# The Distribution of Shrubs used by Indigenous Peoples within the Forest-Tundra Ecotone in Canada

Honours Thesis
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## Abstract

Recent densification of shrub cover has been documented in many Arctic regions. Indigenous people have also reported changes in cover and distribution of useful plants (e.g., berries) on their traditional lands. Many studies have focused on factors influencing shrub densification with climate change, but less consideration has been given to the potential changes in shrub spatial pattern across the forest-tundra ecotone which may provide valuable insight into how a response to climate change is being initiated. I investigated trends in abundance and spatial pattern of six shrub species across the forest-tundra ecotone in the Mt. Nansen region of the Yukon, near Churchill, Manitoba and in the Mealy Mountains of southern Labrador, Canada. Shrub cover was measured in contiguous quadrats along transects up to 100 m long located in Forest, Ecotone, and Tundra sections across the forest–tundra transition. Spatial patterns were analyzed using new local variance to estimate patch size and wavelet analysis to determine the scale and amount of aggregation. Results were site-specific, as Churchill had the highest abundance and largest patch sizes in the Forest, opposite to what was found in Mealys and Nansen. Factors such as local topography, interaction between trees and shrubs, and microclimate could cause these differences across the forest-tundra ecotone. However, in all study areas, the greatest distance between patches of shrubs was found in the Ecotone. With climate change, shrubs across the forest-tundra ecotone will likely undergo change, which will likely vary at different sites. Indigenous communities may need to refer to current strategies (i.e., information sharing networks, resource management) used to cope with seasonal variation in productivity of useful plants to deal with more long term changes in shrub cover and distribution.

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**1.0 Introduction**

Recent evidence supports the prediction that climate warming and its subsequent effects will be felt the earliest and the greatest in arctic and subarctic regions, in comparison to other areas of the world (Serreze et al., 2000; Bret-Harte et al., 2002; Danby and Hik, 2007). Implications of this warming involve significant ecological changes in northern ecosystems such as permafrost thaw, increased forest fire frequency, and changing ecosystem boundaries which are also known as 'zones of transition' or 'ecotones' (Myers-Smith, 2007). Currently, many studies have focused on the expected advance of the forest-tundra ecotone by examining treeline migration and increases in tree density (Danby and Hik, 2007; Harsch et al., 2009). However, it is also projected that ecosystem boundaries between the forest and tundra vegetation communities will be altered as the climate continues to warm by increasing the relative abundance and cover of shrub species (Myers-Smith et al., 2011).

With the general consensus that change is occurring in northern ecosystems, indigenous and local peoples are concerned and anxious about its effects on the plants and animals that they rely upon (Turner and Clifton, 2009). Plants (such as berry-producing shrubs) provide essential vitamins and nutrients in a predominantly meat based diet, and also have various medicinal and cultural properties (Karst, 2010). Range shifts and altered patterns of trees and shrubs may affect this traditional way of life. Thus, the residents of the arctic and subarctic, as well as the flora and fauna, will be forced to adapt to the environmental impacts of this change.

**2.0 Background**

**2.1 Forest-Tundra Ecotone**

The forest-tundra ecotone can be defined as the transition zone between forest and tundra at high latitude or elevation (Payette et al., 2001; Lantz et al., 2010; Harper et al., 2011a). Payette et

al. (2001) characterize the boundary by a change in forested landscape with patches of tundra, to a tundra landscape with patches of forest. Northward or upward, trees (typically *Picea, Larix, Pinus* or *Betula*) give way to tundra dominated by tall shrubs. Shrubs are woody plants that have various growth forms. Tall shrubs are 40 – 400 cm in height, and are typically multi-stemmed willows (*Salix* spp*.*), alder (*Alnus* spp*.*), dwarf birches (*Betula* spp.), and a mix of ericaceous shrubs (*Ledum, Vaccinium,* and *Arctostaphylos* spp*.*). At higher latitudes or altitudes, tall shrubs are replaced by erect dwarf shrub tundra (< 40 cm) that is characterized by dwarf shrubs (*Betula, Salix, Vaccinium, Ledum, Empetrum,* and *Dryas*). Further north or uphill, erect dwarf shrubs are replaced by prostrate dwarf shrubs that are less than 10 cm tall. Often the tallest plants northward and upslope of the treeline ecotone are shrub species, which can often form dense thickets with closed canopies in suitable habitats (Lantz et al., 2010; Myers-Smith et al., 2011).

One of the most consistent predictions in response to climate change is that the treeline vegetation within the forest-tundra ecotone will undergo a significant change in structure and position. It is important to note that although the predicted poleward and altitudinal advance of the treeline has been observed in many areas, the rate and magnitude is variable, and treeline vegetation advance is not a worldwide phenomenon (Harsh et al., 2009; Harper et al., 2011a). The variability in treeline advance is due to site and species specific attributes limiting recruitment and growth, along with the magnitude of climate change. Site-specific factors contributing to this variability in advance include facilitative and competitive interactions among trees and shrubs, local disturbance regimes, microtopography, wind, snow, and temperature which may result in different spatial patterns in the forest-tundra ecotone (Gamache and Payette, 2005; Danby and Hik, 2007; Harper et al., 2011a). These dynamics of the forest-tundra ecotone have been studied around the circumpolar arctic with the aim to detect change, understand

responses to climate variation, and evaluate the threat to biota in response to treeline vegetation movement.

**2.2 Shrub Expansion**

Recent shrub expansion has been recognized in some arctic and alpine areas, and continued expansion is expected to have significant effects on the ecosystem. In contrast to the long tradition of treeline research, examination of changes in cover and position of 'shrubby' vegetation has just begun (Hallinger et al., 2010). There is growing evidence from around the arctic that suggests shrub growth in northern tundra biomes has increased over the last several decades (Chapin et al., 2005; Myers-Smith, 2007; Hallinger and Wilmking, 2011). In addition to published studies, northern peoples are also observing increases in shrub cover in their traditional lands (Myers-Smith et al., 2011).

Shrub expansion can be characterized by three categories which involve either a change in clonal growth or seed recruitment (Figure 1). The three categories are: (a) an increase in shrub density such as the infilling of shrub patches through increased lateral growth as well as recruitment between existing patches; (b) an increase in shrub size (radial and vertical growth); and (c) new colonization of areas beyond their previous range limit (Hallinger et al., 2010; Myers et al., 2011).  Once established, shrubs can thrive and dominate the lower vegetation by canopy shading, which can lead to wide-spread changes in tundra ecosystems.  The low arctic transition zone between tall and dwarf shrub tundra is expected to respond most rapidly to warming, however, it is also projected that shrub species will advance into the high arctic or upslope in mountainous regions (Bret-Harte et al., 2002; Hallinger et al., 2010; Blok et al., 2011; Myers et al., 2011).
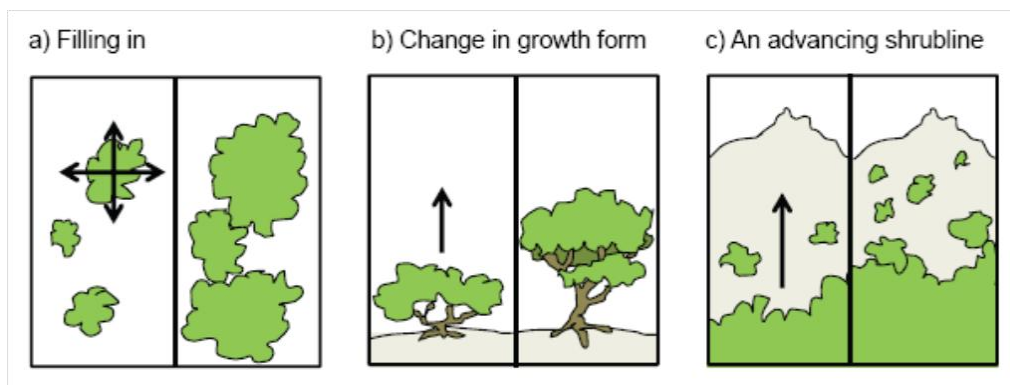
**Figure 1:** The three general categories of shrub increase including a) filling in, b) change in growth form and c) an advancing shrubline. Diagram from Myers-Smith (2011).

