* community and also along a road and with a visibly similar plant community but without the *T.officinale*. The control location was selected because it was approximately the same distance from the Bay, had a similar vegetation community and was also along a roadway, and so seed introduction by vehicle, if that is the vector, was possible. At site

H over 70 individuals of *Taraxacum officinale* were found growing about 5 m off the road in an area dominated by *Salix* and *Betula* shrubs all taller than 2m. The site was considered more important than other roadways with introduced species because here the introduced plants were prevalent beyond the 2m visible disturbance of the roadway and the flowers occurred in what appeared to be unaltered soil. With the exception of the previously noted coastal population, all other introduced species occurred in soils that had been altered either through mechanical disturbance from human activities, roads and building sites are examples, or through the addition of organic material, the dump and other sites containing grain elevator screenings. The soil comparison site was near Clifford's Cabin (site G) because it again had a similar plant community, had a possible seed introduction vector from the road access, and was adjacent to a lake.

The third sampling location for introduced species was from the dump site south of the firing range, site C. The site was interesting because the pile made up of mixed local peat soil and the grain screenings had higher percent cover of introduced species than unmixed screenings piles. The surrounding area did not support introduced species so the nutritional effect of screenings introduction could be looked at by comparing samples from the mixed pile and the undisturbed peat soil.

The last two sites, F and E, were chosen to see if a progression from boreal forest through successively less tree cover showed consistent changes in soil chemistry as well as provide additional examples of possibly different soils types that did not support introduced plants.

2.8 Soil collection procedure

At each site 5 rough cubes, each of approximately 20cm to a side, were excavated from the surface layer. The top vegetation and duff layer were removed by hand and each sample was sealed in a 1 gallon (3.79 L) ziploc freezer bag. Samples were preserved by freezing, although a shipping delay between Churchill and Toronto allowed the samples to thaw. The five high volume samples were taken at each site both because the large number of tests to be run would require a large amount of material but also to increase the statistical power of the work by being able to run full replicates on subsites so as to capture the most representative picture for each area.

2.9 Chemical analysis techniques

Soil chemistry can be measurably heterogeneous over centimeter spatial scales (personal observation) and so my lab work performed as many replicates as possible to avoid the effect of outliers. The first procedure was multiple collections at one site as detailed above. The next procedure was to dry and grind, a required step for most of the extraction procedures listed below, all the soil needed for every test such that each subsample was well mixed. Lastly, each subsample was analyzed three times for each chemical test. Thus 5 samples with 3 replicates per sample were analyzed. The replicates were done to reduce sampling error by being able to average one subsite from repeated analysis. The nitrate/ammonium analysis could not have the 3 analyses per site so only 5 measures per site were done without the replicates.

Extraction and analysis techniques for every target element or compound was from Carter (1993). Ca, Mg, and K were extracted with the ammonium acetate procedure and the atomic absorption analysis was done on a Parkin Elmer Analyst 200. The determination of pH had to be modified for samples from sites H, F, E, and D due to those soils being comprised mostly of peat. Because the dried peat was easily able to absorb several times its own mass in water those samples had to have the ratio of dried soil sample to water increased from 1:2 to either 1:4 or 1:6 which translated into adding 40 or 60mL of de-ionized water instead of 20mL. The readings from the pH probe were adjusted by formula 1.

(1) $-\log_{10}$ ((20mL * 10 ^-pH reading)/actual volume) = adjusted pH

Soil phosphorus was determined with the sodium bicarbonate method and analysis was done with a Technicon autoanalyzer. Nitrate and ammonium were extracted and analyzed via the KCL method with nitrate quantities determined with a Technicon autoanalyzer. The ammonium samples, because York University does not have the necessary safety equipment, were analyzed by the University of Guelph in their lab services division using the same KCL method as outlined in Carter (1993).

The soil iron levels were extracted with the DTPA method with the atomic absorption analysis done on the Parkin Elmer Analyst 200. The method was the last soil analysis run and had to be heavily modified to accommodate peat samples, sites H, F, E, and D. The first modification was that the extractant volume had to be increased to

60mL from 20mL. The alteration was done because the dried peat was able to easily absorb the standard extractant volume such that much of the sample remained dry when a slurry is required for the subsequent sample shaking procedure. The second addition to the iron extraction procedure was that, after shaking, the samples had to be mechanically filtered before gravity filtration. Mechanical filtration was accomplished by wrapping the sample/extractant mud mass in acid washed 0.5mm plastic mesh and then hand squeezing to press out fluid. The pressed fluid was then gravity filtered as normal with fine pore filter paper. Centrifuging was attempted as possible method to separate the soil and extractant following shaking but was not effective even at 1500 g's. I do not recommend the DTPA extraction procedure for determination of available iron for peat soils. I found that the procedural modifications necessary greatly increase the time and effort required which due, to increasing complexity, could be a source of error. Also hand squeezing samples to separate the extractant from solid components is difficult.

2.10 Seed germination

It was observed in the field that introduced plants had distributions limited over short spaces, sometimes less than 1m, see Figure 2.10.1.

Figure 2.8.1 (Photo credit Alex Kent) Taken at the Churchill metal dump the right side of the frame is dominated by introduced species while the left is barren. The only apparent difference was the presence of grain screenings mixed into the soil on the right but absent from soil on the left.

Field observations from the old dump, metal dump, grain elevator, new dump and gun range suggested a correlation between the presence of compost material, screenings from the grain elevator, and the success of introduced plants. The goal of the experiment was to see if fertilization alone could increase the success of an introduced plant in germinating.

2.11 Seed Collection

Seeds of *Taraxacum officinale* were collected between July 21st- 27th, 2013, from individuals around the Churchill landscape. Major sites were along Goose Creek Road, the airport road, Churchill Townsite, and the colony along Hudson's Bay coast (site B for the soil collections). The population found growing at Twin Lakes (site H for soil collections) was not sampled because they had not matured sufficiently by the end of the collection period. Work was usually done before noon as the wind was calm, or absent, which made collection easier.

T.officinale was chosen as the test species because it was the only introduced species observed to occur beyond the bounds of human disturbance and it was the only introduced species that appeared to set mature seed in July. Other species have been recorded to set seed (Staniforth and Scott 1991) but those species appear to set seed later in the season.

Collection was done by delicately drawing fingers, cupped around the seed head, along the ends of the cypselae pappi such that if the light disturbance dislodged seed they would remain in hand. All collected seeds were stored in brown paper bags, which were then stored in 2 L re-sealable freezer bags along with 2 cups of white rice to absorb any excess moisture. The freezer bags were then stored in a standard home use refrigerator, approximately 3°C until use in the first week of November 2013.

2.12 Growth chamber setup

The size of the growth chamber allowed for the planting array to be crafted out of three, 2 inch thick (5.08 cm), 8 inch wide (20.32 cm) , and 40 inch long (101.6 cm) untreated pine boards. Individual planting cells were hand-drilled with a 1/2 inch (1.27 cm) bit to an approximate depth of between 1-1.5 inches (2.54 – 3.81 cm). Holes were placed 1/2 inch (1.27 cm) from the board edge and every inch thereafter so that 7 cells were cut along the width of the board, and 39 cells along the length for a total of 273 cells per board, 819 totals cells (Figure 2.12.1)

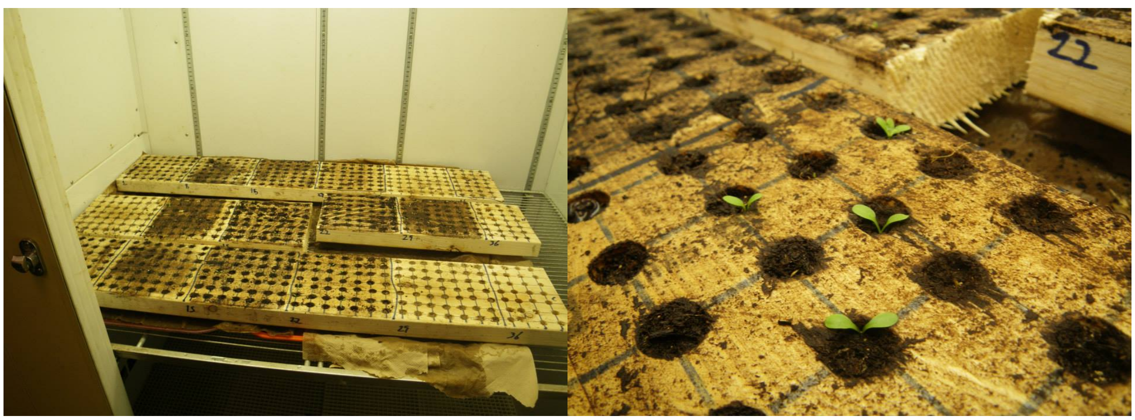


Figure 2.12.1 Left: the completed planting array in the growth chamber. Right: Seedlings growing in the ½ inch (1.27 cm) bore holes packed with the 8 different soil types.

The control group was made by filling a 7X7 block of cells with soil collected in Churchill from one of the soil sampling locations (A, B, C, D, E, F, G, and H). The treatment group was constructed the same way such that the experiment used 784 cells in total. Each cell had one *T. officinale* seed planted at a depth approximately equal to the length of the seed; about 1 cm.

The experiment was started on November 6th, 2013 and was watered to soil saturation every Monday, Wednesday, and Friday until the experiment concluded on November 27th, 2013. Fertilizer was applied, according to the manufacturer recommendations of 1 teaspoon to 1L of water, on the 1st, 7th and 12th day of growing. The number of seedlings present each group was recorded before each watering.

The growth chamber was set to give 18 hours of continual sunlight, reach air temperatures of 13-15°C during the day and drop to 10°C during the 6 hour night. The temperature data used to set the growth chamber conditions were obtained from the Environment Canada database for Churchill (Historical Climate Data). July average readings from 1997 until 2007 were used because the recent climate is known to have warmed significantly from historical averages (Ruhland et al. 2013). Light levels were 74.4 μmol/m^2/s as measured by a photosynthetically active radiation (PAR) sensor and was delivered from combined incandescent and fluorescent light bulbs.

For the experiment I chose “Miracle-Gro® All Purpose” a 24-8-16 fertilizer. I chose the high nitrogen, moderate phosphorus and high potassium fertilizer for the experiment because analysis of available soil nutrients from Churchill revealed significantly higher levels of those three nutrients in sites that supported introduced plants.

A confirmation that experimental procedures appropriately replicate field conditions would be if the soils supporting introduced species under field conditions had higher germination of *T.officinale* than the group of soils not supporting introduced species. A positive result for the experiment would be if the application of fertilizer increased *the T.*officinale germination.

2.13 Microclimate effects: Berm at old dump

An atypical land feature at the old Churchill dumpsite is a man made hill on the east side of its northern access road. The hill has flat faces rotated about 20° east of true north, hereafter faces are referred to as cardinal directions, as well as a flat top; see Figure 2.13.1 for an aerial view of the hill as well as the mid-summer sun exposure.

Figure 2.13.1. Mid July sun exposure at the old Churchill dump. The central feature, surrounded on three sides by light grey is the berm. Reading clockwise from the teardrop map marker the line oriented at 2 o'clock is the dawning sun horizon position. The line oriented at 6 o'clock is the solar noon position and the last line is the setting sun horizon position. The width of the pale crescent indicates the amount of sunlight received. Image retrieved from "www.suncalc.net".

The site was chosen to investigate whether differing levels of sun and wind exposure, which are effected by aspect, influence the introduced plant community. If introduced species have higher amount of ground cover in areas with less exposure then evidence would exist that climate is playing a role in the distribution of introduced species in the Churchill landscape. The null hypothesis would be that climate is not determining the introduced species ground cover in Churchill. The berm, by virtue of being a constructed feature, allows for my study to control for any successional effects by having a uniform community age. The soil nutrition should also have been consistent for all subsites with the berm because discreet patches of vegetation, while the norm in Churchill, and discrete boundaries for introduced species had been observed through the study, no plant community discontinuities were seen on the berm.

The wind predominantly comes from the northeast off of Hudson's Bay exposing the northern hill face the most and the south the least. The north and west faces have the least amount of sun exposure while the south and east have the most. The top face is assumed to have the average values of both wind and sun exposure. Because of those exposures listed the south face is predicted to have the greatest amount of introduced species. See Table 2.13.1 for a conceptual ranking of the different hill faces where a lower rank sum translates into a less exposed area.

Table 2.13.1 Exposure values for the Churchill old dump berm with low values representing colder areas and higher values warmer locations. A lower sum is predicted to have an increased introduced species cover due to an ameliorated environment.

Face	Wind rank	Sun rank	Sum Rank
North	1	1	2
West	2	2	4
Top	3	3	6
East	4	4	8
South	5	5	10

Each side of the hill, for a total of 5 subsites, was sampled 20 times for % cover with a 50 cm square quadrat with 36 grid intersection sampling points. Sample sites were chosen randomly by blindly placing a quadrat 10 paces away from the last sampling location with the first site being chosen at the nearest corner of the face to where I currently stood. Sampling also recorded the vegetation height to the nearest cm taken in the middle of the quadrat. The vegetation height was recorded because field observations showed that badly wind exposed plants had stunted stature, thus if one face was shorter than the other it may be experiencing more severe wind exposure. Native species were not recorded due to time constraints.

2.14 Goose Creek Road and test of effect of snow depth

To test if snow depth has an effect on introduced species establishment, the number of individuals of introduced plant species, occurring in randomly placed quadrats were recorded along Goose Creek Road. The roadway was chosen because conversations with locals revealed that the presence of tree cover adjacent to the road caused deeper snowdrifts to form as compared to areas without trees. Snow depth is known to have a determining role in alpine plant communities (Rixen et al. 2008, Körner 2003). Also, since the road is a fairly uniform substrate (gravel, sand and road crush) confounding results from differences in soil should have been minimized.

The sampling was done with a 1.5m X 5m quadrat laid lengthwise parallel to the road and deep enough into the shoulder such that long edge of the sampling area nearest the road centre was past the start of vegetation growth.

Within the quadrat all rosettes of *Taraxacum laevigatum* (the native dandelion) and *T.officinale* (the introduced dandelion) were counted to give a measure of rosettes/7.5 m^2. To calculate the number of stems in 100 m^2 the counted number of rosettes would have to be multiplied by 13.33. Quadrat placement was done randomly at 40 treed and untreed roadside locations. While traversing the length of the road, if any *Taraxacum (*native or introduced) were observed, the first quadrat of a sampling group was placed within the patch. Subsequent quadrats were placed in alternating pattern on different sides of the road with no two quadrats being within 20 paces of one another. For example while traveling south, a patch of *Taraxacum* was noticed on the roads west shoulder. The quadrat was then laid within the patch and all rosettes of both target species were counted as well as the UTM coordinate recorded. The next quadrat was then laid 20 paces further south and on the east side of the road and the count procedure repeated. The procedure was repeated until no *Taraxacum* were captured by the frame at which point searching for a new patch would begin. If other introduced plants occurred in the quadrat their presence and number of stems were recorded.

The data from the survey were analyzed with a chi-square test to see if tree cover had an effect on the number of introduced, and native species present.

2.15 Seed limitation

Local level introduced seed limitations was assessed by observing whether introduced plant communities diminished gradually, indicating that seeds were travelling from a parent, or stopped at apparent ecological borders which would suggest that seed spread was not limiting to the growth of populations.

Landscape level limitation was investigated by determining the amount and type of agriculture products received by the Churchill port for oceanic export as reported by the Canadian Grain commission. If the volume, type or timing of deliveries changed then evidence might exist that the introduced plant seed rain has changed between 1989 and 2013.

3.Results

3.1 Presence of introduced plants in 2013

Fig 3.1.1 The number of introduced species present in 1989 (first number) and in 2013 (second number) for Churchill MB and the areas surrounding it. Map baselayer retrieved from http://maps.google.com .

In total 35 introduced species were found around Churchill in 2013; see Appendix 2.2 for species by location, which is a decline to 34% of introduced plant species diversity recorded by Staniforth and Scott (1991) . The most species rich area was the old dumpsite, followed by the vegetated area east of the grain elevator (Figure

3.1.1). The clear majority of sites had fewer introduced species than recorded in 1989 (Staniforth and Scott 1991) and some sites having reverted to entirely native communities (Figure 3.1.1).

The old dump, closed in 2005, supported the highest percent cover of introduced species, in some places greater than 100% cover. The old dump was one of two sites where human disturbance has ceased, the other being the former location of the military barracks which had been partially reclaimed with the demolition of all buildings and infilling of the foundations. The recycling station is a new site not sampled by in 1989 (Staniforth and Scott 1991) and it supported 6 different introduced plants. At the southeast end of the road network two other sites, not in the 1989 survey (Staniforth and Scott 1991), were sampled. At Clifford's Cabin 1 introduced *Rosa* species was found but based on observations of the property it is likely that the specimen was an escapee from an old greenhouse.

Figure. 3.1.2 The left half is a plant community on the south side of the old dump and has about 70% introduced species ground cover. The right of the image is a natural *Salix* community and supports 0% introduced species ground cover. A thin strip where only stunted vegetation grows exists between the two zones. Image credit Alex Kent .

With two exceptions, (sites B and H from the soil sampling work and labeled Coast and Twin lakes beach respectively on Figure 3.1.1) no introduced plant was found growing in areas that were not presently, or had historically, been disturbed and modified by human activities. The distance over which an introduced community transitioned into a 100% native was usually about 2m but was often less (Figure 3.1.2).

Fig 3.1.3 This tire track runs through and out from the old Churchill dump. Despite the disturbance which cleared the original flora and a seed source form the adjacent introduced species populations no introduced plants were observed growing on or near the area but native species were beginning to colonize the area. Image credit Alex Kent.