Many factors other than temperature influence vegetation expansion, making it difficult to determine which specific factors control the growth and recruitment of shrub species at a given site. However, Myers et al. (2011) suggest that the three key drivers of shrub change are temperature, soil disturbances (such as fire and permafrost thaw) and herbivory which controls shrub canopy shape and limits range expansion.

A pan-arctic expansion of shrubs may have profound implications for arctic ecosystems and has the potential for feedback in the global climate system. For example, interactions among shrubs, microclimate, litter inputs, carbon storage, nutrient cycling, organic matter decomposition, surface reflectance, erosion, ground temperatures, thaw depth and disturbance are expected to result in positive and negative feedbacks to further shrub expansion (Sturm et al., 2005; Tape et al., 2006; Myers et al., 2011). Currently, the magnitude and direction of these feedbacks is uncertain; it is anticipated that different processes will drive feedbacks in opposite directions.

For instance, across the tundra biome lower albedo has been observed for shrub versus shrub-free tundra because an increased canopy height and cover leads to a higher fraction of solar energy being absorbed rather than reflected (Sturm et al., 2005). Shrub canopies and snow cover

can also interact to influence soil, and permafrost temperatures. Tall shrubs can significantly modify the accumulation, timing, and physical characteristics of snow therefore influencing the exchanges of energy and moisture between terrestrial ecosystems and the atmosphere. An increased snowpack and temperature under shrub canopies has been found in winter, while in summer, shading under shrub canopies decreases soil temperatures and active layer depth (Myers et al., 2011). Vascular plant productivity is limited by nutrients, such as nitrogen and phosphorous (Bret-Harte et al., 2002). Increases in canopy cover and height of shrub species can increase litter inputs to soils, nitrogen mineralization rates, and the amount of carbon stored in above and below ground biomass (Myers et al., 2011).

In addition, increases in shrub abundance could have a negative effect on the species richness of tundra ecosystems due to the loss of shade-intolerant species under both tall and dwarf shrub canopies (Myers et al., 2011). The presence of a taller deciduous shrub canopy can reduce the biomass of evergreen shrubs, graminoids and non-vascular plants (Epstein et al., 2004). Feedbacks between the vegetation, snow, ground temperature, and nutrient availability may accelerate the rate of vegetation change in low arctic. Thus, it is important to understand the variability in patch size across this transition as these feedbacks may be sensitive to threshold patch sizes (Lantz et al., 2010).

**2.3 Ethnobotanical Importance**

The magnitude of these changes in the environment of the arctic and sub-arctic regions will have large implications for northern peoples, and on the ecosystems that indigenous people depend on heavily for food, medicines, and resources for cultural practices. In terms of subsistence foods alone, the value of the Canadian boreal forest to indigenous people is estimated to be between 261.4 and 575.1 million dollars (Anielski and Wilson, 2005). However,

there is inadequate information regarding subsistence food use by native communities in many forest and non-forest regions (Anielski and Wilson, 2005), indicating the need for further study.

Although a minor component of indigenous peoples predominantly meat-based diets, plants contribute essential vitamins and nutrients (such as vitamins A and C, calcium, iron and fibre) (Porsild, 1953; Arnason et al., 1981; Murray et al., 2005; Johnson, 2008; Karst, 2010). For example, berries such as black crowberry (*Empetrum nigrum*) and bearberry (*Arctostaphylos alpina*) exceed the vitamin C content found in oranges (Arnason et al., 1981). Berries are the plant food type most commonly gathered by contemporary indigenous people (Arnason et al., 1981; Karst, 2010), which is often a highly anticipated event as berry picking camps can be set up by groups of friends and family who stay for days or weeks (Parlee et al., 2006). Berries serve as sweet flavoring agents and are typically eaten raw, used in baking, made into preserves, or dried for storage (Arnason et al., 1981; Karst, 2010).

Traditional healing practices and wellness of indigenous people are also centered on plants. Shrubs and trees are the plants most intensively used for the treatments of injuries and ailments and maintenance of general health (Karst, 2010). For example, crowberries (*Empetrum nigrum*) are considered good for a "bad stomach" and cranberry juice is considered a remedy for kidney problems and to help with coughing (Murray et al., 2005). Necessary components of healing involve cultural values, beliefs, rituals and the role of the family and other community members (Karst, 2010).

Changes in vegetation structure and plant species' and distributions associated with climatic warming may have detrimental effects on northern people's way of life. Studies have already shown phenological changes occurring (such as the timing of leaf unfolding, flowering, leaf fall) and indigenous people have observed various changes in plants they use such as

reduced health of plants, dried up berries, and changes in species composition; (Nickels et al., 2005; Karst, 2010). Studies have highlighted the fact that sites may become less productive, or more difficult to cross as shrubs expand their range (Myers et al., 2011). For example, tall shrubs may grow up in berry patches, or along old trails and roads (Johnson, 2008). Parlee et al. (2006) highlight that blueberry patches are susceptible to the succession of willows (*Salix spp.*) and harvesters have made the effort to cut back the willows in order to maintain the areas. Residents of the arctic and subarctic, as well as the flora and fauna, will be forced to adapt to the environmental impacts due to climatic changes within the forest-tundra ecotone.

**2.4 Gaps in Knowledge**

Many questions remain unanswered in relation to how trees and shrubs will change in structure and distribution with a warming climate. Much attention has been focused on factors causing tree line advance and less attention has been given to the difference in spatial pattern across the forest–tundra ecotone, which may offer valuable insight into how a response to climate change is being initiated (Harper et al., 2011a). Processes of treeline change are not as general as initially anticipated, as they are mediated by environmental conditions at more local scales, such as the site specific factors previously discussed (Danby, 2003). Coarse-scale detections (such as aerial photography, satellite imagery) of infilling, treeline migration, and shifting shrub cover and dominance have given a yes or no answer to whether they are changing spatially, however, these studies have not provided insight into how these detections are occurring at finer scales (Lantz et al., 2010; Myers et al., 2011). Once there is an understanding of the current spatial pattern of trees and shrubs within the forest-tundra ecotone and the processes that influence their spatial configuration, predictions of how the spatial pattern of such vegetation is likely to change in response to climate warming can be made.

**3.0 Research Question**

This study focuses on the research question: How does the distribution of shrubs used by indigenous and local peoples vary across the forest-tundra ecotone at three sites in northern Canada? Two objectives will be pursued to answer the research question: (1) to determine how the abundance of the species varies across the forest, ecotone and tundra and (2) to investigate the spatial patterns of the species by examining their patch size, scale (distance between patches), and aggregation. From examining previous studies, I hypothesize that percent cover, and patch size of *Betula glandulosa* (tall shrub) will decrease as we increase in altitude or latitude. However, the berry-producing shrubs will increase in percent cover and patch size (Lantz et al., 2010) as we increase in altitude or latitude and spatial patterns will differ in patch size and scale at each site (De Fields, 2009; Harper el al., 2011a).

Since changes at the forest-tundra ecotone are likely to be site-specific three study areas were chosen for this study:  Mt. Nansen region, Yukon; near Churchill, Manitoba, and Mealy Mountains of southern Labrador. Understanding current vegetation patterns at finer scales in these regions will contribute to the general pool of scientific knowledge and results of the study can be combined with further studies at additional sites across Canada to gain an understanding of the change in spatial patterns of shrubs at Canada's treeline. In addition, the results can be applied when determining adaption strategies for indigenous and local communities surrounding the study areas who rely on these species for essential vitamins and nutrients. Changes along the forest-tundra ecotone could have global effects, and thus warrants further scholarly attention.

The data for this study were collected by researchers from PPS Arctic in 2007-2008 as part of the International Polar Year (IPY 2007-2008). PPS Arctic is a research cluster that focuses on the causes and consequences of changes in the circumpolar forest-tundra transition.

**4.0 Methods**

**4.1 Study Areas**

In the summers of 2007 and 2008, representative locations across Canada were sampled to acquire information on spatial patterns within the forest-tundra ecotone (Figure 2). From west to east, study areas were established in the Mt. Nansen region of the Yukon Territory, near the town of Churchill, Manitoba and in the Mealy Mountains of southern Labrador (hereafter referred to as Nansen, Churchill and the Mealys, respectively).

The Nansen study area (Table 1; Figure 2a) was located in the mountainous Western Yukon Plateau. In this area one site was sampled (Figure 3) which ranged in altitude from 1250 m to 4150 m above sea level (a.s.l) in Mount Nansen (Viktora et al., 2011). Annual, January, and July average temperatures of -3.5, -18.5, and 13.0ºC, respectively, were recorded in the study in 2008-2009 at 1300 m. Total annual precipitation ranges between 300 and 400 mm, approximately 90% of which falls as snow or slush (Harper et al., 2011a). The Little Salmon/Caramacks First Nation traditionally gathers blueberries and cranberries (*Vaccinium* spp.), blackberries and raspberries (*Rubus* spp.), bearberries (*Arctostaphylos* spp.*)* and plus Labrador tea (*Rhododendron groenlandicum*) and other assorted medicinal plants in the Mount Nansen area (Nicholson, 2002).

The Churchill study area (Table 1; Figure 2b) was located within the broad boreal-tundra transition forest on the southwestern side of Hudson Bay. This area is composed of a mosaic of *Pinus glauca* and *Pinus mariana* forest and tundra, as well as wetlands in low lying areas (Harper et al., 2011a). The ecotone in this specific study area next to Hudson Bay is considered narrow, with less than 12 km separating the inland open forests, and the treeless coastal tundra (Kershaw, 2003). Annual, January, and July average temperatures were -6.9, -26.7, and 12.0ºC,

respectively, for 1971-2000 (Environmental Canada, 2009). Total annual precipitation was 431.6 mm, approximately 40% of which fell as snow (Environmental Canada, 2009).

The Mealys study area (Table 1; Figure 2c) was established by the Labrador Highlands Research Group and was located within the Mealy Mountains (Akamiuapishk) National Park. Annual, January and July average temperatures were -1.6, -16.4, and 13.2ºC, respectively, for the period of 2002-2008 (Harper et al., 2011a). Annual precipitation ranges between 2000-3000 mm, approximately 50% of which is snow (Wheeler et al., 2011). The shrub layer is dominated by arctic dwarf birch (*Betula glandulosa*), bilberry (*Vaccinium uliginosum*) and black crowberry (*Empetrum nigrum*) (De Fields, 2009; Wheeler et al., 2011).
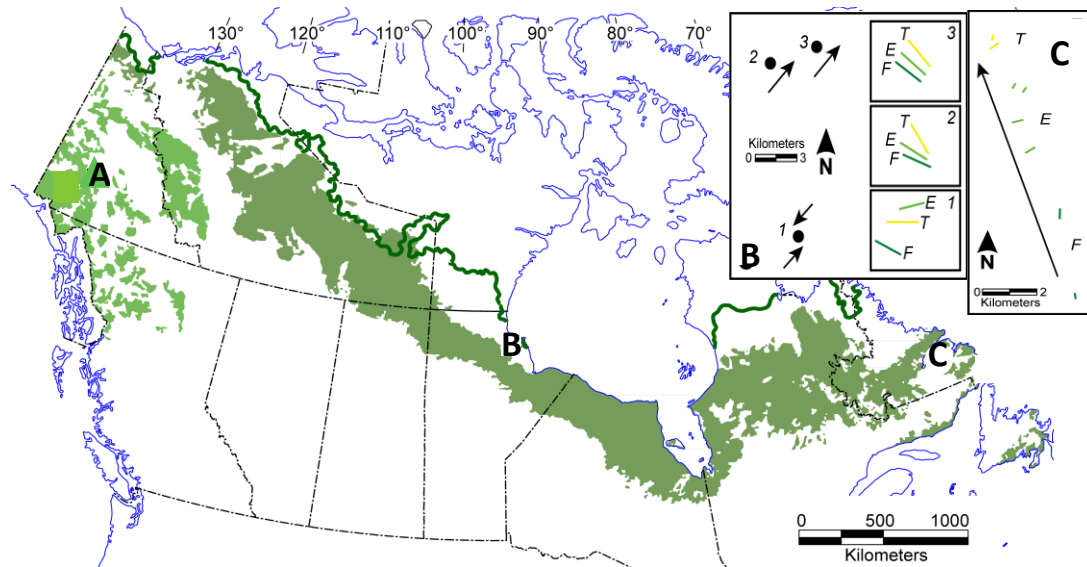
**Figure 2**: Map of Canada illustrating the location of the three study areas in relation to the forest-tundra ecotone. The position of the Arctic treeline is indicated by the dark green line. Boreal-tundra transition forests and subarctic alpine tundra are indicated by the dark green, and light green shading, respectively. Inset maps illustrate the configuration of transects in (A) Nansen (Figure 3) (B) Churchill, and (C) the Mealys in relation to the forest-tundra ecotone each study area. Arrows indicate the general progression of vegetation on the landscape for forest to tundra. Transects are labeled as F (forest), E (ecotone), or T (tundra) for each site. Scale varies for each inset map. Map was produced by Ryan Danby.
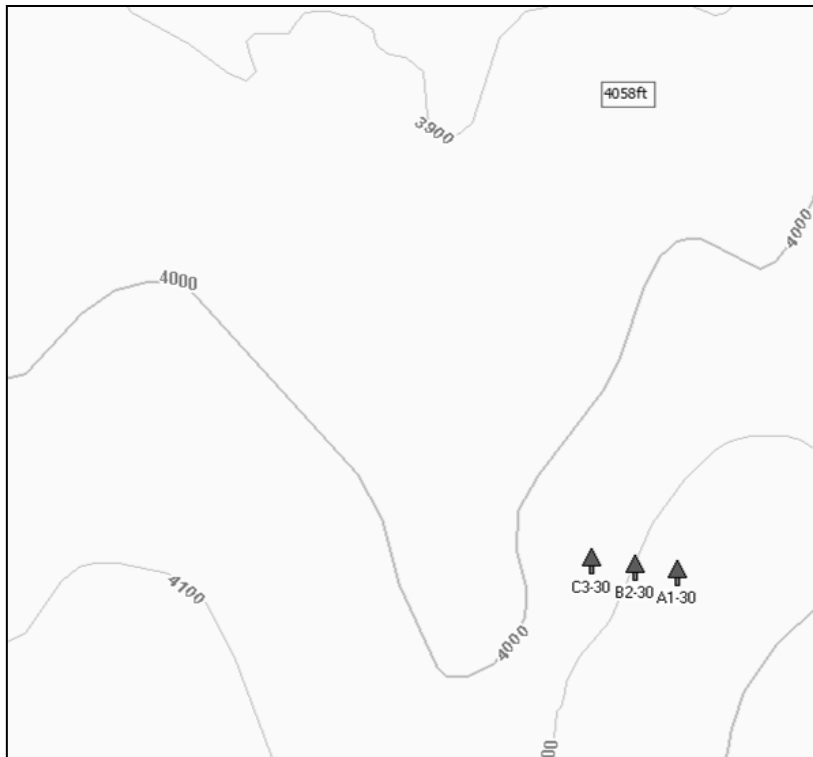
**Figure 3:** Map showing locations of the three sampled transects in the Mt. Nansen region. Map was produced by Rod Savidge.