Even in areas that were mechanically disturbed, supported no native aboveground vegetation due to the disturbance, and were adjacent to areas with predominant introduced species populations no introduced species migrated beyond existing borders between native and introduced plant communities (Figure 3.1.3).

3.2 The fate of established species

Sixteen of eighteen of the established plant species from 1989 (see Table 1.8.1) were still widespread in 2013 and 17 of the 18 still occurred. *Camelina sativa* could not be found and the distribution of *Lappula mysostis* has collapsed from common to almost extirpated. Only two individuals of *L. mysostis* were, found one within the Churchill Town limits and only because Parks Canada staff contacted myself asking for help in identifying a strange plant they had found. The other individual *L. mysostis* was found inside the old Churchill dump. The other 16 species remained the most abundant of the introduced species.

3.3 Climate results

Using regression analysis, the annual average precipitation for the years 1932 to 2012 has been increasing at an average rate of 1.56 mm/year (data are normally distributed, Shapiro-Wilks test, $W = 0.9707$, $p > 0.05$, R^2=0.107, $F = 8.507$, $DF = 1$, $p < 0.05$, Figure 3.3.1)

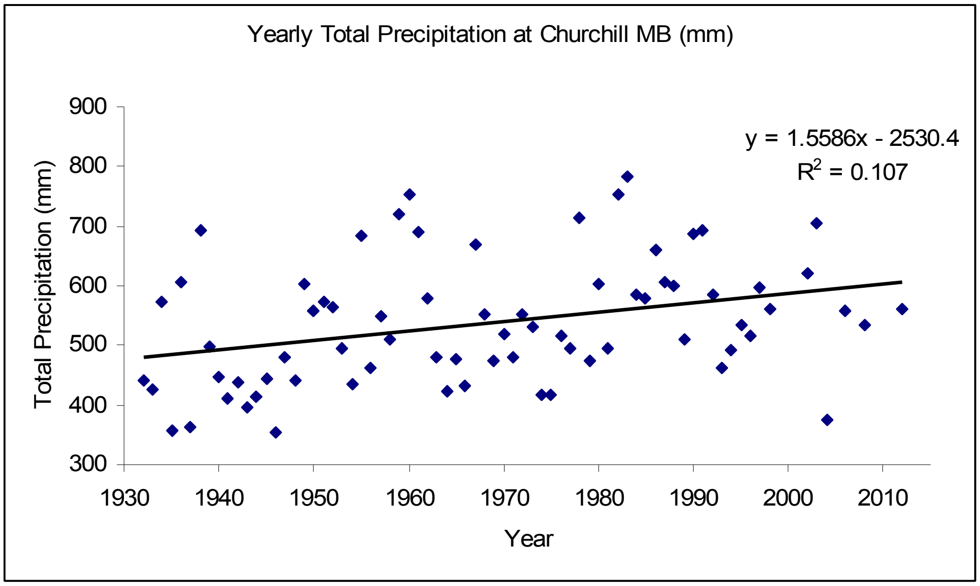


Figure 3.3.1 The increasing trend of average precipitation for Churchill, MB, $p<0.05$

An approximate 25 year cycle in total yearly precipitation, observed from 1930 onward, loses coherence around 2004(Figure 3.2.2).

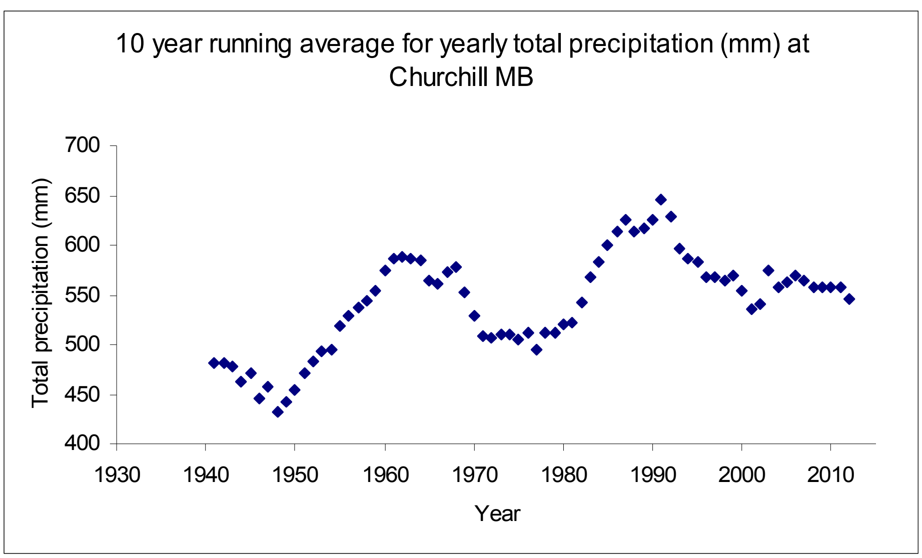


Figure. 3.3.2 The pattern of precipitation at Churchill, MB.

The yearly data were very noisy so the 10 year running average was used to look for multi-year trends, beyond the significant increase (Figure 3.3.1) that may not be immediately obvious looking at unprocessed data. Figure 3.2.2 was created by calculating the 10 year running average such that the first point at 1941 is the average total precipitation between 1932 and 1941. The decision to place the data point at the end of the averaged period was done because I wanted to say that the data represented one 10 year history instead of one 5 year history and 5 year future.

Another climate trend over the last 80 years is that the mean temperature of the growing season (June, July and August) has seen a significant increase of 0.013 °C/Yr (data are normally distributed Shapiro-Wilks test $W = 0.9799$, $p > 0.05$; $R^2 = 0.071$, $F = 7.326$, $DF = 1$, $p < 0.05$, Figure 3.2.3) Data are for 1932 to 2012.

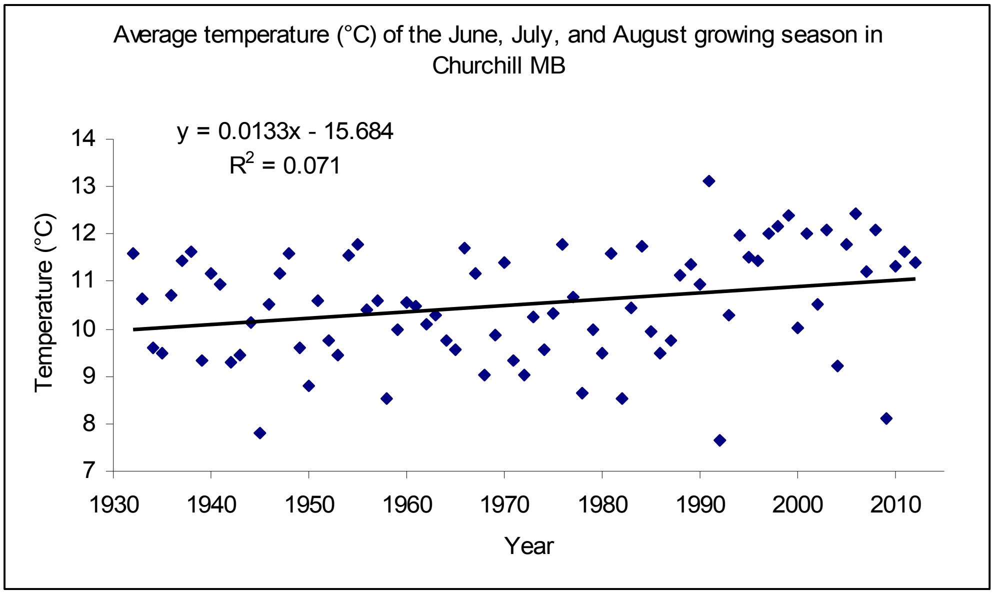


Figure 3.3.3 Average temperature trend for the Churchill summer growing season of June, July, and August.

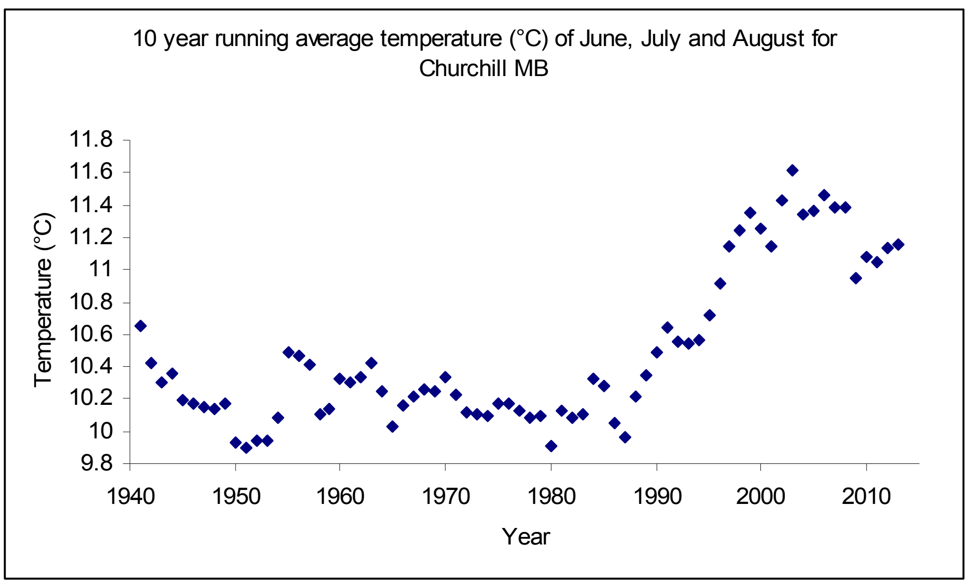


Figure 3.3.4 The pattern of average growing season (June, July, and August) temperature at Churchill, MB

The 10 year running average of summer time temperature (Figure 3.2.4) shows an approximate 1.2 °C increase from historical averages. However the increase appears to come from less variability in temperatures after 1990 as evidenced by the fewer number of low temperature readings in figure 3.3.3 after 1990.

Between the 1930s and early 1990s the average growing season temperature remained consistent, only varying by approximately 0.75 °C but after the early 1990's the average growing season temperature spiked upward by about 1.2 °C from 10.2 to 11.4 °C. My temperature findings are consistent with those of other researchers (Rühland et al. 2013) and a similar trend is observable for yearly average temperatures (data are normally distributed Shapiro-Wilks test W = 0.9757, $p > 0.05$, $R^2 = 0.1206$, F = 9.872, DF = 1, $p < 0.05$, Figure 3.3.5 and Figure 3.3.6 for the 10 year running average). The slope of the annual average temperature regression (0.0178 °C/year is greater than the summer only value (0.0133 °C/year) showing that the largest warming is happening in the winter season.

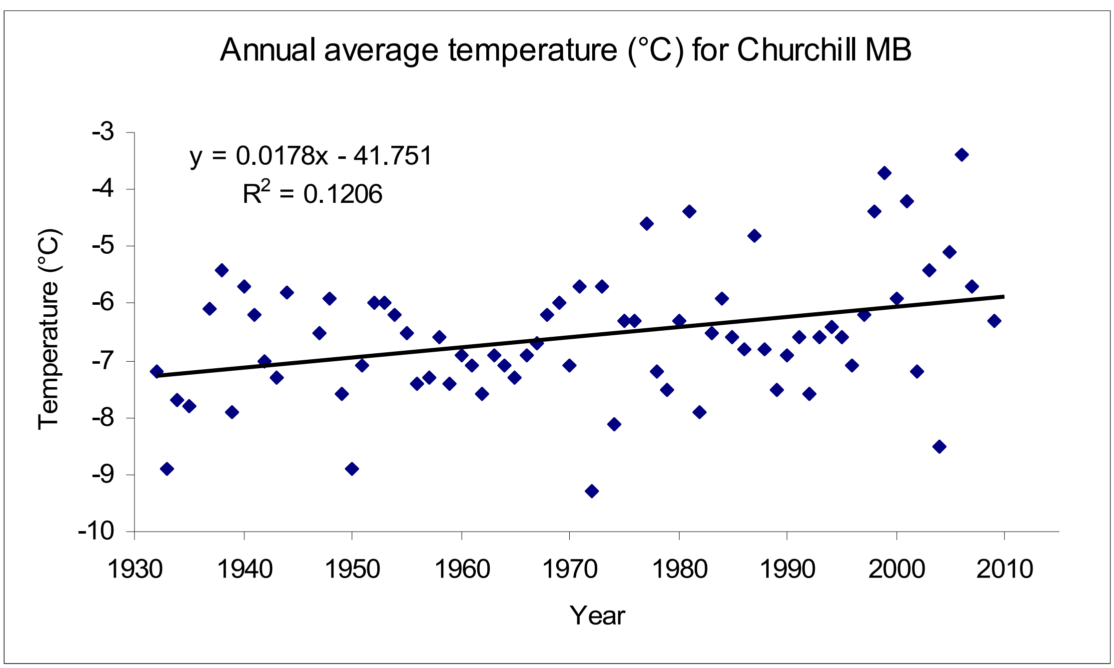


Figure 3.3.5 The annual average temperature at Churchill, MB

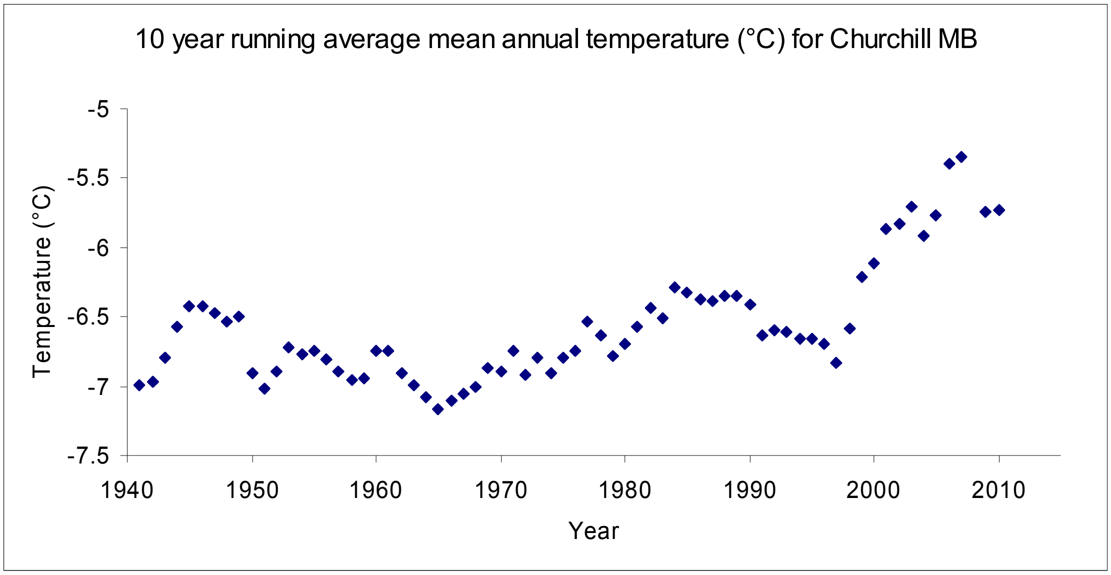


Figure 3.3.6 The 10 year running average annual average temperature at Churchill, MB

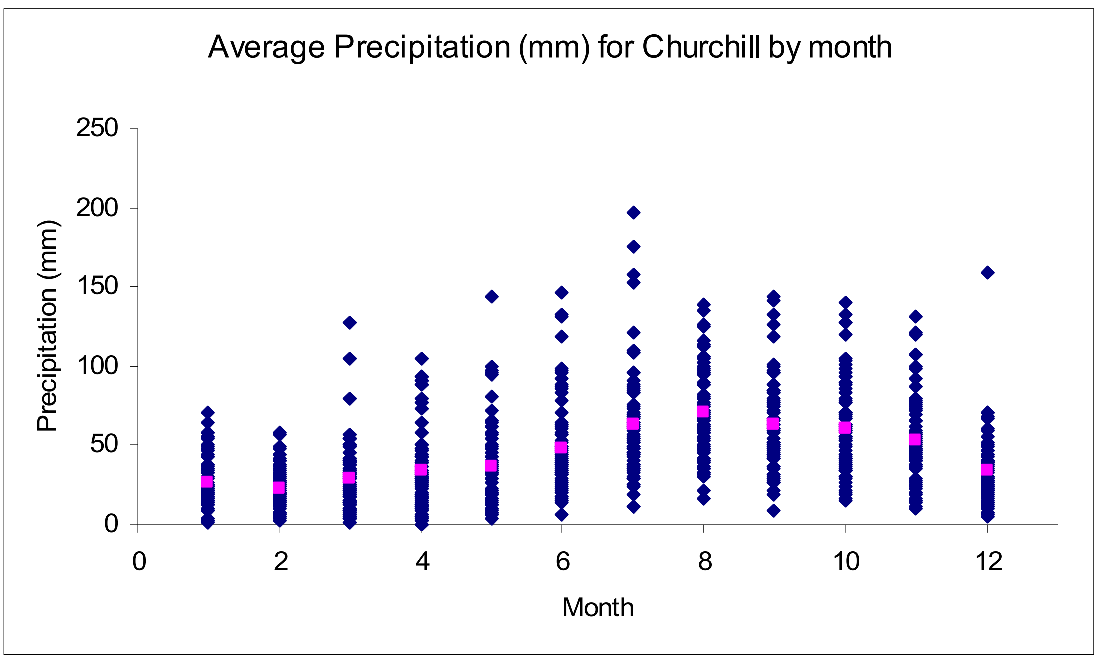


Figure 3.3.7 The average precipitation values by month for Churchill. Light coloured dots are monthly averages using data from 1931 until 2010. August has the most precipitation followed by July and then September.

The increase in growing season temperature coincides with the average precipitation values by month for Churchill (Figure 3.3.7.).

3.4 Levels of invasion between grain elevator, Goose Creek Road , old dump, and seaside introduced plant community

The dump has remained the most invaded site and those areas sampled had an average introduced species cover of 58.61 SE % = 27.64%. The grain elevator has 4 distinct ecotypes: wetland, industrially disturbed, rock outcrop and beach, but only wetland and industrially disturbed areas supported introduced species. The percent cover of introduced plants at those sites were 12.82% SE = 14.95% and 3.16% SE = 2.41% respectively. The coast that supported introduced plants had an average introduced plant cover of 8.47% SE=4.4%.

3.5 Seed limitation

No evidence for seed limitation at a local level could be observed as populations of introduced species were found to abruptly cease over distances of only a few metres or less and seeds, especially windborne ones, have larger dispersal range. Pollinator visits were observed (Figure 3.5.1) and several species were recorded producing seed in previous work (Staniforth and Scott 1991)

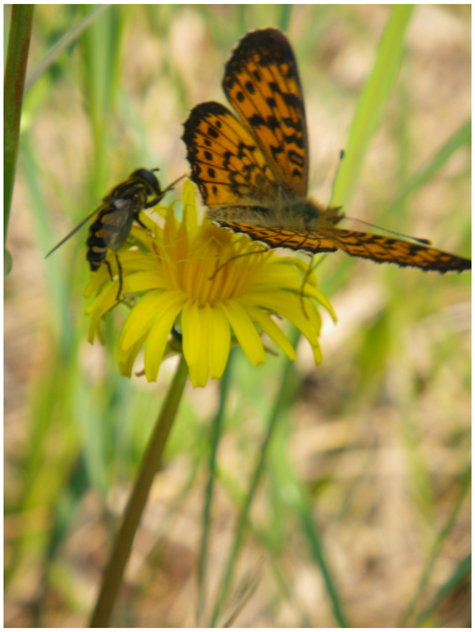


Figure 3.5.1 Pollinators visiting an introduced *Taraxacum officinale*. Image credit Alex Kent

There is evidence for landscape level seed limitation from changes in the grain shipments to the Churchill port. It was noted by previous work that 59.5% of the grain to Churchill was barley (Staniforth and Scott 1991) with the other 41.5% comprised of wheat (Figure 3.5.2). Following 1991 Churchill stopped receiving barley until 2012; see Figure 3.5.2. Barley contains a higher proportion of non-agricultural seeds (Staniforth and Scott 1991).

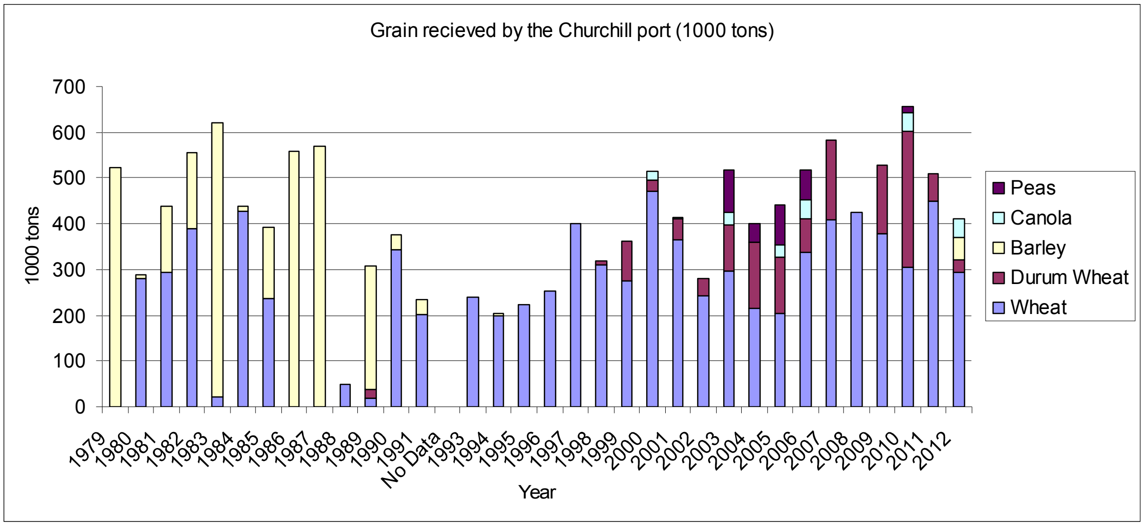


Figure 3.5.2 The amount and types of agricultural products received to Churchill for oceanic export.

After 1991, the port recovered from low volume years and began to transport more diverse crops by adding durum wheat, canola, and peas. Unlike in years previous to 1991 years the exports are made almost entirely of wheat varieties.

3.6 Introduced species present vs. previous functional trait differences?

The present species were found to occur in significantly colder, drier, and more variable environments (Chi-square statistic =19.7, n = 37, df = 3, $p < 0.05$). Also, 7 of the 38 test variables were found to be significantly different between species present in 1989 but absent in 2013 and species present in both 1989 and 2013 (table 3.6.1)

Table 3.6.1 Significantly different climate envelope variables between species occurring in 1989 but presently absent versus species persisting since 1989 to the present. The two variables whose normal distribution allowed comparison with a t-test both had equal variances as determined via an f-test.

Variable	Normal data (Shapiro-Wilks p value	1 tailed t-test p value	1 tailed Wilcoxon rank sum test p value
Minimum mean temperature of wettest quarter	Not normal, p<0.05	-	p<0.05
Min precipitation seasonality CofV	Not normal, p<0.05	-	p<0.05
Standard deviation annual precipitation	Not normal, p<0.05	-	p<0.05
Standard deviation mean diurnal range	Not normal, p<0.05	-	p<0.05
Standard deviation mean temperature of the wettest quarter	Not normal, p<0.05	-	p<0.05
Standard deviation precipitation of driest period	Normal, p>0.05	p<0.05	-
Standard deviation precipitation of driest quarter	Normal, p>0.05	p<0.05	-

See Appendix 3.2 for the results of all model runs. The *a priori* model using a culled data set to limit auto-correlation was deemed the best for both parsimony, and that it did not return infinite or otherwise impossible confidence intervals. See Table 3.6.2 for the best models significant predictors and confidence intervals.

Table 3.6.2 Best model significant variables and confidence intervals.

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)	2.50%	97.50 %
Life History Perennial	-1.6107	0.7569	-2.128	0.0333	0.0453 1	0.8805 1
SD Mean Temperature of Wettest Quarter	0.4656	0.1939	2.401	0.0163	1.0893	2.3297 1
Min Mean Temperature of Wettest Quarter	-0.2392	0.1181	-2.026	0.0427	0.6246 2	0.9922 5
SD Mean Diurnal Range	1.7575	0.9398	1.87	0.0614	0.9190 8	36.579 0
SD Max Temperature of Warmest Period	-0.7926	0.525	-1.51	0.1311	0.1617 6	1.2666 6

The best model returned a result stating that annuals are favoured over perennials, while species from more variable, on average cooler summer temperatures that have lower maximum temperatures and come from ranges with higher diurnal fluctuations are most likely to exist in Churchill. The climate data do not show a shift in the mean temperature of the wettest quarter (July, August, September) or in the amount of variability for that measure (Figure 3.6.1).

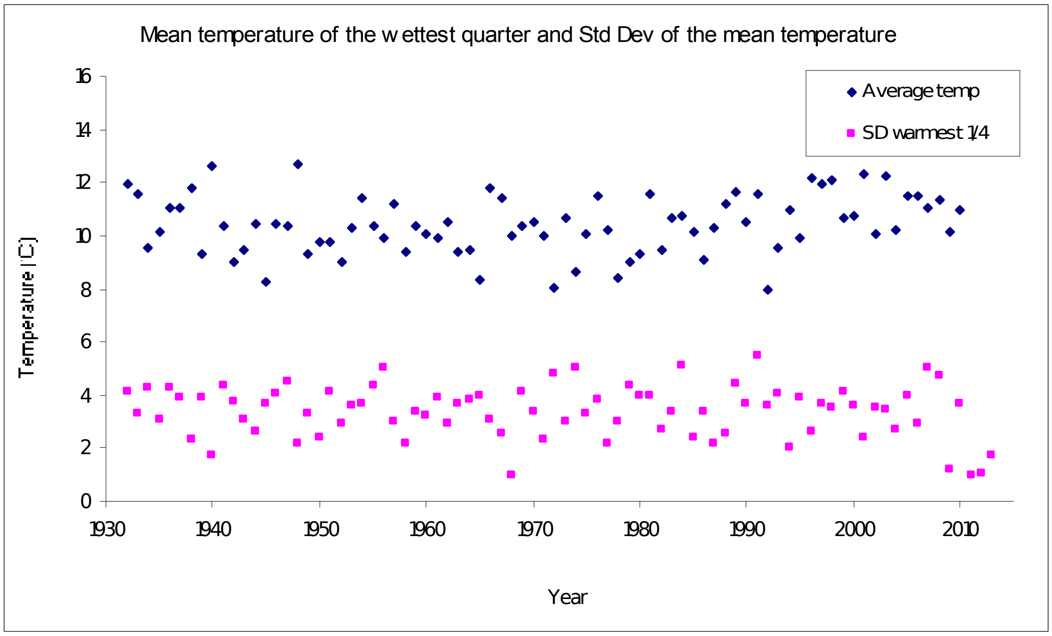


Figure 3.6.1 Mean temperature of the wettest quarter (July, August, September) and the standard deviation of each year's measure

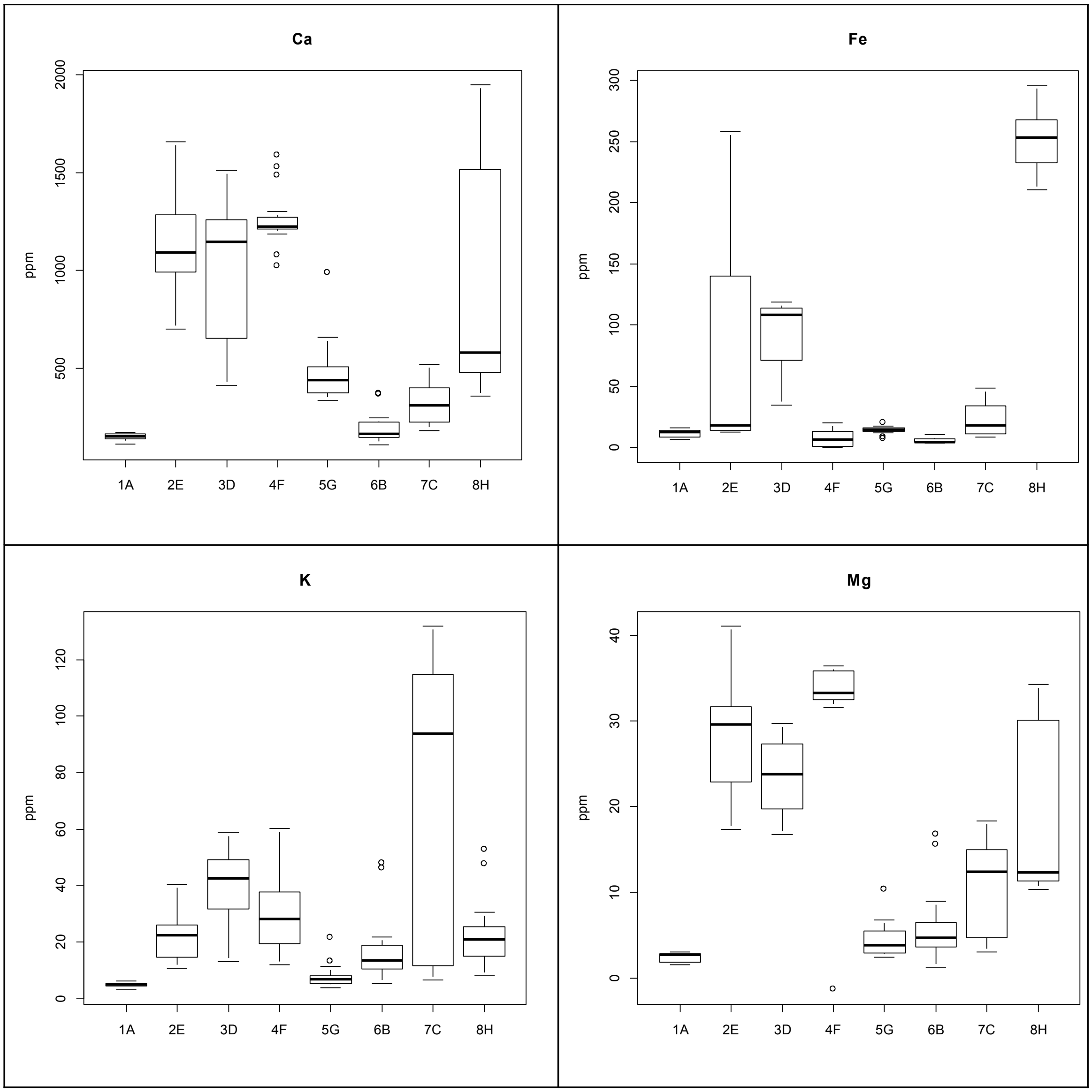
3.7 Soil Nutrition results

Available phosphorous, potassium, and ammonium where significantly higher in areas supporting introduced species and available calcium was significantly lower. The data were not normal and transformations could not normalize the variables so Wilcoxon rank sum tests were used, between areas that supported introduced plants and those that did not for phosphorus, calcium, potassium, and ammonia; see Table 3.7.1 for statistical outputs.

Table 3.7.1 Results of Wilcoxon rank sum test for differences in 8 soil nutrients between sites in Churchill MB that support introduced plant species and those that do not. For these statistics the n= 120 except for NO_3 and NH_4 where the n = 40 each and the df =1.

Compound	W score	P value
P	957	$7.577*10^{-5}$
pH	1914	0.2205
Ca	2310	0.000747
K	1287	0.03014
Mg	1957	0.1448
Fe	794	0.613
NO_3	210	0.5368
NH_4	350	$5.992*10^{-6}$

For nutrient comparisons of all sites see Figure 3.7.1. The two coastal soil sites, A and B, comprised almost entirely of sand were on average nutrient poorer than other sites. The three peat soil sites, D, E and F , appear similar except for E having a noticeably higher NH_4 concentration. Site C had lower calcium, iron, and magnesium concentrations than site D, which was the undisturbed pair for site C. In general the coastal communities, A and B, had lower levels of available nutrients than peat soils E, D and F and the pH across the landscape tended toward slightly acidic.


Ca
ppm
500
1000
1500
2000
1A
2E
3D
4F
5G
6B
7C
8H
Fe
ppm
0
50
100
150
200
250
300
K
ppm
0
20
40
60
80
100
120
Mg
ppm
0
10
20
30
40

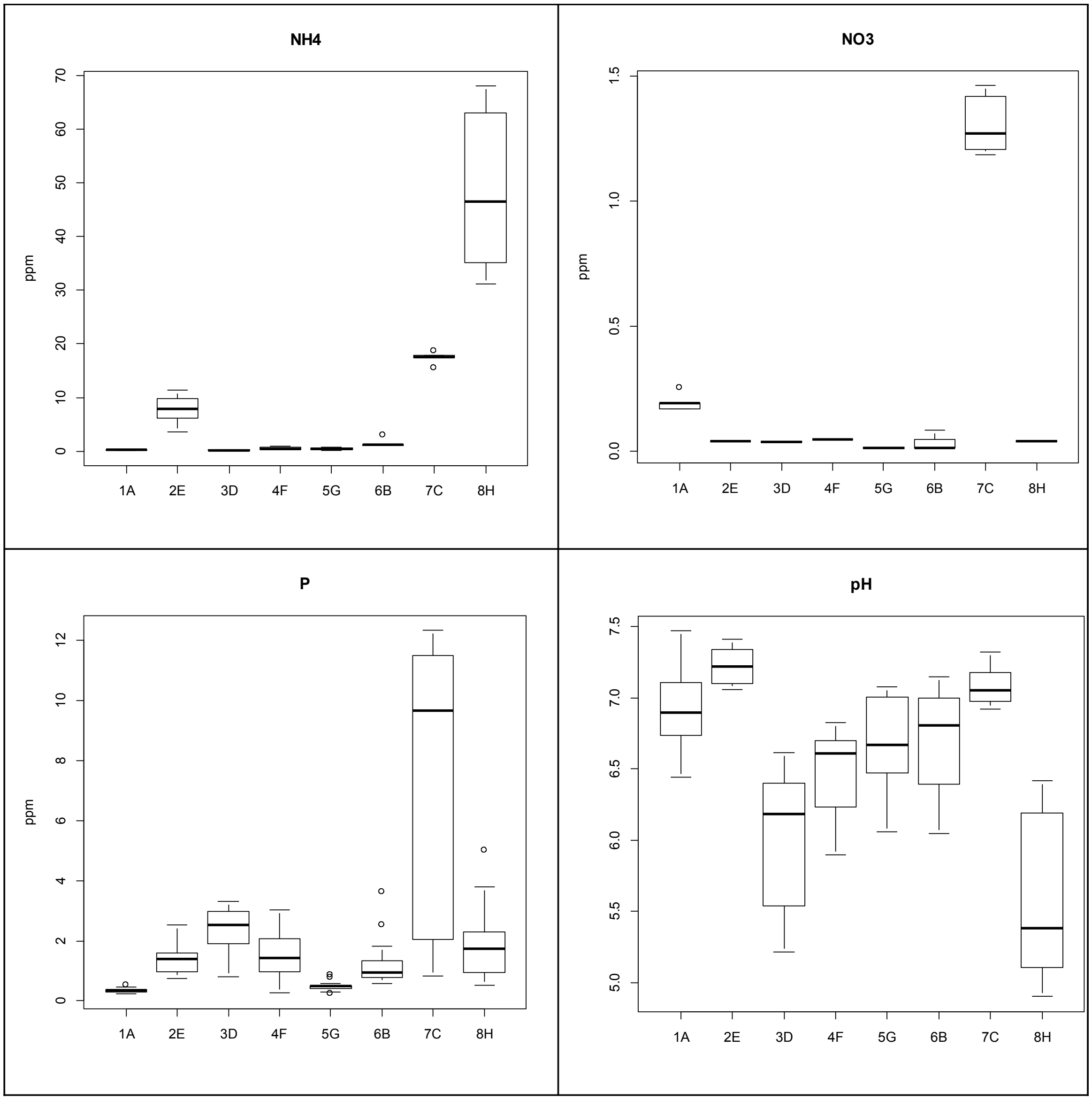


Figure 3.7.1 The average ppm measures for 8 compounds at the 8 different soil sampling sites. Each column is labeled with its column number and the letter designation of the soil sampling location.