**Table 1**: Location and sampling design for each location.

| Study area | Number of sites (gradients) | Location | Elevation (m) | Number of transects | | | Transect length (m) | Quadrat size (m) | Cover classes (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | F* | E | T | | | |
| Nansen | 1 | 62.18ºN, 137.28ºW | 1250- 4140 | 1 | 1 | 1 | 60 | 2 x 2 | Presence/ absence |
| Churchill | 3 | 58.88ºN, 94.18ºW | 22 | 3 | 3 | 3 | 100 | 1 x 1 | 0–1, 1–5, 5–10, 10–25, 25–50, 50–75, 75–100 |
| Mealys | 1 | 53.68ºN, 58.88ºW | 517-819 | 2 | 4 | 2 | 50, 100** | 1 x 1 | 0–5, 6–25, 25–50, 50–75, 75–100 |

**Note:** *Transects are labeled as forest (F), ecotone (E), and tundra (T).

**Transect length was 50 m in half of the transects and 100 m in the other half.

**4.2 Ethnobotany of Study Species**

The following species were chosen based on their use by indigenous peoples in the Arctic (Table 2) and their frequency in the study areas.

The **American Dwarf Birch/Resin Birch** (*Betula glandulosa*) is a woody shrub (up to 3 m in height) that has matted prostrate or ascending stems with warty resinous glands. This species can be found in tundra areas that are acidic, rocky or gravely, and have high organic content, or peat. This species is used for bedding, fishing spears, firewood, and flooring in tents (Aiken et al., 2003; Karst, 2010).

**Bearberry** *(Arctostaphylos uva-ursi)* is a trailing, evergreen shrub that is 7.5 – 10 cm tall, and often forms mats with 50-100 cm long flexible rooting branches. The bark is brownish red to dark grey, and is peeling.  The fruit are 6-10 mm in length and width, and are dull red in color (Lakehead University, 2011). They can be found in sandy and well-drained areas in woodlands and open areas. The berries are considered tasteless and 'mealy', but one can acquire a taste for them (Porsild, 1953). The berries and sometimes the whole plant are made into juice or tea for chest pains, stomach ailments and infections (Crewe and Johnstone, 2008).

**Black crowberry** *(Empetrum nigrum)* is considered the most important fruit in Arctic regions because of its abundance and hardiness (Porsild, 1953). It is a dwarf shrub that is matted, freely branching, evergreen, and standing at 5-10 cm high (but up to 30 cm in warmer sites, or by rocks). Fruit (berries) are 3-8 mm in width and length; black, purple, or blue in color and are sweet, juicy, and crunchy (due to the large, hard, seeds). It is typically found in dry, acidic and low nutrient soils and on rocky or gravely slopes, ridges, or seashores (Porsild, 1953; Aiken et al., 2003). Berries are used to make jam, and are thought to be tasty when eaten alone or mixed

with other berries.  A tea can be made by boiling the roots, berries, and stems which is considered a remedy for stomach aches and bad colds. The branches can be used a summer mattress, and if leaves are attached they can be used to clean gun barrels (Aiken et al., 2003; Karst, 2010).

**Bog blueberry/Bilberry** (*Vaccinium uliginosum)* is a dwarf, semi-prostrate or erect, freely branching, and matted shrub that 20-60 cm high. Fruit are 5-10 mm in length and width, and reach a blue color at maturity (Aiken et al., 2003; Crewe and Johnstone, 2008). The berries are used to make jams, pies, and muffins and were recommended for a person who had diarrhea (to harden stool). The stems could also be boiled to make a tea for cold symptoms. The branches have been used to remove stains that ordinary soap could not remove (Aiken et al., 2003; Karst et al., 2010).

**Low bush cranberry/ Lingonberry** (*Vaccinium vitis-idaea*) is a prostrate dwarf shrub, which is low, and creeping (2-10 cm high) with lustrous leathery evergreen leaves. Fruit are 6-9 mm in length and width, and are red at maturity. They are typically found in acidic soils with high organic content (or peat) in hummock, tundra, slope and ridge substrates in dry or moderately well drained areas (Aiken et al., 2003). Berries are used in jams, pies, muffins, breads, and puddings.  Juice from raw or boiled fruit are used to treat kidney problems, urinary tract infections, mouth infections, loss of appetite, digestion, sore throats and coughing. The fruit is also used as a source of brilliant red dye for clothes, and porcupine quills (Aiken et al., 2003; Karst, 2010).

**Labrador Tea** (*L. groenlandicum*) is a dwarf shrub (30-60 cm that is much branched, decumbent or ascending, and has dark green, linear, aromatic leaves. Leaves are covered beneath by a dense, rust-colored 'felt' (Porsild, 1953; Aiken et al., 2003).  They typically grow in

imperfectly drained moist areas, or on seepage slopes, that have acidic soils and are found in moss-lichen heath habitats. Medicinal teas are made from the leaves to help general stomach aches, sore throats, people to relax, and to ease breathing (by inhaling the steam). The chewed leaves can be used in an ointment, and to treat toothaches and eye disorders (Aiken et al., 2003; Karst, 2010).

**4.3 Sampling Design**

Sampling followed standard protocols developed by the International Polar Year research group on the forest-tundra ecotone (Hofgaard and Rees, 2008). At each site 50, 60 or 100 m long transects were located perpendicular to the main gradient extending from the forest to the tundra (Table 1; Figure 2). Transects were shorter than 100 m at some sites because of time constraints or difficult terrain. The nature of this ecotone varied across sites, with shorter and sharper gradients in Churchill and Nansen, and a more gradual and diffuse gradient in the Mealys. Gradient lengths (distance between the lowermost and uppermost transects) ranged from 75 m in Churchill to over 8.5 km in the Mealys. At Churchill, separate gradients were sampled at different locations within each study, but only one gradient was used for Nansen and Mealys. For this study, a site refers to the set of transects along a given gradient. Distances between adjacent transects varied at each site, ranging from 10 m in Nansen to over 2 km in the Mealys, with averages of 10, 42, and 1071 m for Nansen, Churchill, and Mealys respectively.

In Churchill and the Mealys, percent shrub cover for each individual species was estimated in 1 x 1 contiguous quadrats along the entire length of each perpendicular transect (Table 1). Shrub cover for Churchill was classified on a 7-point scale with the following classifications 1 (0-1%), 2 (1-5 %), 3 (5-10%), 4 (10-25%), 5 (25-50%), 6 (50-75%), and 7 (75-

100%). Shrub cover for the Mealys was classified on a 5-point scale 0.5 (1-5 %), 1 (6-25%), 2 (25-50%), 3 (50-75%), and 4 (75-100%). In the Nansen site, the presence or absence of the species was recorded in 2 x 2 contiguous quadrats along the entire length of each transect.

## 4.4 Data Analysis

All estimates of shrub cover were converted from the cover classes to the midpoint of the range for the cover estimate (e.g. a value of 1 representing 0-1% cover was converted to 0.5%). From these midpoint values, the average shrub percent cover and standard error (SE) were calculated using Microsoft Excel for each species along each transect to look at their distribution in the Forest, Ecotone, and Tundra transects.