3.8 Germination results

The data were not normally distributed (Shapiro-Wilks test, $W = 0.8097$, $p < 0.05$) thus the Wilcoxon rank sum and Kruskal-Wallis tests were employed. None of the four groups in the 2X2 block, soils with/without introduced species by fertilized/unfertilized treatments, had significantly different germination (Kruskal-Wallis chi-square = 3.0835, df = 3, $p > 0.05$). There was no effect of fertilization on the germination of *T. officinale* seeds (Wilcoxon rank sum test $W = 30.5$, $p \gg 0.05$). Also there was no significant effect observed for germination between the two groups of plant communities (Wilcoxon rank sum test $W = 48$, $p > 0.05$) (Figure 3.8.1.). The communities lacking introduced species under field conditions tended to have higher germination of the introduced species *T. officinale*; the opposite was the case in field conditions.

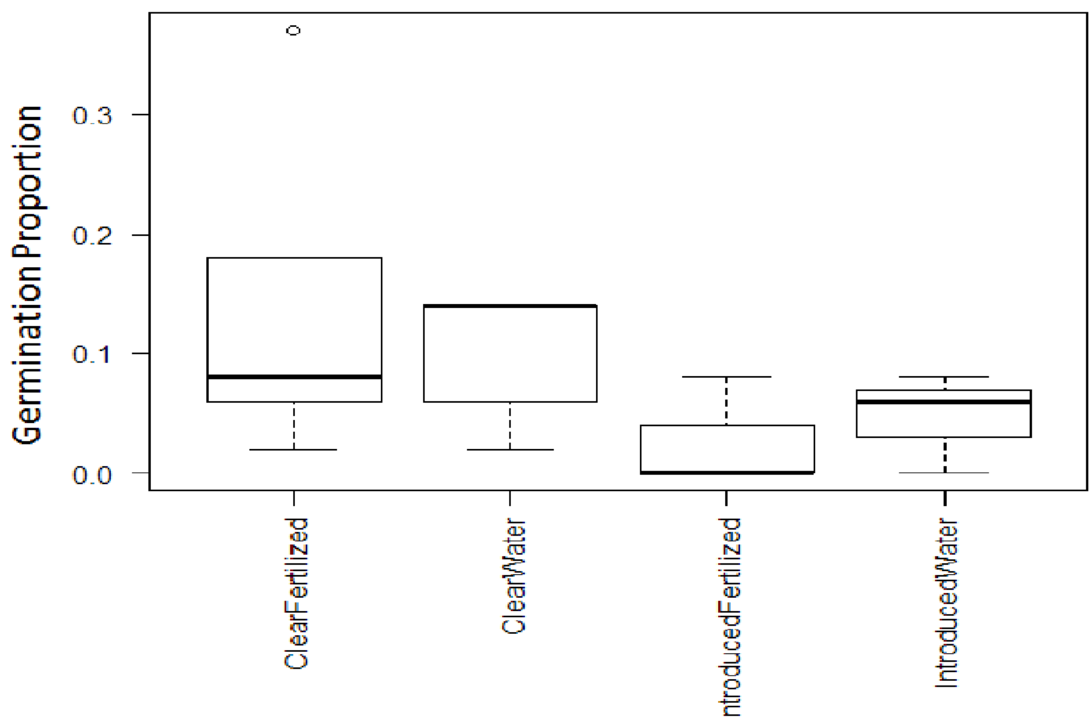


Figure 3.8.1 The mean and quartile ranges for sample groups within the germination experiment.

3.9 Berm microclimate results

To analyze the similarities of the community data, a canonical correspondence analysis (CCA) was chosen because only one variable, species cover, was used in the dataset (Ter Braak 1995). Analysis was done with R statistical package, version 3.02, with the "VEGAN" package, version 2.0; see Appendix 4.1 for statistical software code and output. All other non ordination analysis was done with R statistical package 3.02.

See Figure 3.9.1 for the resulting CCA. The top face and east face are similar to all other faces while the south, north and west faces are all dissimilar from each other. The south and east face are similar but introduced species are more associated with the south face. The north face shares species with other faces while the west area has less of its plant community occurring on different faces. There was one species that could not be identified because only basal leaves were present. People familiar with the native flora of Churchill were not familiar with the leaf type so the unknown was counted as an introduced species.

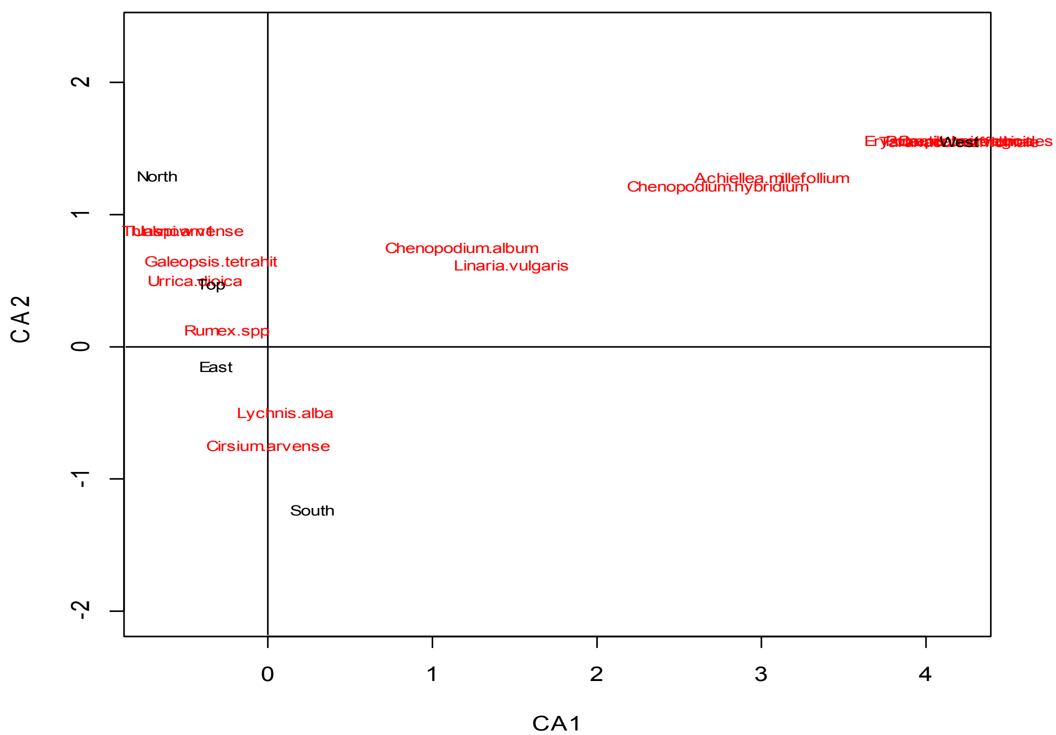


Figure 3.9.1 CCA analysis looking for similarities between the plant communities on different faces of the Churchill old dump berm.

The data for vegetation height was normal (Shapiro-Wilks test: W = 0.9818, $p > 0.05$) and no face had significantly different vegetation height (Homoscadastic data: Levene's test = 1.8358, $p > 0.05$, two way ANOVA: DF = 4, F-value= 2.03, $p > 0.05$, Figure 3.9.2) .

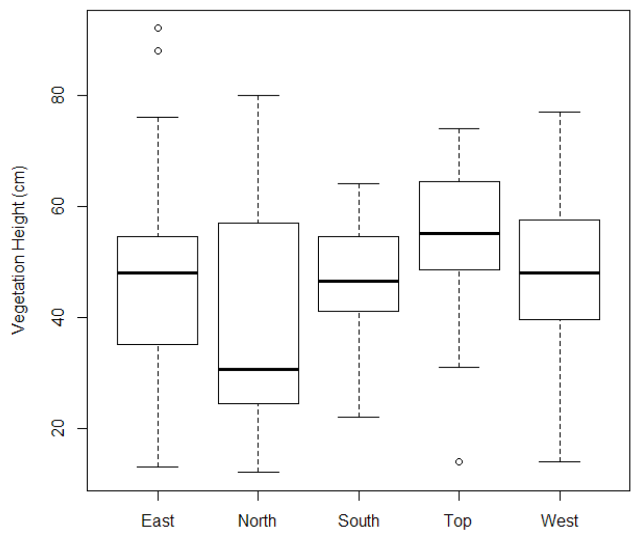


Figure 3.9.2 The vegetation height for plant communities on different faces of the Churchill old dump berm

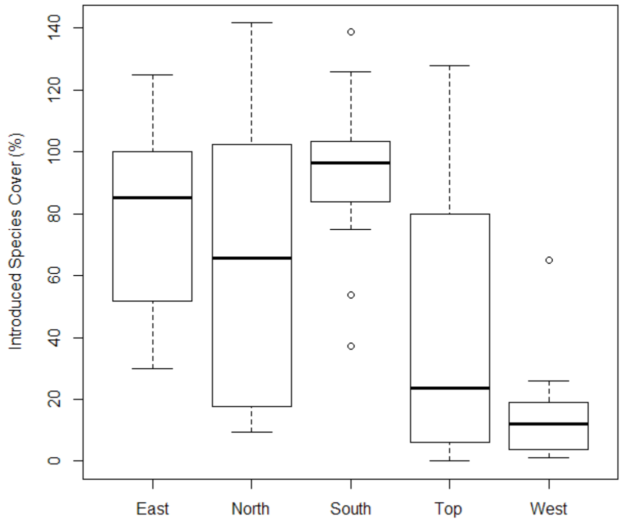


Figure 3.9.3 Percent cover of introduced plant species for the different faces of the Churchill old dump berm

The percentage of cover made up of introduced species was not normal (Shapiro-Wilks test: $W = 0.9069$, $p < 0.05$). A significant difference in the percentage of introduced plant ground cover was found (Kruskal-Wallis test: chi-square = 40.9295, df = 4, $p < 0.05$). The west face had lower levels of introduced species cover, or a higher amount of native species cover, while the south face had the least native species cover (Figure 3.9.3).

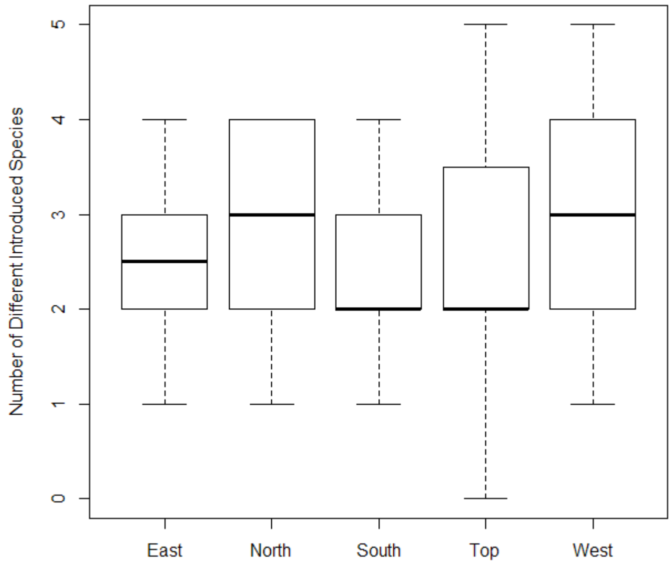


Figure 3.9.4 The average number of introduced plant species found on different faces of the Churchill old dump berm

The data for the number of introduced species in each sampling quadrat were not normal (Shapiro-Wilks test: $W = 0.9279$, $p < 0.05$). No face had significantly more or less introduced species diversity (Kruskal-Wallis test: chi-square = 3.04, df = 4, $p > 0.05$, Figure 3.9.4).

It was observed in the field that although native species were not quantified only two species were predominantly present, *Chamerion angustifolium* (Fireweed) and *Leymus arenarius* (Sea Lyme grass). No plot had bare ground, so any time introduced species cover was less than 100% I have assumed the difference was made up by native species.

3.10 Goose Creek snow depth

There was no detectable difference on the colonization success of introduced or native dandelion (*Taraxacum laevigatum*) as a response to snow cover (Chi-squared = 0.0733, df = 1, $p > 0.05$). The introduced, and native, species occurred almost equally between tree and untreed areas.

Erysimum cheiranthoides was observed occurring in exposed, un-treed, areas of the road that had been recently reconstructed just south of the community pier. There were also introduced species other than *T.officinale,* along the roadside, within 50 m of where main rail line intersects the road.

4. Discussion

During my July 2013 field season I was able to locate and identify 36 introduced species, see Appendix 2.1 for species list and locations, a 76% reduction from the 106 introduced species counted in the 1989 survey (Staniforth and Scott 1991).

Increasing temperatures from climate change, as observed in Churchill (Rühland et al. 2013), have been predicted to increase the levels of species introduction outside historical ranges (Hellman et al. 2008) but my observations showing a decreased number of introduced species suggests other factors beyond climate amelioration are important. Recent modeling work predicts that "biomes harboring extreme climatic conditions such as ice, hot desert, tundra and wooded tundra were not predicted to be suitable for invasive alien species by 2100" (Bellard et al. 2013, p. 4). Despite significant warming Churchill is still a sub-arctic environment and so qualifies as an extreme climate.

My study provides evidence that climate warming, may not have yet increased the ability of new plants to establish in the Arctic unless large scale disturbance, soil modification and habitat restructuring also occur as what was observed at the old dump site. An explanation for my observations could be that, while the climate has ameliorated, the niche envelope required by the various introduced species has not been replicated and so introduced has not lead to invasion. Another possible explanation, that is difficult to test, is that the milder climate has loosened the climate constraints on the native flora making them stronger competitors and possibly displacing the introduced species.

My study found only 34% of the introduced plant species the last survey found (Staniforth and Scott 1991). I am confident that the number is a true result as my field assistant and I were able to, over our field season, locate and identify almost every native vascular species. I found one new species, *Drabas oligisperma* to add to the total species list compiled by Staniforth and Scott (1991).

A possible reason for some variation between my 2013 survey and the 1989 one (Staniforth and Scott 1991) was that 2013 was a very dry year while 1989 and the late 1980s in general were heavy rain years (Figure 3.3.2). Field work in 2013 still required waterproof footwear to comfortably walk through the landscape but some ponds were dried up and residents of Churchill did comment on how dry the season was. Drought conditions could very likely be a reason for low introduced species diversity observed in 2013.

In Churchill despite continued seed input from the active railway and grain elevator, and significant climate amelioration, fewer introduced plants are present than in the original 1959 survey (Becket 1959). I have found precedent for a decline in introduced species diversity following abandonment in long term studies of former agriculture fields (Meiners et al. 2002). The Meiners et al (2002) study found that following abandonment both the number of introduced species and the percentage ground cover of introduced plants declined. An interesting shared result from both Churchill and the Meiners et al (2002) study was that introduced annual plants persisted over some introduced perennial species. However, the ecological conditions between a temperate climate agricultural area and the sub-arctic tundra around Churchill are very different so a direct comparison is questionable.

There is also precedent for introduced species forming self-sustaining communities following abandonment (Kulmatiski 2006) which was observed at the old town dumpsite. The result was not universal, as a conversation with Parks Canada staff said that an obvious patch of *Linaria vulgaris* that had occurred on the main road as one headed south out of town had recently disappeared. Also, the reclaimed barracks site no longer supported any introduced species, having lost the 23 previously recorded to have occurred.

One important difference from the previous studies, however, is that a single introduced species, *Taraxacum officinale*, was found occurring outside human disturbed areas. This is the first time such a finding has been recorded. *T. officinale* is a hardy species, and one that was well established in human disturbed areas in 1989 (Staniforth and Scott 1991). From this study I conclude that the *T.officinale* is not invasive in Churchill, MB, as it was not ecologically dominant over other native plants as it did not appear to be crowding out any of the other native plants in the area.

Generally the proportion of different introduced species at different sites remained consistent between 2013 matched 1989 (Staniforth and Scott 1991) in intensity with the old dump having the most established species, the grain elevator second, the metal dump third and all other locations have only a few of the total number of introduced species present in the landscape. The number of colonies has fallen though with the loss of 23 species to 0 at the old Barrack site and from 11 to 0 at the cottage area on the SW side of the Churchill town site. A feature that was preserved between the two studies was that the old dump, while the most introduced species rich, remains an island of introduced species with apparently no transfer eastward (Figure 2.1.1). This suggests that introduced species seeds from local populations may not be an important determinant for the spread and establishment of introduced species in Churchill. There are studies that indicate propagule pressure is important for successful establishment of introduced species (Lockwood et al. 2005, Simberloff 2009), my results partially contradict that theory as no evidence of propagule pressure from local sources was observed. Because local introduced plants populations could grow and disperse viable seed (Staniforth and Scott 1991), but the plants could not expand beyond their initial introduction sites into undisturbed areas. My work finds some support for a landscape level propagule pressure effect because of the change in grain shipments to Churchill between 2013 and 1989 are expected to have changed the landscape level seed inputs which could help explain the drop in introduced plant diversity.

The analysis of soil showed that introduced plants tended to occur in more nutritionally rich areas. My attempts to verify whether soil nutrition is limiting via a germination experiment was not successful though as the experiment was unable to replicate observed field conditions as the greatest germination occurred in soils that had no occurrence of introduced species under field conditions. The lab test had no significant differences between fertilized and unfertilized treatments. I am confident in the veracity of my soil nutrition results due to extensive sampling and analysis done to minimize the effect of outliers. I believe a confounding factor that I did not test for in my investigation on whether different soil types were more hospitable for introduced species was the presence of moss/lichen in the field but absent in the lab. Introduced plant seeds generally cannot germinate on non-vascular plant mats unless specially adapted to do so(Sanderson et al. 2012). Additionally soil nutrition may be a due to a nitrogen and phosphorus limitation that is in fact a function of the distance to the water table, waterlogged arctic peat soils have lower rates of nutrient mineralization (Bliss 1962). Through the field period introduced plants seems to occur in mounded areas so these drier areas, that are also further from the frost table, might be better locations for introduced plants.

Microclimate differences based on wind and sun exposure were shown to be an important determinant of the introduced plant community, when soil conditions were controlled for, with the sunnier and less wind exposed zones showing a higher proportion of introduced species cover. The study based on data from the old dump berm did not return values in accoCCAnce with expectations as the north face contained a higher proportion of introduced species than predicted. I suggest that wind effects are less important than sunlight ones. The vegetation on the berm was thick, often up to 70cm in height and so leaves not at the canopy would be shield neighbouring plants from wind exposure. There could also be a strong moisture component relating to the probable differential desiccation of the berm due to asymmetric microclimate. To test the effect of moisture would require further study.

Two sites that supported 'wild' populations of the introduced *T.officinale* species were not particularly similar, one being boreal forest and the other a coastal community, but again supported similar introduced species. If different plant communities do not have different soil chemistry then nutrition could be limiting but of less importance than topography, microclimate and the existing vegetation community.

The non-significant effect of snow cover on introduced species occurrence on the Goose Creek Road study may in part be due to a confounding variable in that while at the landscape level more snow deposits in areas along the road with tree cover the same may not be important for the immediate sides of the road. Since the roadway is ploughed the side of the road where the *T.officinale* are found would likely always have some snow cover. Sections of the road would probably have more snow than others but the difference between some snow cover and more snow cover may not be important. However, from discussions with persons familiar with Churchill the two locations where introduced *Taraxacum* were found (soil sampling sites H and B) are areas where very deep snow occurs (snowdrifts > 3 m). The role of snow cover is currently indeterminate.

My modeling work was successful in adding support to the current theory in invasion ecology in that I found that the introduced species that have persisted in Churchill between 1989 (Staniforth and Scott 1991) and 2013 are on average more tolerant of colder and drier conditions as well as being from more climatically variable home ranges which is accoCCAnce with the predictions that species will not usually leave their adapted climate envelope (Petitpierre et al. 2012) and that species whose original range is large and climatically variable are more likely to be invasive in new places (Pysek et al. 2009). The modeling exercise was able to parse and return a reasonable model but no direct evidence for its validity could be found in the climate records for Churchill. A limitation on the modeling work is that no introduced species had Churchill as part of its projected range in the climate envelope. I think the modeling exercise could be a valuable way to assess the chance introduced species will colonize an area but only once a much larger database forms the basis of the original models. Also, a comparison to other sub-arctic areas that have records of introduced species through time would be valuable for comparison. Another possible limitation of the modeling exercise is that because of the dry year only introduced species able to survive drier conditions would be found which could skew the results to favour species tolerant of lower precipitation.

My investigation did not find any evidence of the enemy release hypothesis, where introduced species can prosper because their predators and pathogens are absent, as no significant herbivory or disease was observed on either native species or introduced plants. This study also did not find evidence to support the novel weapons hypothesis, where new species to an area have unprecedented strategies and/or adaptations that give them competitive advantages, as introduced species did not appear to be outcompeting neighbouring native species and were in fact contained in particular areas which suggests a complete inability to compete with native species in native (unaltered) areas. There were two instances of 'wild' populations of an introduced species, *T.officinale* growing in patches near the Hudson's Bay and in the Boreal forest of the Twin Lakes glacial kame, but I would describe the introduced species occurring there as innocuous, as they did not seem to be outcompeting any other native plants. In more southerly Canadian locations *T.officinale* can grow in dense clusters that exclude other species, but that was not observed in Churchill. Instead, the introduced plants appeared to be evenly scattered in the two areas (soil sampling sites B and H) where they were growing wild and I could observe no apparent exclusion of other plant species.

The invasional meltdown hypothesis, where the introduction of new species into an area modifies the environment in such a way that additional new species can more easily establish, could be a possible explanative theory for introduced species in Churchill. The old Churchill dump no longer undergoes seed inputs, or disturbance, but unlike other sites in the landscape does not appear to be reverting to a natural community. The dump has ecological borders so stark that one can visualize from Google Earth images where the dump stops and where the native community begins. It is possible that the soil modification from decades of grain screenings inputs, as well as clearing away any native plants and favorably altering the topography has given some introduced plant species enough advantage to persist against extirpation. There still however has been a large drop in the number of introduced plants species found at the dump declining from 53 in 1989 (Staniforth and Scott 1991) to 24 in 2013. For comparison the grain elevator and metal dump are areas in Churchill that has always been under disturbance and seed inputs but have fewer introduced species than the old dump. Thus constant disturbance may not be required for the persistence of introduced plants once some threshold is passed.

Lastly, it is entirely possible that the reduction in introduced plants in Churchill is due to 30 years of advancement in agriculture. Tillage practices and herbicides have changed causing reductions to agricultural weed communities in the Canadian prairies (Van Acker 2002), the source of grain for the Churchill port, and it is not a large logical leap to assume that the seed rain of introduced species to Churchill has also decreased. Churchill no longer receives barley in large quantities which it did in the 1980s, the years leading up to the last survey (Staniforth and Scott 1991). The reason for the drop in barley shipment appears to be the collapse of the Soviet Union who had previously been a major importer of Canadian barley (Canadian Grain Exports 1981-2012). The timing of the reduction in barley shipments, 1991, is consistent with the political turmoil that lead to the dissolution of the Soviet Union. The probable change in landscape level seed inputs coupled with the sharp drop in diversity of introduced species suggests that many of the species recorded as occurring in Churchill were only transient, doomed, populations that were being constantly replenished by new seeds brought in on the railway.

5 Conclusions

The Churchill region has experienced change in its introduced plant community that is against expectations based on historical observations and current invasion ecology theory as well as predictions based on the increasing warming and climate disruption from climate change. My work suggests that hardier species are persisting in Churchill and that these plants may just now have begun their transition into wild environments. I have also been able to conclude that the massive decline in introduced species diversity can perhaps be best explained because the landscape level seed inputs have changed due to shifts in the geopolitics of grain trading and Canada's grain export markets.

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Appendix 1. Dominant Plant Species

Table 1. Plant communities on sand/clay deposits

Strand and Salt Marsh Communities	Dune Communities	Sandy Pools
Smooth Orache - Atriplex glabriuscula Hairgrass-Like Grass - Calamagrostis deschampsoides Seaside Sedge - Carex maritima Arctic Chrysanthemum - Chrysanthemum arcticum Scurvy-Grass - Cochlearia officinalis Fisher's Dupontia - Dupontia fisheri Sea-Beach Sandwort - Honckenya peploides Sea-Shore Chamomile - Matricaria ambigua Seaside Lungwort - Mertensia maritima Seaside Plantain - Plantago juncoides Egede's Cinquefoil - Potenitilla egedii Seaside Buttercup - Ranunculus cymbalaria Four-Leaved Mare's Tail - Rubus chamaemorus Seaside Buttercup - Ranunculus cymbalaria Seaside Arrow-Grass - Triglochin maritima	Yarrow - Achillea nigrescens Pygmyflower - Androsace septentrionalis Red Bearberry - Arctostaphylos alpina Sand-Dwelling Rock-Cress - Arabis arenicola Glacier Sedge - Carex glacialis Sheathed Sedge - Carex vaginata Purple Paintbrush - Castilleja raupii Arctic Chrysanthemum - Chrysanthemum arcticum White Mountain-Avens - Dryas integrifolia Sea-Lime Grass - Elymus arenarius Fireweed - Epilobium angustifolium Broad-Leaved Fireweed - Epilobium latifolium Alpine Fescue - Festuca brachyphylla Sweet Vetch - Hedysarium mackenzii Sea-Shore Chamomile - Matricaria ambigua Large Grass-of-Parnassus - Parnassia palustris Alpine Bistort - Polygonum viviparum Branched and Beautiful Cinquefoils - Potentilla multifida Greenland Primrose - Primual egalikensis Erect Primrose - Primula stricta Stemless Raspberry - Rubus acaulis Snow Willow - Salix reticulata Canada Buffaloberry - Shepherdia canadensis Spike Trisetum - Trisetum spicatum	Dwarf Scouring-Rush - Equisetum variegatum Common Mare's Tail - Hippuris vulgaris Arctic Rush - Juncus arcticus Sago-Pondweed - Potamogeton pectinatus

Table 2. Plant communities on outcrop ridges

Lichen-Health Community	Ledge and Crevice Rock Communities	White Spruce Shrub Community
Red Bearberry - Arctostaphylos alpina Alpine Milk-Vetch - Astragalus alpinus White Mountain-Avens - Dryas integrifolia Black Crowberry - Empetrum nigrum Alpine Azalea - Loiseleuria procumbens	Bog-Rosemary - Andromeda polifolia Moon Fern - Botrychium lunaria Alpine Bluebell - Campanula uniflora Fragile Fern - Cystopteris fragilis Hoary Whitlow-Grass - Draba incana Common Juniper - Juniperus communis	Velvet Bells - Bartsia alpina Early Coralroot - Corallorhiza trifida Northern Comandra - Geocaulon lividum Small Northern Bog Orchid - Habenaria obtusata

Lapland Lousewort - Pedicularis lapponica Lapland Rose-Bay - Rhododendron lapponicum Snow Willow - Salix reticulata Alpine Bilberry - Vaccinium uliginosum Dry-Ground Cranberry - Vaccinium vitis-idaea	Early Sandwort - Minuartia rubella Large-Flowered wintergreen - Pyrola grandiflora One-Sided Wintergreen - Pyrola secunda Northern Blackcurrant - Ribes hudsonianum Snow Willow - Salix reticulata Tufted Saxifrage - Saxifraga caespitosa Three-Toothed Saxifrages - Saxifraga tricuspidata	One-Flowered Wintergreen - Moneses uniflora Round-Leaved Orchid - Orchis rotundifolia Large and Small Grass of Parnassus - Parnassia palustris White Spruce - Picea glauca Lesser Wintergreen - Pyrola secunda Lapland Lousewort - Pedicularis lapponica Yellowrattle - Rhinanthus borealis Stemless Raspberry - Rubus acaulis Cloudberry - Rubus chamaemorus Three-Leaved Solomon's-Seal - Smilicina trifolia Bog Asphodel - Tofielda pusilla

Table 3. Plant communities in plain

Ice Ridge Communities	Hummocky Bog and Muskeg Communities	Black Spruce-Larch Forest Community	Freshwater Meadow-Marsh Communities
Yellow Anenome - Anemone richardsonii Dwarf Birch - Betula glandulosa Water Sedge - Carex aquatilis Swamp Horsetail - Equisetum arvense One Spike Cotton-Grass - Eriophorum scheuchzeri Buck-Bean - Menyanthes trifoliata Sweet Gale - Myrica gale Myrtle-Leaved - Salix myrtillifolia Lime Willows - Salix lanata	Bog Rosemary - Andromeda polifolia Meadow Bitter Cress - Cardamine pratensis Northern Stitchwort - Honckenya peploides Bog Laurel - Kalmia poliflia Labrador Tea - Ledum decumbens Swamp Cranberry - Oxycoccus microcarpus Sweet Gale - Myrica gale Flame-Coloured Lousewort - Pedicularis flammea Purple Rattle - Pedicularis sudetica Cloudberry - Rubus chamaemorus Bog and Yellow Marsh Saxifrage - Saxifraga hirculus Tufted Bulrush - Scirpus caespitosus Marsh and Seaside Arrow-Grasses - Triglochin maritima	Early Coralroot - Corallorhiza trifida Green-Flowered Bog Orchid - Habenaria hyperborea Bog Laurel - Kalmia poliflia Labrador Tea - Ledum decumbens Stiff Club-Moss - Lycopodium annotinum Cloudberry - Rubus chamaemorus Alpine Bilberry - Vaccinium uliginosum	Water Sedge - Carex aquatilix Common Mare's tail - Hippuris vulgaris Duckweed - Lemna spp. Buck-Bean - Menyanthes trifoliata Marsh Cinquefoil - Potentilla palustris

Table 4. Plant community in gravel ridges

Lichen-Heath Communities	Sedge Meadow Community	Taiga (Willow-Birch Shrub) Community
Yarrow - Achillea nigrescens Cut-Leaved Anenome - Anemone multifida Red and Alpine bearberries - Arctostaphylos alpina Alpine Arnica - Arnica alpina Hoary Draba - Draba incana White Mountain-Avens - Dryas integrifolia Alpine Bistort - Polygonum viviparum Purple Saxifrage - Saxifraga oppositifolia Canada Buffaloberry - Shepherdia canadensis Lacerate Dandelion - Taraxacum lacerum	Northern Bog Sedge - Carex gynocrates Scant Sedge - Carex rariflora Swamp Cranberry - Oxycoccus microcarpus Flame-Coloured Lousewort - Pedicularis flammea Arrow-leaved Colt's-Foot - Petasites sagittatus Arctic Blue Grass - Poa arctica Greenland Primrose - Primula egalikensis Lapland Buttercup - Ranunculus lapponicus Yellow Marsh Saxifrage - Saxifraga hirculus Seaside Arrow-Cross - Triglochin maritima	Green Alder - Alnus crispa Dwarf Birch - Betula glandulosa Marsh Reed Grass - Calamagrostis canadensis Baltic Rush - Juncus balticus Sweet Gale - Myrica gale Short-Capsuled Willow - Salix brachycarpa Hoary Willow - Salix candida Flat-Leaved Willow - Salix planifolia

Table 5. Plants in freshwater wetlands

Submerged and Floating Plants	Marginal or Partly Submerged Plants
Mare's Tails - Hippuris vulgaris Spiked Water-Milfoil - Myriophyllum exalbescens Slender-leaved Pondweed - Potamogeton alpinus Narrow-Leaved Bur-Reed - Parganium hyperboreum Northern Water-Starwort - Stellaria longipes	Northern Water-Starwort - Callitriche hermaphroditica Water-Hemlock - Cicuta mackenzieana Creeping Spike Rush - Eleocharis palustris Common Cotton Grass - Eriophorum angustifolium Baltic Rush - Juncus balticus Marsh Ragwort - Senecio congestus Northern Bur-Reed - Sparganium hyperboreum

Appendix 2.1 The 'weedy' species recorded by Staniforth and Scott (1991)

Family	Species
Amaranthaceae	*Amaranthus retroflexus*
Amaranthaceae	*Monolepis nuttalliana*
Amaranthaceae	*Salsola kali*
Apiaceae	*Heracleum lanatum*
Asteraceae	*Achillea millefolium*
Asteraceae	*Artemisia absinthium*
Asteraceae	*Artemisia biennis*
Asteraceae	*Artemisia campestris*
Asteraceae	*Artemisia herriotii*
Asteraceae	*Chrysanthemum leucanthemum*
Asteraceae	*Cirsium arvense*
Asteraceae	*Conyza canadensis*
Asteraceae	*Crepis tectorum*
Asteraceae	*Helianthus annuus*
Asteraceae	*Iva xanthifolia*
Asteraceae	*Lactuca scariola*
Asteraceae	*Lactuca tatarica*
Asteraceae	*Matricaria maritima*
Asteraceae	*Matricaria matricarioides*
Asteraceae	*Senecio vulgaris*
Asteraceae	*Sonchus arvensis*
Asteraceae	*Sonchus oleraceus*
Asteraceae	*Taraxacum laevigatum*
Asteraceae	*Taraxacum officinale*
Boraginaceae	*Asperugo procumbens*
Boraginaceae	*Lappula myosotis*
Boraginaceae	*Mertensia paniculata*
Brassicaceae	*Barbarea vulgaris*
Brassicaceae	*Brassica kaber*
Brassicaceae	*Brassica oleracea*
Brassicaceae	*Brassica rapa*
Brassicaceae	*Camelina sativa*
Brassicaceae	*Capsella bursa-pastoris*
Brassicaceae	*Conringia orientalis*
Brassicaceae	*Descurainia sophia*
Brassicaceae	*Erucastrum gallicum*
Brassicaceae	*Erysimum cheiranthoides*
Brassicaceae	*Lepidium densiflorum*
Brassicaceae	*Lepidium ramosissimum*
Brassicaceae	*Neslia paniculata*
Brassicaceae	*Sisymbrium altissimum*
Brassicaceae	*Sisymbrium loeselii*
Brassicaceae	*Thlaspi arvense*
Caryophyllaceae	*Cerastium vulgatum*
Caryophyllaceae	*Lychnis alba*
Caryophyllaceae	*Saponaria vaccaria*
Caryophyllaceae	*Silene cucubalus*
Caryophyllaceae	*Silene noctiflora*
Caryophyllaceae	*Stellaria media*
Chenopodiaceae	*Atriplex patula*