New local variance (NLV) and wavelet analysis were used to estimate the patch size and scale of spatial pattern, respectively, for each transect using the Pattern Analysis, Spatial Statistics and Geographic Exegesis (PASSaGE 2) (Rosenberg, 2009) software. Patch size is the average width of clumps of high shrub abundance, and scale is the distance between these patches (Figure 4) (Harper et al., 2011a). Wavelet analysis also provides a measure of aggregation (amount of clumping) or the contrast between patches and gaps. Together these three metrics (size, spacing, and aggregation) provided characteristics of shrub spatial patterns. Wavelet diagrams also allowed me to examine the distribution of patches visually along each transect (Harper et al., 2011a). The Nansen study area was excluded from the spatial analysis due to the small size of transects (60 m) and the form of the data (recorded as presence/absence).
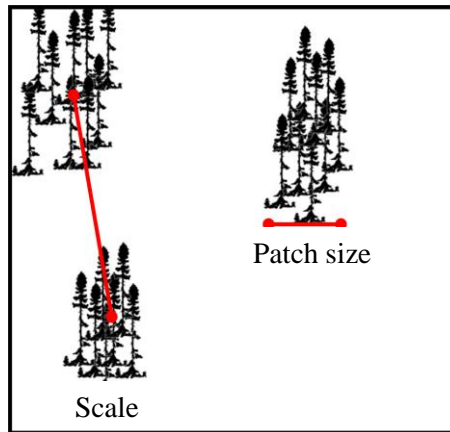
**Figure 4:** The distance between two patches is known as the scale, and the average width of clumps of high shrub abundance is called the patch size.

The two-term version of NLV is recommended for estimating patch size (Dale, 1999). In this method, when the quadrat variance is plotted against block size, the peaks of these graphs are interpreted as the patch size of the mapped phenomenon. Specifically, the peak value of the variance plot in the two-term NLV represents the mean size of the smaller phases (gaps or patches) (Dale, 1999). Wavelet analysis is recommended for assessing the scale of the pattern because it offers several advantages over the blocked or 'local' quadrat or paired quadrat variance calculations (Dale & Mah, 1998). One way to understand the wavelet analysis method is to visualize a particular wave form in a moving window that travels along the sequence (such as the transect in this case). The transform gives a high positive value when the portion of the data sequence in the window matches the wave template in shape and dimension and a low value when it does not (Figure 5). For longer transects, the commonly used Mexican Hat wavelet function (Dale & Mah, 1998) was used to detect patches. The French Top Hat wavelet function has been found to give more detailed and appropriate results for shorter transects (Harper et al., 2011a) and was used for the shorter Mealy transects (50 m).
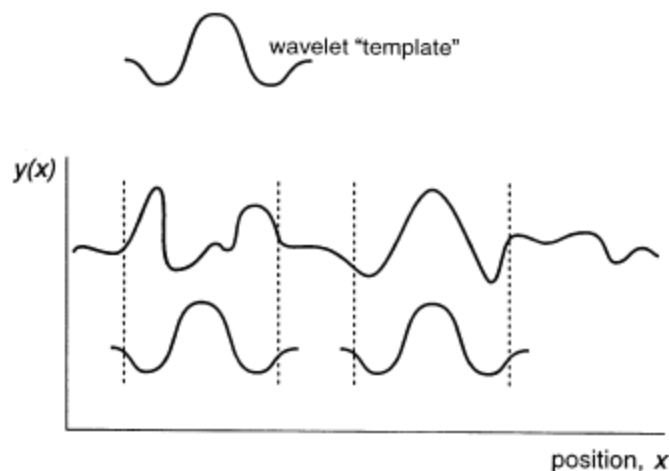
**Figure 5:** A visualization of how the wavelet transform is used to analyze pattern. The Mexican Hat wavelet template is a poor match for the data sequence at some locations (e.g. left window), giving a negative value, and gives a positive value where the match is good (e.g. right window). Diagram from Dale and Mah (1998).

In order to determine the statistical significance of the patterns detected, randomization tests were conducted using 999 iterations (the default number for PASSaGE 2) with a 95% confidence interval for both analyses. In general, a greater number of iterations lead to greater accuracy and smaller variance. However, resampling procedures can be very time consuming. While 1000 iterations may be much better than 100 iterations, 5000 iterations may be virtually no different than 1000 (Rosenberg, 2009) which is why 999 iterations were used. Randomization tests for wavelet analysis work by randomizing the order of the quadrats within the transect and recalculating the wavelet profile for the randomized data. Significant scales can be identified from the observed data when the observed peak exceeds the expectation generated from the randomization test (Rosenberg, 2009). Maximum distances of 33% and 25% were used for NLV and wavelet analysis respectively.

NLV and wavelet scale diagrams were examined visually to estimate patch size and scale. For patch size, the distances of the first two peaks (high point in the graph) were selected;

for a wide peak, the middle distance was chosen. Only peaks that were significantly greater than the 95% confidence interval derived from randomization tests were used; nearby peaks were considered if the first or second peak was not significant. Scale was estimated as the distance of the first two significant peaks of the wavelet scale diagram except a scale of one quadrat was not considered as recommended by Campbell et al. (1998); however, these authors suggest that scales of two or three quadrats can be considered if multiple transects are used.

Also, the wavelet variance was summed for the scales of 1-10 m to provide an estimate of aggregation at the same distances for both study areas (Harper et al., 2011a). I then standardized the results by dividing the wavelet variance by the sample variance (Rossi et al., 1992) which enabled comparisons of trends in pattern, regardless of trends in abundance.

### 4.5 Limitations and Delimitations

The major limitation to this study was time constraints. It was mandatory to limit the study to only six species because it required time to run the transects through the PASSaGE 2 software, and examine the graphs visually. In addition, due to previous commitments data were only available for analysis from one transect in each of the Forest, Ecotone, and Tundra sections in the Mt. Nansen Region, Yukon.

The study areas were limited to Churchill, Mealys, and Nansen because transects were established at these areas as part of PPS Arctic Canada in 2007-2008. Therefore, these areas were both a reliable and feasible source of information as my supervisor Dr. Karen Harper had access to the data collected. The data was limited to six study species based on their use by northern peoples, and their frequency within the study areas.

**5.0 Results**

**5.1 Abundance**

The variation in shrub abundance and species composition across the different study areas provides a context for the results of the spatial pattern analysis. In the Churchill study area, *Betula glandulosa*, *Empetrum nigrum*, *Rhododendron groenlandicum*, *Vaccinium uliginosum*, and *Vaccinium vitis-idaea* decreased in abundance across the forest-tundra ecotone with the greatest percent cover in the Forest section, and lowest in the Tundra section. *Arctostaphylos spp*. was the only species to peak in abundance in the Ecotone section (Figure 6a).

In the Mealys study area, there was an opposite trend; the abundance of *E. nigrum*, *V. uliginosum*, *V. vitis-idaea,* and *Arctostaphylos uva-ursi* increased across the forest-tundra ecotone the Forest to the Tundra. *B. glandulosa* and *R. groenlandicum* were both more abundant in the Ecotone rather than the Tundra section (Figure 6b). Notably, *B. glandulosa* had a higher abundance across the forest-tundra ecotone in the Mealys study area (> 30% cover in the Ecotone section) compared to the Churchill study area where cover did not exceed 5%.  At both study areas, *V. vitis-idaea* and *A. spp*. had either low abundance (< 5%) or were not present in the Forest section (Figure 6).