Chenopodiaceae	*Axyris amaranthoides*
Chenopodiaceae	*Chenopodium album*
Chenopodiaceae	*Chenopodium glaucum*
Chenopodiaceae	*Chenopodium hybridum*
Chenopodiaceae	*Chenopodium leptophyllum*
Chenopodiaceae	*Kochia scoparia*
Fabaceae	*Lathyrus palustris*
Fabaceae	*Medicago lupulina*
Fabaceae	*Medicago sativa*
Fabaceae	*Melilotus alba*
Fabaceae	*Melilotus officinalis*
Fabaceae	*Thermopsis rhombifolia*
Fabaceae	*Trifolium hybridum*
Fabaceae	*Trifolium repens*
Fabaceae	*Vicia americana*
Geraniaceae	*Erodium cicutarium*
Geraniaceae	*Geranium bicknellii*
Lamiaceae	*Galeopsis tetrahit*
Lamiaceae	*Moldavica parviflora*
Linaceae	*Linum usitatissimum*
Malvaceae	*Malva rotundifolia*
Plantaginaceae	*Plantago major*
Poaceae	*Agropyron repens*
Poaceae	*Agrostis hyemalis*
Poaceae	*Agrostis stolonifera*
Poaceae	*Avena fatua*
Poaceae	*Avena sativa*
Poaceae	*Bromus inermis*
Poaceae	*Hordeum vulgare*
Poaceae	*Lolium persicum*
Poaceae	*Phleum pratense*
Poaceae	*Poa compressa*
Poaceae	*Poa pratensis*
Poaceae	*Setaria viridis*
Poaceae	*Triticum aestivum*
Polemoniaceae	*Collomia linearis*
Polygonaceae	*Polygonum arenastrum*
Polygonaceae	*Polygonum convolvulus*
Polygonaceae	*Polygonum lapathifolium*
Polygonaceae	*Polygonum ramosissimum*
Polygonaceae	*Polygonum scabrum*
Polygonaceae	*Rumex crispus*
Polygonaceae	*Rumex maritimus*
Polygonaceae	*Rumex salicifolius*
Polygonaceae	*Rumex stenophyllus*
Ranunculaceae	*Anemone canadensis*
Rosaceae	*Potentilla norvegica*
Rosaceae	*Rosa acicularis*
Rosaceae	*Rubus idaeus*
Rubiaceae	*Galium aparine*
Rubiaceae	*Galium boreale*
Salicaceae	*Populus tremuloides*
Scrophulariaceae	*Linaria vulgaris*
Solanaceae	*Solanum triflorum*
Urticaceae	*Urtica dioica*

Appendix 2.2 Introduced plants of the Churchill, MB, region 2013

Global List	North of the Grain Elevator	Old Dump	Goosecreek Road - southern most Railway crossing	Goosecreek Road around cottage area	Recycling Depot	Metal Dump	Twin Lakes sandy beach cabin (soil site H)	Cape Merry	New Dump	Churchill Northern Studies Centre	Airport road turnoff	Denee village	Coastal region North of Golf Balls, soil site B	Firing range refuse tip
Achiellea millefollium	1	1			1	1	1							
Agropyron repens			1											
Artemisia absinthium		1												
Artemisia biennis	1	1												
Brassia rapa	1													
Capsella bursa-pastoris	1					1			1					
Chenopodium album	1	1				1			1					1
Chenopodium glaucum	1	1							1					
Chenopodium hybridium		1				1								
Cirsium arvense		1				1								
Collomia linearis		1												
Conyza canadensis		1												
Crepis tectorum	1					1	1							
Descurainia sophia	1	1				1								1
Draba oligosperma		1												
Erysimum cheiranthoides	1	1	1		1					1	1	1		
Galium aparine	1													
Galeopsis tetrahit		1												
Lappula myosotis		1												
Linaria vulgaris		1												
Lychnis alba		1												
Marticaria maririma					1									
Matricaria matricarioides	1	1				1								
Melilotus officinalis					1									
Monolepsis nutiliana									1					
Neslia panaculata						1								
Plantago major	1				1	1	1							
Polygonum arenastrum	1	1				1								
Potentilla norvegica		1				1								
Rosa acicularis						1								
Rumex maritinus		1												
Rumex salicifolius		1												
Taraxacum officinale	1	1	1	1	1		1	1		1	1	1	1	
Thlaspi arvense	1	1				1			1					
Urrica dioica		1				1								

Appendix 3.1 Bioclim variable descriptions

Annual Mean Temperature

The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.

Mean Diurnal Range Mean(period max-min))

The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.

Isothermality 2/7

The mean diurnal range (parameter 2) divided by the Annual Temperature Range (parameter 7).

Temperature Seasonality

ANUCLIM (cov=TRUE) returns the temperature Coefficient of Variation (C of V) as the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in degrees Kelvin is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small. Worldclim (cov=FALSE) returns the the standard deviation of the weekly mean temperatures.

Max Temperature of Warmest Period

The highest temperature of any weekly maximum temperature.

Min Temperature of Coldest Period

The lowest temperature of any weekly minimum temperature.

Temperature Annual Range (5-6)

The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period.

Mean Temperature of Wettest Quarter

The wettest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

Mean Temperature of Driest Quarter

The driest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

Mean Temperature of Warmest Quarter

The warmest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

Mean Temperature of Coldest Quarter

The coldest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

Annual Precipitation

The sum of all the monthly precipitation estimates.

Precipitation of Wettest Period

The precipitation of the wettest week or month, depending on the time step.

Precipitation of Driest Period

The precipitation of the driest week or month, depending on the time step.

Precipitation Seasonality(C of V)

The Coefficient of Variation (C of V) is the standard deviation of the weekly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).

Precipitation of Wettest Quarter

The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

Precipitation of Driest Quarter

The driest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

Precipitation of Warmest Quarter

The warmest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

Precipitation of Coldest Quarter

The coldest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

Appendix 3.2 Different models compared against each other

Variable	Null	Full	Backward	Forward	Stepwise	Significant variables only	Only Variables used in creating	Reduced model excluding duplicated
LifeHistory	•	•!	•!	•	•*	•	•*	•*
MinAnnualMeanTemperature		•!	•!				•	•
MinAnnualPrecipitation		•!					•	•
MinIsothermality		•!						•
MinMaxTemperatureofWarmestPeriod		•!	•!				•	•
MinMeanDiurnalRange		•!						•
MinMeanTemperatureofColdestQuarter		•!	•!					•
MinMeanTemperatureofDriestQuarter		•!						
MinMeanTemperatureofWarmestQuarter		•!						•
MinMeanTemperatureofWettestQuarter		•!			•*	•		•*
MinMinTemperatureofColdestPeriod		•!	•!				•	•
MinPrecipitationofColdestQuarter		•!	•!				•	
MinPrecipitationofDriestPeriod		•!						•
MinPrecipitationofDriestQuarter		•!						•
MinPrecipitationofWarmestQuarter		•!					•	
MinPrecipitationofWettestPeriod		•!	•!		•*			•
MinPrecipitationofWettestQuarter		•!	•!					•
MinPrecipitationSeasonalityCofV		•!				•		
MinTemperatureAnnualRange		•!	•!					•
MinTemperatureSeasonalityCofV		•!						
SDAnnualMeanTemperature		•!	•!		•*		•	•
SDAnnualPrecipitation		•!				•	•*	•
SDIsothermality		•!			•*!			•
SDMaxTemperatureofWarmestPeriod		•!	•!		•*!		•	•
SDMeanDiurnalRange		•!	•!			•		•*
SDMeanTemperatureofColdestQuarter		•!						•
SDMeanTemperatureofDriestQuarter		•!	•!					•
SDMeanTemperatureofWarmestQuarter		•!						•
SDMeanTemperatureofWettestQuarter		•!	•!		•*	•		•*
SDMinTemperatureofColdestPeriod		•!					•	•
SDPrecipitationofColdestQuarter		•!	•!		•*!		•	
SDPrecipitationofDriestPeriod		•!	•!			•		•
SDPrecipitationofDriestQuarter		•!				•		•
SDPrecipitationofWarmestQuarter		•!	•!		•*!		•	
SDPrecipitationofWettestPeriod		•!			•*!			•
SDPrecipitationofWettestQuarter		•!	•!		•*			•
SDPrecipitationSeasonalityCofV		•!			•*			
SDTemperatureAnnualRange		•!	•!					•
SDTemperatureSeasonalityCofV		•!	•!		•!			
AIC	99.83	82	44	99.828	77.036	103.81	96.162	90.603

•= variable model selection allowed to use

! = infinity, incorrect sign or impossible number

* = significant

Appendix 3.3 Data used to assess climate envelopes for introduced species present in 2013 and those recorded in 1989 but absent in 2013

Species	Presence	LifeHistory	MinAnnualMean Temperature	MinAnnualPrecipitation	MinIsothermality	MinMaxTemperatureofWarmestPeriod	MinMeanDiurnalRange	MinMeanTemperatureofColdestQuarter	MinMeanTemperatureofDriestQuarter	MinMeanTemperatureofWarmestQuarter
Agrostis scabra	absent	Perennial	-5.05	284.54	0.19	11.54	7.71	-23.54	-22.77	6.76
Agrostis stolonifera	absent	Perennial	-4.54	320.12	0.21	14.72	7.61	-22.2	-22.2	8.17
Amaranthus retroflexus	absent	Annual	2.09	318.87	0.22	21.43	7.87	-15.05	-14.73	15.5
Anemone canadensis	absent	Perennial	-2.82	284.54	0.21	17.63	7.32	-20.69	-19.28	10.51
Artemisia campestris	absent	Biennial	-1.06	319.8	0.23	15.14	7.83	-18.19	-14.64	8.69
Artemisia ludoviciana	absent	Perennial	-1.84	284.54	0.22	15.12	8.07	-15.57	-15.19	7.83
Atriplex patula	absent	Annual	1.73	520.95	0.22	20.78	8.04	-14.19	-13.59	12.15
Avena sativa	absent	Annual	3.54	855.35	0.24	24.7	8.55	-10.91	-5.82	16.84
Barbarea vulgaris	absent	Biennial	1.37	630.75	0.22	21.82	8.11	-14.99	-14.68	14.6
Brassica juncea	absent	Annual	3.45	820.57	0.24	23.03	8.72	-10.81	-6.19	16.41
Bromus inermis	absent	Perennial	-2.9	319.8	0.22	11.53	7.34	-17.12	-13.54	6.46
Camelina microcarpa	absent	Annual	1.44	307.5	0.23	23	8.13	-8.31	-8.23	11.75
Cerastium fontanum	absent	Biennial	-4.58	521.17	0.19	17.89	8.11	-22.55	-22.24	10.81
Dracocephalum parviflorum	absent	Annual	1.87	395.45	0.22	23.03	9.48	-15.57	-15.16	11.96
Galium boreale	absent	Perennial	-4.63	284.54	0.19	10.38	6.56	-22.6	-22.29	5.63
Geranium bicknellii	absent	Annual	-1.27	375.6	0.21	15.85	8.44	-20.46	-16.25	9.18
Helianthus annuus	absent	Annual	-1.2	372.06	0.24	20.44	8.53	-15.51	-14.58	9.42
Heracleum maximum	absent	Perennial	-4.69	513.03	0.19	16.34	7.61	-22.66	-22.37	10.17
Kochia scoparia	absent	Annual	1.59	607.08	0.22	24.63	8.5	-15.57	-14.9	15.63
Lactuca biennis	absent	Biennial	-2.07	375.96	0.23	12.09	7.2	-18.05	-13.74	6.86
Lathyrus palustris	absent	Perennial	-5.22	469.27	0.18	17.48	7.15	-23.55	-22.99	10.68
Lepidium densiflorum	absent	Annual	1.99	285.86	0.21	21.23	7.32	-15.29	-14.96	12.85
Leucanthemum vulgare	absent	Perennial	-0.87	404.08	0.22	17.52	7.85	-18.28	-17.97	11.54
Linum usitatissimum	absent	Annual	-0.63	475.94	0.24	21.86	9.02	-11.52	-6.83	10.24
Malva neglecta	absent	Annual	3.47	862.23	0.22	23.03	8.1	-11.18	-6.54	16.41
Medicago lupulina	absent	Annual	1.37	311.68	0.22	19.53	8.13	-15.26	-14.93	12.02
Medicago sativa	absent	Annual	1.37	311.68	0.22	19.88	8.99	-15.56	-14.93	11.9
Mertensia paniculata	absent	Perennial	-4.89	286.24	0.19	11.54	7.72	-23.19	-22.65	6.76
Persicaria lapathifolia	absent	Annual	-4.64	521.28	0.19	17.8	8.12	-22.6	-22.3	10.73
Phleum pratense	absent	Perennial	-4.88	320.12	0.19	11.54	7.2	-23.19	-22.64	6.76
Poa compressa	absent	Perennial	-4.63	372.4	0.19	17.81	7.95	-22.6	-22.29	10.74
Poa pratensis	absent	Perennial	-4.9	303.87	0.19	15.95	7.32	-23.21	-22.66	7.53
Polygonum ramosissimum	absent	Annual	1.86	410.95	0.23	20.78	7.83	-14.67	-13.85	11.93
Populus tremuloides	absent	Perennial	-6.59	220.86	0.06	7.29	0.61	-24.44	-22.29	2.59
Rubus idaeus	absent	Perennial	-5.02	285.56	0.2	12.23	3.56	-22.67	-22.42	6.72
Rumex crispus	absent	Perennial	-2.1	311.68	0.21	17.5	7.32	-16.63	-14.48	8.34
Senecio vulgaris	absent	Annual	-2.61	488.38	0.2	15.95	7.74	-16.24	-14.82	9.7
Setaria viridis	absent	Annual	1.19	607.82	0.22	23.14	7.84	-15.56	-15.15	15.78
Silene noctiflora	absent	Annual	0.09	461.3	0.21	16.97	7.32	-15.36	-15.04	10.18
Sisymbrium altissimum	absent	Annual	2.09	334.02	0.21	22.05	7.32	-14.03	-13.72	12.46
Sonchus arvensis	absent	Perennial	0.93	284.54	0.22	21.58	8.42	-15.78	-15.48	13.07
Sonchus oleraceus	absent	Annual	1.84	518.37	0.23	21.66	8.66	-15.56	-14.63	15.65
Stellaria media	absent	Annual	-4.88	443.75	0.19	18.11	7.87	-23.19	-22.64	11.24
Thermopsis rhombifolia	absent	Perennial	1.2	284.54	0.23	20.17	10.41	-15.39	-15.14	11.94
Trifolium hybridum	absent	Annual	-4.63	311.68	0.19	17.5	7.74	-22.6	-22.29	9.42
Trifolium repens	absent	Perennial	-2.09	336.65	0.22	17.57	7.02	-19.89	-17.22	8.48
Triticum aestivum	absent	Annual	5.78	894.91	0.25	23.03	9.54	-5.95	-5.42	16.41
Vicia americana	absent	Perennial	-2.91	286.41	0.21	14.55	6.92	-21.91	-15.37	8.47
Achillea millefolium	present	Perennial	-5.44	274.48	0.18	10.23	6.4	-24.38	-23.21	5.79
Artemisia absinthium	present	Perennial	1.98	461.3	0.22	21.37	8.94	-15.56	-14.93	13.35
Artemisia biennis	present	Annual	-4.88	214.13	0.19	17.49	8.14	-23.19	-22.64	10.43
Brassica rapa	present	Annual	1.73	869.35	0.24	22.91	9.45	-13.13	-10.56	15.35
Capsella bursa-pastoris	present	Annual	-4.89	365.16	0.19	17.5	7.74	-23.19	-22.65	11.23
Chenopodium album	present	Annual	-4.57	317.17	0.19	17.89	7.84	-22.55	-22.23	10.81
Chenopodium glaucum	present	Annual	2.68	626.08	0.23	22.83	8.08	-14.2	-13.28	15.88
Chenopodium simplex	present	Annual	0.54	583.33	0.22	20.76	7.84	-16.84	-16.62	15.05
Cirsium arvense	present	Perennial	-1.68	284.54	0.22	16.25	7.82	-18.28	-17.97	8.92
Collomia linearis	present	Annual	-2.33	341.82	0.22	18.33	8.31	-15.55	-15.1	7.67
Crepis tectorum	present	Annual	-4.89	407.37	0.19	15.86	8.29	-23.19	-22.65	9.15
Descurainia sophia	present	Annual	1.29	318.87	0.22	20.93	8.2	-15.57	-14.64	11.28
Elymus repens	present	Perennial	-2.06	461.3	0.22	16.34	7.2	-19.88	-17.21	11.03
Erysimum cheiranthoides	present	Annual	-4.89	396.83	0.19	16.05	7.8	-23.19	-22.65	8.83
Galeopsis tetrahit	present	Annual	0.61	416.43	0.24	18.39	9.04	-16.62	-13.43	11.21
Galium aparine	present	Annual	-0.57	448.98	0.23	21.29	8.11	-17.71	-14.33	11.6
Lappula squarrosa	present	Annual	-2.1	304	0.22	13.2	8.3	-15.6	-14.9	7.5
Linaria vulgaris	present	Perennial	0.06	382.7	0.22	20.29	8.14	-15.3	-15.01	9.86
Melilotus officinalis	present	Annual	-0.87	311.68	0.22	20.7	8.3	-18.28	-17.97	12.57
Plantago major	present	Perennial	-4.63	311.68	0.19	11.7	7.2	-22.59	-22.29	6.68
Potentilla norvegica	present	Annual	-4.63	318.87	0.19	14.57	8.3	-22.59	-22.29	8.34
Rosa acicularis	present	Perennial	-5.05	233.43	0.06	7.29	0.61	-23.54	-22.77	2.59
Rumex fueginus	present	Annual	-4.84	341.92	0.19	17.49	8.06	-22.8	-22	10.32
Silene vulgaris	present	Perennial	1.56	615.92	0.22	22.72	8.32	-15.36	-15.04	15.2
Taraxacum officinale	present	Perennial	-2.85	274.48	0.22	11.54	7.02	-21.82	-17.22	6.6
Thlaspi arvense	present	Annual	-0.35	327.78	0.23	19.83	8.13	-15.56	-14.63	10.35
Urtica dioica	present	Perennial	-1.6	303.87	0.22	16.5	7.72	-20.09	-14.69	8.09
		Average								
		Absent	-1.292244898	416.178979592	0.2093878	17.88918367	7.696326531	-17.8412245	-16.4744898	10.64612245
		Present	-1.8165384615	393.807307692	0.2073077	17.69307692	7.803846154	-18.93	-17.6807692	10.38038462

Agrostis scabra	MinMeanTemperatureofWettestQuarter	MinMinTemperatureofColdestPeriod	MinPrecipitationofColdestQuarter	MinPrecipitationofDriestPeriod	MinPrecipitationofDriestQuarter	MinPrecipitationofWarmestQuarter	MinPrecipitationofWettestPeriod	MinPrecipitationofWettestQuarter	MinPrecipitationSeasonalityCofV	MinTemperatureAnnualRange
Agrostis stolonifera	-9.89	-30.98	32.18	2.02	32.18	109.23	11.76	128.85	7.53	29.63
Amaranthus retroflexus	-10.75	-31.17	39.8	2.33	38.73	109.33	12.57	131.21	7.88	31.21
Anemone canadensis	-5.43	-24.07	44.74	2.73	44.74	120.58	13.48	132.78	7.73	31.28
Artemisia campestris	-5.62	-29.63	32.18	2.02	32.18	115.6	13.01	128.85	7.93	29.86
Artemisia ludoviciana	-7.69	-26.84	44.9	2.61	44.9	120.73	13.52	132.98	11.29	32.93
Atriplex patula	-2.92	-25.41	32.18	2.02	32.18	107.16	12.24	128.72	8.62	33.37
Avena sativa	-3.58	-23.73	58.48	3.96	57.74	153.49	17.71	189.95	8.95	30.15
Barbarea vulgaris	-3.25	-19.08	118.44	6.9	116.89	248.41	21.34	250.76	8.1	35.78
Brassica juncea	-6.07	-24.12	68.93	4.35	68.15	217.82	20.58	234.88	8.06	33.91
Bromus inermis	-2.11	-18.79	110.02	6.44	110.02	214.9	20.32	227.75	11.89	35.34
Camelina microcarpa	-12.05	-25.23	44.9	2.37	44.9	120.73	13.52	132.98	8.07	29.61
Cerastium fontanum	8.95	-15.93	27.08	1.76	26.66	111.48	13	140.07	11.63	35.78
Dracocephalum parviflorum	-4.65	-30.12	58.48	3.96	57.74	204.6	19.52	225.83	8.8	35.11
Galium boreale	-2.9	-25.41	33.02	2.25	32.7	129.79	14	155.96	7.96	33.47
Geranium bicknellii	-12.21	-30.15	32.18	2.02	32.18	100.7	9.55	111.57	6.89	28.68
Helianthus annuus	-4.65	-28.75	37.51	2.15	36.83	159.76	16.27	159.76	6.21	32.68
Heracleum maximum	-4.62	-25.36	56.09	3.11	52.29	117.81	13.55	142.01	8.1	35.78
Kochia scoparia	-6.03	-30.13	58.11	4.02	57.25	132.56	14.53	167	7.82	29.62
Lactuca biennis	-0.18	-25.41	68.56	4.31	67.86	210.12	20.08	234.17	10.18	35.44
Lathyrus palustris	-6.51	-27.55	46.1	2.81	45.49	128.54	14.95	161.89	7.28	28.63
Lepidium densiflorum	-4.59	-30.74	55.05	0.1	29.93	33.94	18.09	200.27	6.89	16.58
Leucanthemum vulgare	-4.45	-24.2	36.97	2.14	35.82	120.13	13.48	128.98	7.7	34.27
Linum usitatissimum	-5.58	-27.9	58.32	2.56	54.96	150.97	13.11	152.31	7.28	31.04
Malva neglecta	-4.45	-19.43	101.97	6.44	101.63	130.87	13.63	156.8	8.48	35.34
Medicago lupulina	-4.42	-19.63	110.02	6.44	110.02	246.48	20.86	246.48	8.74	35.34
Medicago sativa	-7.74	-24.79	33.63	2.01	33.63	113.12	13.16	137.61	7.54	33.21
Mertensia paniculata	-4.62	-25.39	33.63	2.01	33.63	113.12	13.16	134.85	7.89	34.47
Persicaria lapathifolia	-10.99	-30.51	45.4	1.19	28.82	113.96	13.21	133.03	15.62	29.55
Phleum pratense	-0.58	-30.15	58.48	3.96	57.74	212.57	20.42	225.78	10.86	34.67
Poa compressa	-10.75	-30.51	35.83	2.04	35.83	104.42	12.1	125.72	7.39	30.16
Poa pratensis	-5	-30.15	54.75	3.37	53.51	117.82	13.55	142.03	7.54	34.35
Polygonum ramosissimum	-5.77	-30.52	26.2	1.69	25.79	105.07	11.76	126.49	7.54	32.09
Populus tremuloides	-4.37	-24.21	58.48	3.96	57.74	149.24	16.45	161.68	9.58	29.35
Rubus idaeus	-11.96	-32.24	29.28	0.69	22.94	41.39	6.06	70.77	6.05	9.32
Rumex crispus	-11.05	-31.09	26.2	1.69	25.79	85.07	8.23	96.1	8.22	8.29
Senecio vulgaris	-7.74	-26.38	33.63	2.01	33.63	109.27	12.56	131.12	7.39	30.99
Setaria viridis	-4.74	-24.79	66.02	3.74	61.21	180.06	17.5	199.8	8.14	31.14
Silene noctiflora	-5.97	-25.39	68.56	4.31	67.86	231.66	19.65	235.33	8.1	35.56
Sisymbrium altissimum	-5.46	-24.57	56.09	3.11	52.29	175.16	18.06	204.5	7.96	29.85
Sonchus arvensis	-4.68	-23.7	49.55	2.93	49.32	121.28	13.79	134.93	7.85	35.17
Sonchus oleraceus	-5.58	-25.11	32.18	2.02	32.18	115.6	13.01	128.85	7.54	34.84
Stellaria media	-4.09	-25.39	66.02	4.41	65.89	204.66	19.78	221.41	8.1	31.76
Thermopsis rhombifolia	-4.59	-30.51	56.09	2.94	52.29	206.14	18.96	209.84	8.1	31.25
Trifolium hybridum	9.78	-25.23	32.18	2.02	32.18	115.6	13.01	127.55	18.61	33.9
Trifolium repens	-8.63	-30.15	33.63	2.01	33.63	113.12	12.44	137.49	7.54	33.69
Triticum aestivum	-5.58	-29.35	41.75	2.64	40.73	109.33	12.57	131.21	7.54	30.52
Vicia americana	-2.59	-13.26	118.44	6.71	116.89	265.53	24.39	296.69	13.16	35.34
Achillea millefolium	-8.76	-30.01	35.32	1.89	35.32	118.1	11.45	127.36	10.39	26.04
Artemisia absinthium	-12.47	-31.26	21.07	0.72	20.66	64.78	9.01	101.07	7.44	20.11
Artemisia biennis	-4.34	-25.39	56.09	3.11	52.29	202.14	18.78	204.23	7.79	35.34
Brassica rapa	-3.31	-30.51	34.2	2.26	34.2	55.87	8.65	75.36	8.45	35.1
Capsella bursa-pastoris	-5.62	-21.87	118.44	6.71	116.89	243.57	20.78	250.17	7.89	35.34
Chenopodium album	-4.76	-30.51	54.79	3.26	51.47	120.44	13.49	143.51	7.7	33.91
Chenopodium glaucum	-4.59	-30.12	42.44	2.31	41.39	120.73	13.75	129.83	7.54	32.98
Chenopodium simplex	-4.14	-23.8	65.35	4.43	64.38	214.1	19.51	231.48	7.12	33.5
Cirsium arvense	-5.16	-27.5	59.28	3.96	58.49	239.39	20.97	241.99	6.21	29.59
Collomia linearis	-8.63	-27.9	32.18	2.01	32.18	108.65	12.44	128.85	7.39	30.99
Crepis tectorum	-7.74	-25.36	46.94	3.12	46.82	110.38	12.73	132.75	8.08	33.39
Descurainia sophia	-7.43	-30.51	56.51	2.8	49.77	152.15	16.92	164.58	8.08	32.42
Elymus repens	-1.22	-25.41	44.74	2.41	44.74	120.58	13.48	132.78	10.59	35.89
Erysimum cheiranthoides	-5.58	-29.34	56.09	3.11	52.29	205.37	20.21	221.83	7.54	29.84
Galeopsis tetrahit	-10.66	-30.51	56.51	3.65	55.11	116.76	12.65	142.87	7.83	33.44
Galium aparine	-7.9	-25.07	53.09	2.37	50.38	160.42	17.08	189.94	8.03	32.56
Lappula squarrosa	-4.13	-26.92	64.93	3.78	59.91	163.14	17.28	176.47	7.32	29.97
Linaria vulgaris	-7.7	-25.4	35	0	35	123	14	137	8	31.4
Melilotus officinalis	-7.12	-24.79	58.73	3.3	55.64	127.99	13.94	152.56	7.54	32.9
Plantago major	-6.53	-27.9	33.63	2.01	33.63	113.12	12.44	137.49	7.54	32.98
Potentilla norvegica	-11.99	-30.14	33.63	2.01	33.63	113.12	13.11	139.64	7.54	30.04
Rosa acicularis	-10.53	-30.14	44.74	2.73	44.74	115.72	12.78	132.78	7.37	32.65
Rumex fueginus	-12.21	-30.84	32.18	0.31	7.03	11.5	6.94	75.1	8.31	9.32
Silene vulgaris	-4.48	-30.13	49.54	2.66	49.28	126.37	12.97	137.61	7.3	31.27
Taraxacum officinale	-5.92	-24.57	68.13	4.22	67.43	205.4	19.51	233.99	7.92	35.34
Thlaspi arvense	-12.09	-29.4	21.07	1.3	20.66	103.1	11.58	128.85	7.54	29.86
Urtica dioica	-6.95	-25.39	47.69	2.88	47.67	113.24	12.94	134.08	8.11	33.44
	-8.76	-27.59	26.2	1.69	25.79	109.33	12.57	131.21	7.82	31.88
Average										
Absent	-5.5016327	-26.416735	51.4004081633	2.9773469388	49.662653	140.8530612	14.87653061	162.1228571	8.695918367	30.94795918
Present	-6.9034615	-27.577308	49.6969230769	2.7846153846	47.338846	138.2915385	14.67307692	157.9596154	7.790384615	31.74384615

Agrostis scabra	MinTemperatureSeasonalityCofV	SDAnnualMeanTemperature	SDAnnualPrecipitation	SDIsothermality	SDMaxTemperatureofWarmestPeriod	SDMeanDiurnalRange	SDMeanTemperatureofColdestQuarter	SDMeanTemperatureofDriestQuarter	SDMeanTemperatureofWarmestQuarter	SDMeanTemperatureofWettestQuarter
Agrostis stolonifera	2.59	3.21	240.99	0.05	3.1	1.8	4.53	7.34	3.34	6.5
Amaranthus retroflexus	2.72	2.88	284.68	0.06	2.93	2.39	4.3	9.07	2.96	7.76
Anemone canadensis	2.71	2.83	144.78	0.02	2.59	1.04	3.37	8.47	2.53	8.5
Artemisia campestris	2.56	3.75	231.74	0.03	2.78	1.22	5.37	7.86	2.94	7.58
Artemisia ludoviciana	2.83	3.68	201.38	0.03	3.65	1.25	4.43	5.22	3.78	6.11
Atriplex patula	2.68	3.67	242.04	0.05	3.33	1.67	3.62	5.17	4.22	4.92
Avena sativa	2.64	2.63	137.15	0.03	2.9	1.31	2.79	8.76	2.75	8.53
Barbarea vulgaris	3.07	2.07	88.04	0.02	1.64	0.66	2.63	7.62	1.64	3.83
Brassica juncea	2.92	3.35	121.64	0.02	2.92	1.02	3.99	7.93	2.93	9.07
Bromus inermis	3.07	2.02	97.53	0.02	1.83	0.74	2.47	6.91	1.73	3.92
Camelina microcarpa	2.71	4.65	217.93	0.03	5.42	1.36	4.16	6.41	5.39	8.31
Cerastium fontanum	2.88	2.21	152.66	0.03	1.91	1.5	2	3.56	2.39	3.24
Dracocephalum parviflorum	3.08	2.66	120.37	0.01	1.93	1.2	4.03	7.16	2.05	7.52
Galium boreale	2.54	3.79	202.84	0.04	2.58	1.11	5.67	7.47	2.75	4.74
Geranium bicknellii	2.68	1.72	135.73	0.04	2.22	1.19	3.76	4.5	2.03	4.25
Helianthus annuus	2.82	2.92	229.24	0.04	2.77	1.12	4.3	9.6	2.78	8.31
Heracleum maximum	2.8	2.78	139.34	0.03	2.17	0.94	3.28	7.26	2.49	4.46
Kochia scoparia	2.49	4.03	259.68	0.05	3.61	1.72	5.96	9.64	3.21	8.74
Lactuca biennis	3.29	2.1	106.89	0.01	0.94	0.9	3.58	7.11	1.23	5.05
Lathyrus palustris	2.59	3.31	177.09	0.02	2.73	1.11	4.4	7.91	2.81	9.27
Lepidium densiflorum	0.97	4.38	246.57	0.06	3.59	1.34	6.36	11.3	3.42	9.19
Leucanthemum vulgare	2.79	3.09	190.32	0.03	2.68	1.33	3.49	7.63	2.89	7.37
Linum usitatissimum	2.7	3.63	157.55	0.02	3.36	1.16	4.34	9.37	3.27	10
Malva neglecta	3.07	3.36	149.23	0.03	2.97	1.4	3.06	5.72	3.55	7.55
Medicago lupulina	3.07	2.1	87.9	0.02	2.1	0.89	2.3	5.27	1.98	6.01
Medicago sativa	2.8	3.44	166.55	0.03	3.14	1.23	3.82	8.35	3.3	9.07
Mertensia paniculata	2.94	3.56	213.4	0.02	3	0.78	4.21	7.94	3.21	6.47
Persicaria lapathifolia	2.6	1.39	117.36	0.04	1.87	0.85	3.57	3.74	1.59	2.34
Phleum pratense	3.26	3.93	147.91	0.01	2.38	1.33	6.16	7.76	2.63	4.84
Poa compressa	2.61	3.87	258.54	0.05	3.91	1.91	4.05	7.5	4.32	7.43
Poa pratensis	2.76	3.48	158.83	0.03	3.02	1.47	4.12	8.1	3.22	8.16
Polygonum ramosissimum	2.67	4.12	276.46	0.06	3.37	2.38	4	8.05	4.56	7.49
Populus tremuloides	2.57	3.27	187.29	0.03	2.84	1.07	4.19	9.66	2.87	7.57
Rubus idaeus	0.66	2.99	243.93	0.05	2.86	1.46	5.02	7.87	2.74	7.21
Rumex crispus	0.45	2.02	231.34	0.04	2.21	1.3	3.98	5.83	1.87	8.29
Senecio vulgaris	2.69	3.86	239.84	0.04	3.4	1.8	3.71	8.57	4.1	8.92
Setaria viridis	2.71	3.19	176.44	0.02	3.35	1.2	3.79	7.75	3.24	8.65
Silene noctiflora	3.07	2.97	121.45	0.02	2.37	0.82	3.75	8.19	2.42	6.63
Sisymbrium altissimum	2.61	3.39	204.31	0.02	3.5	1.07	3.79	7.44	3.49	9.66
Sonchus arvensis	2.79	2.86	158.78	0.03	2.59	1.03	3.1	6.94	2.75	7.23
Sonchus oleraceus	2.89	3.09	252.71	0.02	2.88	1.05	3.71	9.52	2.92	10.33
Stellaria media	2.75	3.05	138.18	0.02	2.72	0.85	3.86	7.34	2.67	7.29
Thermopsis rhombifolia	2.71	3.14	139.85	0.02	2.89	1.17	3.74	8.4	2.81	7.21
Trifolium hybridum	2.84	1.13	123.69	0.03	2.34	0.92	2.11	5.11	1.94	2.16
Trifolium repens	2.77	4.32	260.05	0.04	4.11	1.17	4.85	8.1	4.37	7.54
Triticum aestivum	2.71	4.22	258.37	0.05	3.62	1.97	4.34	8.18	4.45	8.1
Vicia americana	3.07	1.68	91.8	0.02	1.69	0.56	2.03	7.18	1.55	4.7
Achillea millefolium	2.32	1.66	114.23	0.04	1.87	0.89	3.7	4.28	1.8	3.85
Artemisia absinthium	1.54	1.88	190.57	0.04	2.29	1.21	4.05	5.45	1.93	7.5
Artemisia biennis	3.02	2.98	257.6	0.05	3.44	1.79	4.21	6.49	3.34	6.93
Brassica rapa	2.81	3.07	203.02	0.02	2.59	0.99	4.18	9.55	2.63	9.72
Capsella bursa-pastoris	3.07	3.9	206.08	0.03	2.96	1.43	5.29	6.61	3.11	5.61
Chenopodium album	2.82	3.55	100.03	0.02	2.81	0.7	4.29	8.68	2.98	9.9
Chenopodium glaucum	2.79	3.7	177.55	0.04	3.26	1.37	4.13	8.46	3.54	7.8
Chenopodium simplex	2.92	3.63	205.27	0.03	3.14	1.43	4.22	8.51	3.4	8.5
Cirsium arvense	2.48	2.56	139.42	0.02	2.37	1.13	3.15	7.68	2.32	6.56
Collomia linearis	2.57	3.09	250	0.04	1.83	1.38	5.33	10.61	1.84	8.07
Crepis tectorum	2.6	3.32	272.59	0.05	3.24	1.95	3.59	8.19	3.8	8.44
Descurainia sophia	2.83	2.87	210.71	0.07	2.61	2.06	3.5	8.35	3.72	7.16
Elymus repens	2.77	3.3	251.25	0.02	2.8	1.27	4.92	9.62	2.78	8.01
Erysimum cheiranthoides	2.61	2.95	198.71	0.04	2.54	1.66	3.06	6.59	3.07	5.88
Galeopsis tetrahit	2.89	2.66	192.89	0.02	2.62	1.39	4.06	8.87	2.32	9.02
Galium aparine	2.84	3.73	217.08	0.04	3.54	1.61	4.12	7.81	3.85	8.93
Lappula squarrosa	2.61	2.62	226.11	0.03	2.77	1.09	3.23	4.03	2.8	7.97
Linaria vulgaris	2.85	3.79	150.79	0.03	2.87	1.27	4.79	8.34	3.22	5.3
Melilotus officinalis	2.35	3.08	201.92	0.04	3.58	1.52	4.04	8.44	3.61	9.31
Plantago major	2.78	3.41	162.91	0.03	2.98	1.24	3.92	8.11	3.21	10.01
Potentilla norvegica	2.74	3.49	174.72	0.03	3.01	1.08	4	8.75	3.21	9.33
Rosa acicularis	2.87	3.25	256.02	0.03	3.18	1.5	4.25	8.66	3.14	9.19
Rumex fueginus	0.66	4.3	227.79	0.03	3.64	1.08	5.6	8.84	3.69	8.85
Silene vulgaris	2.64	3.29	225.55	0.03	2.62	1.47	4.6	11.75	2.75	9.6
Taraxacum officinale	3.07	1.77	148.02	0.01	1.29	1.06	2.74	9.58	1.29	10.08
Thlaspi arvense	2.64	3.31	241.04	0.05	3.41	1.98	3.81	5.69	3.75	6.44
Urtica dioica	2.77	3.96	228.82	0.04	3.51	1.57	3.53	7.79	4.39	7.65
	2.68	4.14	252.42	0.05	3.89	1.68	4.57	5.24	4.47	6.12
Average										
Absent	2.63387755	3.04755102	180.31	0.0318367347	2.7932653	1.242040816	3.915102041	7.377755102	2.894081633	6.925918367
Present	2.68	3.29692308	206.858076923	0.0342307692	2.9423077	1.411538462	4.120384615	8.124615385	3.162692308	8.091538462