Similar to the Mealys study area, the study species increased in frequency from the forest to the tundra at the Nansen study area. However, R. *groenlandicum* and *V. uliginosum* both decreased in frequency from the Ecotone to the Tundra. Comparable to Churchill and the Mealys, *V. vitis-idaea* was not found at the Nansen study area.  *Arctostaphylos rubra* demonstrated an opposite trend from the Mealys, decreasing in frequency from the Forest to Tundra section (Figure 6c).
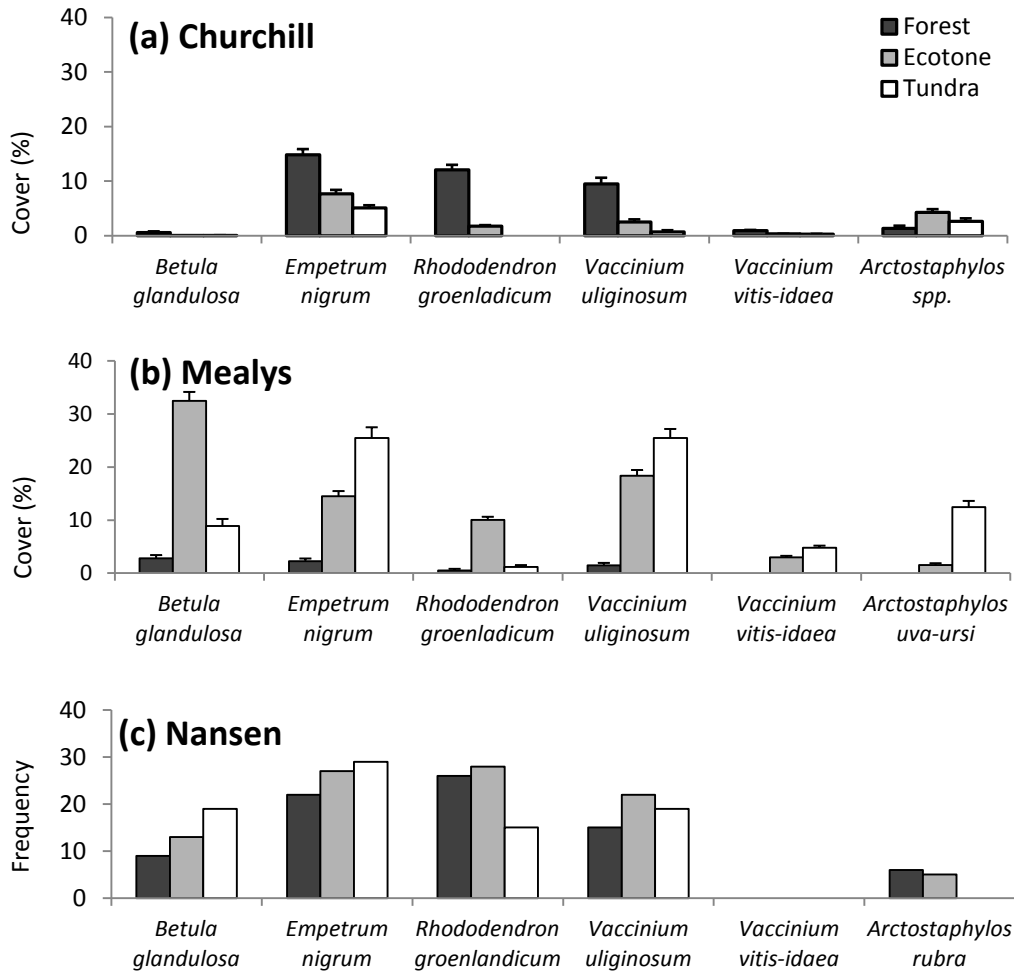
**Figure 6:** Abundance of study species in the Forest, Ecotone, and Tundra sections across the forest-tundra ecotone at (a) Churchill (b) the Mealys and (c) Nansen. Note that average (±SE) percent cover was used for (a) and (b) but frequency for (c).

**5.2 Patch Size**

Patch size varied between the two study areas, as well as across the forest-tundra ecotone. At Churchill, patch size typically ranged between 5-11 m. A few patches reached as large as 20-32 m, and as low as 2 m in size (individual results not shown, Figure 7a). At the Mealys study area, patch size typically ranged between 10-15 m with few patches ranging up to 22 m, and as low as 3-5 m in size (Figure 7b).

Overall, patch size at Churchill was largest in the Forest section. However, patches of *R. groenlandicum* and *V.uliginosum* were larger in the Ecotone and *Arctostaphylos* spp. had larger patches in the Tundra (Figure 7a). The Mealys study area showed an opposite trend, as patch size was typically greatest in the Tundra section. However, both *E.nigrum* and *V. vitis idaea* had larger patches in the Ecotone section. Significant patch sizes were not found in the Forest section for *R. groenlandicum* and *V.uliginosum*. It is also important to note that *V. vitis idaea* and *A. uva ursi* were not present in the Forest section in the Mealys study area (Figure 7b).
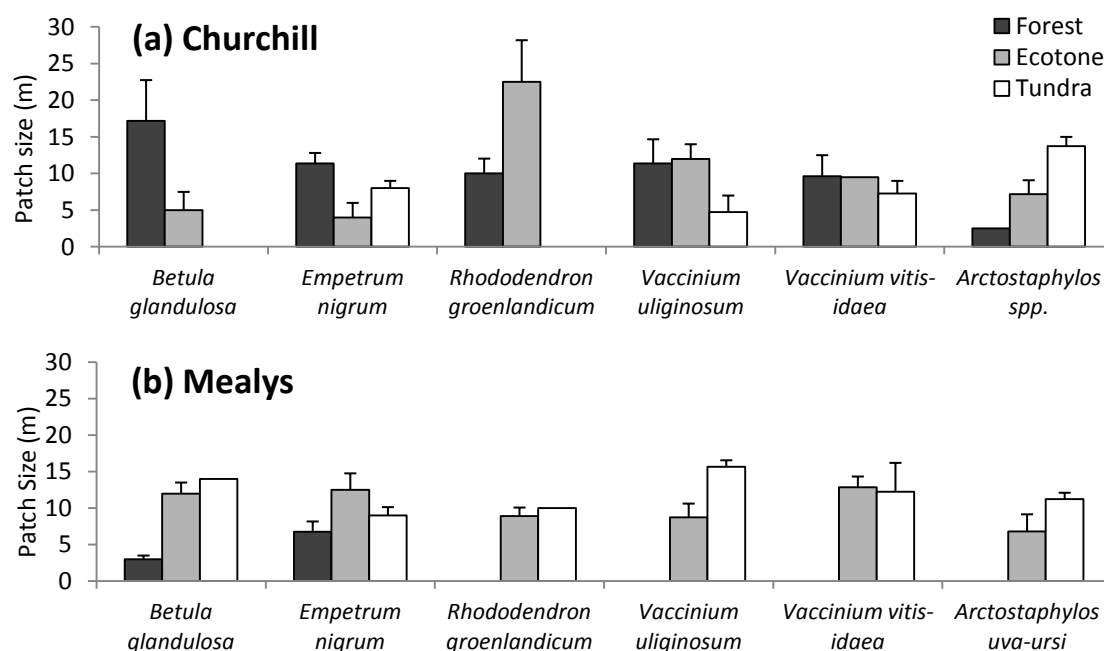


**Figure 7:** Average (±SE) patch size as estimated by the first two significant peaks of NLV within the Forest, Ecotone and Tundra sections of the forest-tundra ecotone for each study species at study sites (a) Churchill and (b) Mealys. Sample sizes for Forest, Ecotone and Tundra, respectively, are as follows: (a) Churchill: *B. glandulosa*, 3,2,0; *E. nigrum*, 4, 2,2; *R. groenlandicum*,4,4,0; *V. uliginosum*, 4,2,2; *V. vitis-idaea*, 4,1,2; *A.spp.,* 1,3,2. (b) Mealys: *B. glandulosa*, 2,8,1; *E. nigrum*, 4, 8, 4; *R. groenlandicum*,0,7,1; *V. uliginosum*, 0,8,3; *V. vitis-idaea*, 0,6,4; *A. uva-ursi*, 0,5,4.