Species	SDMinTemperatureofColdestPeriod	SDPrecipitationofColdestQuarter	SDPrecipitationofDriestPeriod	SDPrecipitationofDriestQuarter	SDPrecipitationofWarmestQuarter	SDPrecipitationofWettestPeriod	SDPrecipitationofWettestQuarter	SDPrecipitationSeasonalityCofV	SDTemperatureAnnualRange	SDTemperatureSeasonalityCofV
Agrostis scabra	5.26	77.45	4.53	64.39	52.77	4.19	54.5	18.83	4.86	0.65
Agrostis stolonifera	5.21	97.02	5.19	74.85	61.13	5.16	67.06	17.86	4.96	0.63
Amaranthus retroflexus	3.64	67.4	4	52.54	25.96	2.62	33.79	9.79	2.64	0.28
Anemone canadensis	6.34	84.64	4.81	67.61	36.76	3.8	49.14	16.34	5.02	0.55
Artemisia campestris	5.27	56.33	2.95	44.66	44.99	3.38	46.31	15.45	4.02	0.47
Artemisia ludoviciana	4.14	51.39	3.09	47.86	69.72	5.02	65.62	11.45	3.46	0.49
Atriplex patula	3.11	68.45	3.76	50.11	29.57	2.69	36.11	9.61	2.93	0.29
Avena sativa	2.78	47.8	3.09	38.92	17.64	1.79	20.3	6.55	1.61	0.19
Barbarea vulgaris	4.52	61.54	3.67	48.31	22.59	2.36	28.95	9.35	2.8	0.28
Brassica juncea	2.62	51.52	3.21	39.97	22.95	2.12	24.71	7.06	1.79	0.2
Bromus inermis	4.37	65.61	3.84	54.63	42.95	3.63	47.32	16.06	3.58	0.4
Camelina microcarpa	2.08	43.39	2.94	40.97	43.08	3.4	42.81	8.32	1.87	0.19
Cerastium fontanum	5.5	54.81	3.45	45.59	20.22	1.93	22.13	12.68	4.36	0.39
Dracocephalum parviflorum	6.48	75.99	4.64	66.54	38.78	3.4	40.69	17.84	4.48	0.57
Galium boreale	4.19	46.45	2.4	36.49	44.23	3.64	41.63	16.2	4.77	0.7
Geranium bicknellii	5.18	87.12	5.51	77.22	37.7	2.89	35.52	19.81	4.65	0.55
Helianthus annuus	3.57	53.57	3.52	46.01	29.74	2.57	32.23	9.54	2.22	0.27
Heracleum maximum	6.75	100.14	4.98	73.83	43.35	5.02	63.77	13.29	5.92	0.65
Kochia scoparia	4.88	46.06	3.07	42.47	19.59	1.67	15.78	12.57	4.19	0.4
Lactuca biennis	5.3	76.3	4.55	64.37	35.13	2.8	34.2	14.06	4.16	0.42
Lathyrus palustris	7.09	130.09	5.21	72.9	46.74	7.17	90.27	15.36	5.82	0.67
Lepidium densiflorum	3.86	63.79	3.99	54.49	46.19	3.72	49.01	11.07	2.62	0.28
Leucanthemum vulgare	4.91	70.95	4.09	54.38	28.25	2.99	37.31	10.51	3.5	0.36
Linum usitatissimum	3.22	59.22	3.25	45.85	44.56	3.55	42.39	7.83	2.01	0.22
Malva neglecta	2.38	52.27	3.32	41.3	20.51	2.01	23.26	7.47	1.74	0.16
Medicago lupulina	4.19	62.28	3.83	52.01	42.37	3.39	42.48	10.67	2.86	0.31
Medicago sativa	4.56	65.65	4.17	58.04	43.12	3.47	48.17	12.48	2.41	0.3
Mertensia paniculata	3.89	34.88	1.65	26.24	35.27	3.1	35.59	13.36	4.91	0.68
Persicaria lapathifolia	7.8	64.61	4.15	60.81	20.43	1.93	17.86	19.15	6.18	0.61
Phleum pratense	4.54	78.05	4.61	64.95	60.05	4.77	61.01	17.52	3.57	0.48
Poa compressa	4.72	61.1	3.64	48.41	38.73	3.34	41.91	10.48	3.27	0.35
Poa pratensis	4.54	81.64	4.55	65.34	67.28	5.46	71.77	11.91	3.16	0.46
Polygonum ramosissimum	4.74	74.1	4.62	61.91	35.58	2.76	37.81	12.71	3.59	0.41
Populus tremuloides	5.76	80.42	4.44	62.27	62.64	5.59	66.99	17.23	5.78	0.75
Rubus idaeus	4.95	98.75	3.33	47.68	50.61	6.86	80.96	18.78	5.14	0.66
Rumex crispus	4.05	75.05	4.39	61.91	57.84	4.59	60.78	11.06	2.75	0.34
Senecio vulgaris	4.68	71.06	3.95	54.45	30.47	2.81	40.1	12.71	3.82	0.38
Setaria viridis	4.18	58.63	3.52	46.51	20.08	2.21	27.3	8.83	2.55	0.28
Silene noctiflora	4.34	83.07	4.65	65.1	36.38	3.15	41.86	14.35	3.85	0.4
Sisymbrium altissimum	3.26	65.15	3.85	51.99	36.14	3.03	38.58	8.95	2.06	0.25
Sonchus arvensis	4.19	90.96	5.2	74.61	44.36	3.45	51.04	17.11	3.17	0.35
Sonchus oleraceus	4.37	65.33	3.8	50.77	23	2.07	26.17	10.06	3.19	0.35
Stellaria media	4.05	61.24	3.67	47.6	26.8	2.73	34.82	9.83	2.64	0.28
Thermopsis rhombifolia	2.63	38.79	1.75	30.34	41.81	2.92	41.03	12.83	4.02	0.46
Trifolium hybridum	5.31	80.85	5.03	71.71	43.35	3.62	49.05	19.92	3.26	0.43
Trifolium repens	4.85	79.07	4.56	65.06	62.87	4.95	63.96	11.49	3.35	0.45
Triticum aestivum	2.05	51.33	3.14	40.46	15.52	1.52	16.93	5.71	1.38	0.18
Vicia americana	4.08	38.98	1.71	26.79	40.32	3.6	40.6	14.45	4.6	0.67
Achillea millefolium	5	76.56	2.49	37.06	55.32	6.3	72.92	16.95	5.65	0.72
Artemisia absinthium	4.7	83.64	4.67	65.76	56.28	4.91	60.93	19.67	4.82	0.65
Artemisia biennis	5.02	83.12	4.85	69.83	30.88	2.85	41.36	16.38	4.05	0.44
Brassica rapa	6.03	62.38	4.15	58.31	49.33	3.93	50.83	14.95	4.26	0.48
Capsella bursa-pastoris	4.71	58.86	3.54	45.33	19.67	2.36	26.24	8.27	2.47	0.27
Chenopodium album	4.47	64.94	3.91	52.97	40.83	3.23	41.74	10.39	2.65	0.34
Chenopodium glaucum	4.68	74.81	4.48	62.47	41.39	3.51	46.92	13.27	3.23	0.37
Chenopodium simplex	3.69	64.08	3.65	47.53	30.06	3.18	42.45	9.94	3.09	0.28
Cirsium arvense	6.55	94.22	5.55	81.72	34.01	3.65	44.97	17.22	5.7	0.62
Collomia linearis	4.23	85.7	4.88	70.18	63.65	4.87	64.22	16.32	3.81	0.5
Crepis tectorum	4.31	70.58	3.41	50.85	68.88	4.78	61.15	13.82	4.48	0.67
Descurainia sophia	6.04	90.19	5.4	76.02	34.94	3.2	45.32	20.55	5.09	0.55
Elymus repens	3.7	56.49	3.81	51.46	53.24	3.91	52.85	12.1	2.95	0.3
Erysimum cheiranthoides	5.41	77.2	4.16	59.62	29.33	3.07	41.23	13.4	5.29	0.5
Galeopsis tetrahit	4.6	78.45	4.32	62.04	49.96	3.99	50.24	13.94	3.43	0.41
Galium aparine	4.13	77.39	4.88	69.18	33.61	2.69	32.39	23.18	3.18	0.33
Lappula squarrosa	5.59	56.11	3.53	47.63	32.93	2.92	37.79	11.07	3.88	0.4
Linaria vulgaris	5.33	74.46	7	63.09	40.6	3.03	39.6	17.56	5.67	0.62
Melilotus officinalis	4.39	71.16	4.14	56.67	34.54	2.96	37.54	11.56	3.11	0.35
Plantago major	4.4	71.77	4.24	58.16	35.88	3.04	38.72	11.69	2.68	0.32
Potentilla norvegica	5.08	88.43	5.27	74.13	41.19	3.93	51.01	18.3	4.33	0.47
Rosa acicularis	6.2	81.56	4.83	68.78	36.45	3.38	44.93	16.68	4.12	0.51
Rumex fueginus	5.38	92.68	5.06	72.38	33.71	3.44	47.99	15.88	4.57	0.48
Silene vulgaris	3.68	59.85	3.14	45.64	27.78	2.91	36.1	8.31	3.37	0.3
Taraxacum officinale	4.51	74.67	4.59	63.07	51.55	4.22	53.29	19.54	3.83	0.51
Thlaspi arvense	3.79	67.15	3.9	56.46	58.87	4.37	58.63	9.69	2.59	0.35
Urtica dioica	4.85	63.9	3.74	56.36	66.41	5.03	63.37	17.13	3.39	0.55
Average										
Absent	4.47714286	67.894898	3.8318367347	53.4342857143	39.090612	3.492653061	43.96938776	12.92734694	3.615102041	0.424693878
Present	4.82576923	73.9919231	4.4269230769	60.9861538462	42.152692	3.590769231	46.60807692	14.64653846	3.847692308	0.445

Appendix 4.1 RDA code and output

```
library(vegan)
library(MASS)

burmccatest3 <-read.table(file="C:/Documents and Settings/default/My Documents/burmccatest4.txt", sep="\t", header=TRUE)
burmccatest3

burmcca.test3 <- metaMDS(burmccatest3, trace = FALSE)
burmcca.test3
plot(burmcca.test3, type = "t")

plots <- c("Top", "North", "West", "East", "South")
rownames(burmccatest3) <- plots
faces <-c("Top","North", "West", "East","South" )
faces

vare.dca <- decorana(burmccatest3)
vare.dca

burmRDA.test3 <- rda(burmccatest3)
burmRDA.test3
burmRDA.test4 <- rda(burmccatest3, scale = TRUE)
burmRDA.test4
burmCCA.test4 <- cca(burmccatest3, scale = TRUE)
burmCCA.test4

biplot(burmRDA.test4,type = "text", scaling = -3)
```

```
R version 3.0.2 (2013-09-25) -- "Frisbee Sailing"
Copyright (C) 2013 The R Foundation for Statistical Computing
Platform: i386-w64-mingw32/i386 (32-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
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Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.
```

```
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Previously saved workspace restored]

> library(vegan)
Loading required package: permute
Loading required package: lattice
This is vegan 2.0-9
> library(MASS)
>
> burmccatest3 <-read.table(file="C:/Documents and Settings/default/My
Documents/burmccatest4.txt", sep="\t", header=TRUE)
> burmccatest3
Achiellea.millefollium Chenopodium.album Chenopodium.hybridium
1 0.139 0.1390 0.4165
2 0.000 0.8335 0.0000
3 0.417 0.7445 0.8835
4 0.000 0.0000 0.0000
5 0.000 0.5165 0.0000
Cirsium.arvense Crepis.tectorum Erysimum.cheiranthoides Galeopsis.tetrahit
1 0.0000 0.000 0.00 7.0445
2 0.0000 0.000 0.00 21.6780
3 0.0000 0.139 0.05 1.0000
4 2.6390 0.000 0.00 8.4055
5 3.1945 0.000 0.00 3.9115
Linaria.vulgaris Lychnis.alba Potentilla.norvegica Rumex.spp
1 0.9335 16.9945 0.000 2.5505
2 1.9945 8.5230 0.000 7.6390
3 3.7505 4.5840 2.084 0.0000
4 0.8335 40.4170 0.000 1.2500
5 2.2225 76.6670 0.000 6.9960
Taraxacum.officinale Thlaspi.arvense Urrica.dioica Unknown1
1 0.000 1.3500 14.6335 0.0000
2 0.000 1.9165 20.5555 0.7055
3 0.139 0.0000 0.0500 0.0000
4 0.000 0.1500 23.6110 0.2780
5 0.000 0.0500 0.0000 0.0000
>
> burmcca.test3 <- metaMDS(burmccatest3, trace = FALSE)
Warning messages:
1: In metaMDS(burmccatest3, trace = FALSE) :
```

```
Stress is (nearly) zero - you may have insufficient data
2: In postMDS(out$points, dis, plot = max(0, plot - 1), ...) :
skipping half-change scaling: too few points below threshold
> burmcca.test3

Call:
metaMDS(comm = burmccatest3, trace = FALSE)

global Multidimensional Scaling using monoMDS

Data: wisconsin(sqrt(burmccatest3))
Distance: bray

Dimensions: 2
Stress: 0
Stress type 1, weak ties
No convergent solutions - best solution after 20 tries
Scaling: centring, PC rotation
Species: expanded scores based on 'wisconsin(sqrt(burmccatest3))'

> plot(burmcca.test3, type = "t")
>
> plots <- c("Top", "North", "West", "East", "South")
> rownames(burmccatest3) <- plots
> faces <-c("Top","North", "West", "East","South" )
> faces
[1] "Top" "North" "West" "East" "South"
>
> vare.dca <- decorana(burmccatest3)
> vare.dca

Call:
decorana(veg = burmccatest3)

Detrended correspondence analysis with 26 segments.
Rescaling of axes with 4 iterations.

DCA1 DCA2 DCA3 DCA4
Eigenvalues 0.3219 0.167569 0 0
Decorana values 0.3504 0.007918 0 0
Axis lengths 2.0058 0.828742 0 0

>
> burmRDA.test3 <- rda(burmccatest3)
```

```
> burmRDA.test3
Call: rda(X = burmccatest3)

Inertia Rank
Total 1097
Unconstrained 1097 4
Inertia is variance

Eigenvalues for unconstrained axes:
PC1 PC2 PC3 PC4
911.955 151.105 32.658 1.105

> burmRDA.test4 <- rda(burmccatest3, scale = TRUE)
> burmRDA.test4
Call: rda(X = burmccatest3, scale = TRUE)

Inertia Rank
Total 15
Unconstrained 15 4
Inertia is correlations

Eigenvalues for unconstrained axes:
PC1 PC2 PC3 PC4
8.5355 3.6606 2.0315 0.7724

> burmCCA.test4 <- cca(burmccatest3, scale = TRUE)
> burmCCA.test4
Call: cca(X = burmccatest3, scale = TRUE)

Inertia Rank
Total 0.7244
Unconstrained 0.7244 4
Inertia is mean squared contingency coefficient

Eigenvalues for unconstrained axes:
CA1 CA2 CA3 CA4
0.35044 0.30793 0.05550 0.01052

>
> biplot(burmRDA.test4,type = "text", scaling = -3)
>
```