**5.3 Scale**

At Churchill, scale (distance between patches) typically ranged between 3-9 m and 15-24 m (Figure 8a). At the Mealys study area, the scale was generally between 5-10 m, patches were only sometimes 15-22 m apart (individual results not shown, Figure 8b). Overall, Churchill had patches that on average were further apart across the forest-tundra ecotone than the Mealys (Figure 8a). Generally, distance between adjacent patches was the greatest in the Ecotone at both study areas. *A.* spp. was the only species to increase in distance between patches in the Tundra (Figure 8a, b).
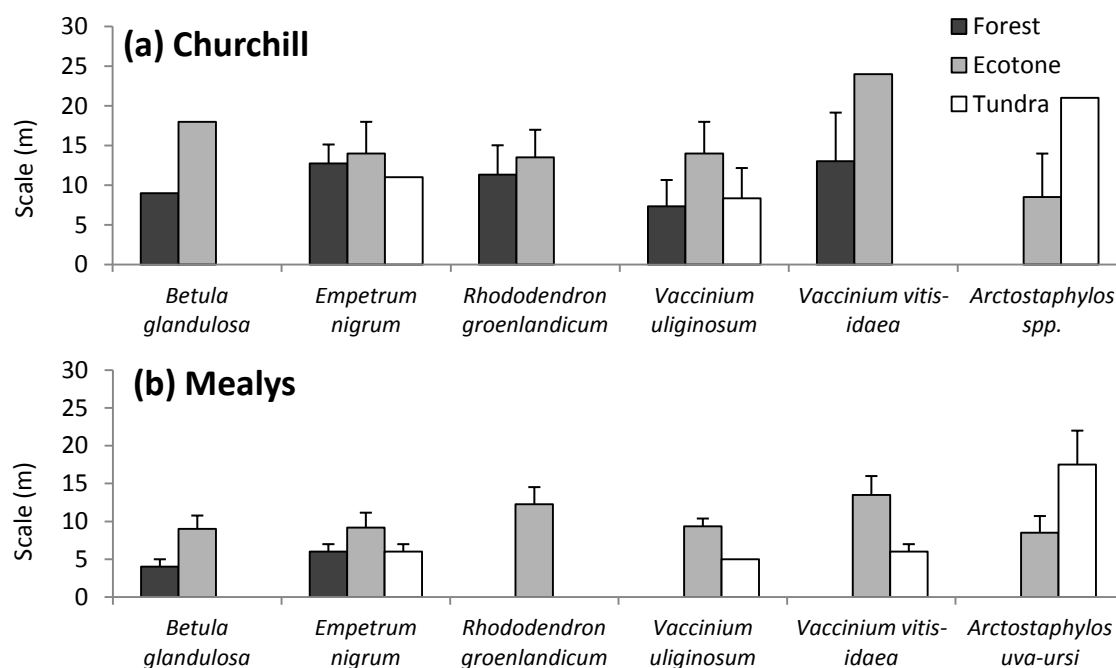


**Figure 8:** Average scale (±SE) as estimated by the first two significant peaks in wavelet variance within the Forest, Ecotone and Tundra sections of the forest-tundra ecotone for each study species at study sites (a) Churchill and (b) Mealys. Sample sizes for Forest, Ecotone and Tundra, respectively, are as follows: (a) Churchill: *B. glandulosa*, 1,1,0; *E. nigrum*, 4, 2,1; *R. groenlandicum*,3,2,0; *V. uliginosum*, 3,2,3; *V. vitis-idaea*, 3,1,0; *A.spp*, 0,2,1. (b) Mealys: *B. glandulosa*, 2,4,0; *E. nigrum*, 2, 6, 2; *R. groenlandicum*,0,4,0; *V. uliginosum*, 0,6,1; *V. vitis-idaea*, 0,2,2; *A. uva-ursi*, 0,4,2.

**5.4 Aggregation**

In Churchill, standardized aggregation (amount of clumping) generally increased (or remained the same) from the Forest to Tundra, except for *V. vitis-idaea* (Figure 9a). In the Mealys, the amount of clumping increased from the Forest to Ecotone. Although the amount of aggregation increased for *E. nigrum* and *V. vitis-idaea* in the Tundra – *B. glandulosa*, *R. groenlandicum, V. uliginosum,* and *A. uva-ursi* became less clumped from either the Forest or Ecotone in the Mealys (Figure 9b).
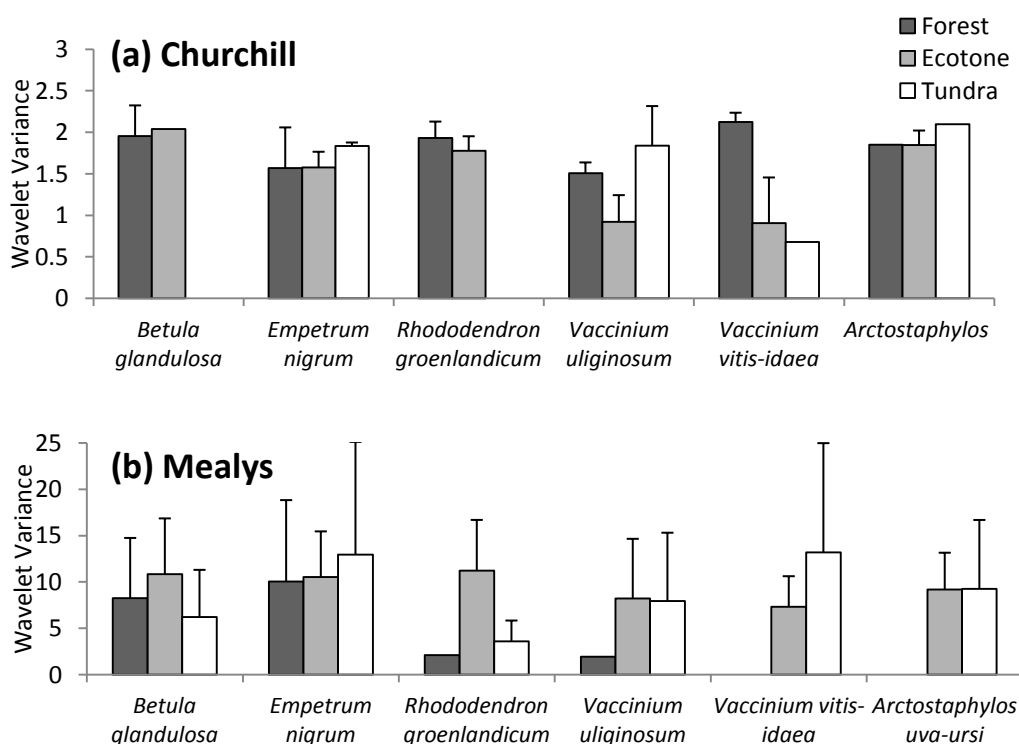


**Figure 9:** Average (±SE) standardized wavelet variance at scales of 1-10 m for the Forest, Tundra, and Ecotone sections across the forest-tundra ecotone for each study species at (a) Churchill and (b) the Mealys. Sample sizes for Forest, Ecotone and Tundra, respectively, are as follows: (a) Churchill: *B. glandulosa*, 2,1,0; *E. nigrum*, 2, 2,2; *R. groenlandicum*,2,2,0; *V. uliginosum*, 2,2.2; *V. vitis-idaea*, 2,2,1; *A.spp*, 1,2,1; (b) Mealys: *B. glandulosa*, 2,4,2; *E. nigrum*, 2, 4,2; *R. groenlandicum*,1,4,2; *V. uliginosum*, 1,3,2; *V. vitis-idaea*, 0,4,2; *A. uva-ursi,* 0,4,2. Note the different scale for the y axis for the two graphs.

**5.5 Position Variance**

Wavelet diagrams of position variance provide a detailed examination of the distribution of shrub cover along transects at each site (Figures 10-15). Overall, there were fewer patches of shrub cover along transects in the Tundra, notably at Churchill, however, these patches were generally significant. The patches within the Tundra at the Mealys resembled the Ecotone, with more patches, clumped together, but often insignificant. In Churchill, patches in both the Forest and Ecotone were typically clumped, with one or two significant patches. However, the Mealys Ecotone had more patches that were clumped together and significant than within the Forest section (individual graphs for all study species not shown).

In Churchill, *B. glandulosa* occurred in isolated, significant, patches in the Forest and Ecotone (Figure 10). In the Mealys, however, *B. glandulosa* was more clumped across the forest-tundra ecotone, extending more extensively into the Ecotone and Tundra – however, patches were mostly insignificant.  Isolated, significant patches were found in the Forest which is similar to Churchill (Figure 11).

*E.nigrum* had evenly spaced and mostly non-significant patches across the forest-tundra ecotone in Churchill. However, significant patches were predominant in the Tundra section (Figure 12). Within the Mealys, patches were clumped and more abundant in the Tundra and Ecotone.  Similar to Churchill, more significant patches were found in the Tundra (Figure 13).

In Churchill, *V.uliginosum* patch cover was low in the Tundra and Ecotone. However, patches that were present were significant. The Forest section had many patches; however, few were significant (Figure 14).  In the Mealys, *V.uliginosum* was clumped and patchy within the

Tundra and Ecotone, but had isolated patches in the Forest. There were only one or two

significant patches of *V.uliginosum* on all transects (Figure 15).
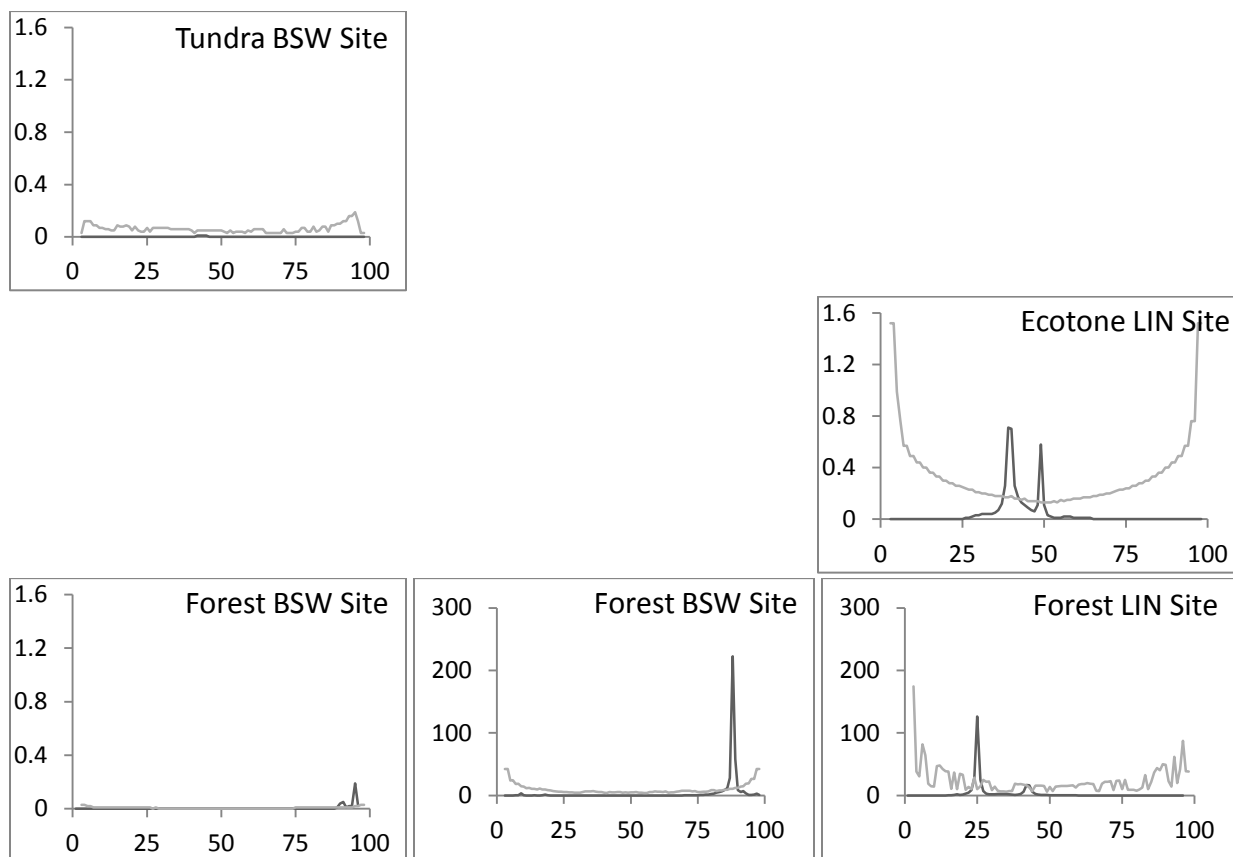


**Figure 10:** Position variance of *B. glandulosa* along the Forest, Ecotone and Tundra transects in the Churchill study area. Position variance is the wavelet variance summed across all scales for each distance. The gray line represents the results of the randomization test; peaks in the position variance (black line) that are above the thin line were significant.

**Figure 11:** Position variance of *B. glandulosa* along the Forest, Ecotone and Tundra transects in the Mealys study area. Transects are ordered with increasing elevation up the valley. Note the difference in scale for the y-axis of the first transect in the Forest section. See the caption for Figure 10 for details about interpreting position variance.

**Figure 12:** Position variance of *E. nigrum* along the Forest, Ecotone and Tundra transects at the Churchill study area. See the caption for Figure 10 for details about interpreting position variance.
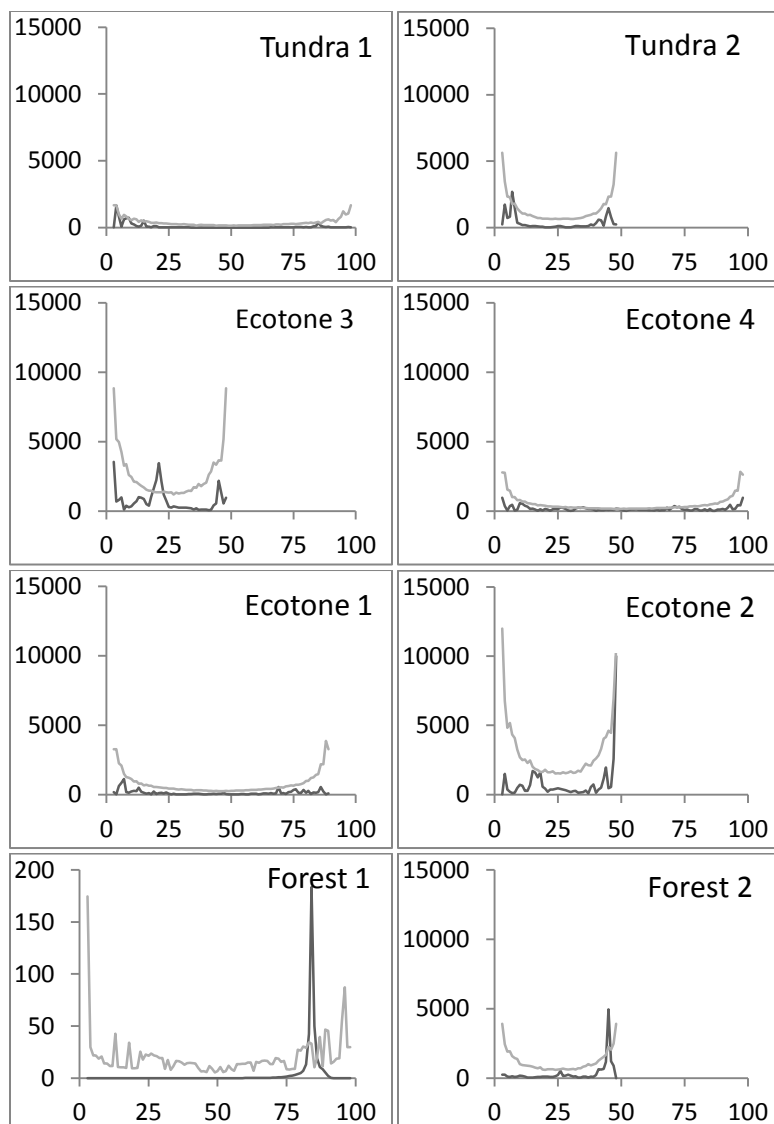
**Figure 13:** Position Variance *E. nigrum* along Forest, Ecotone and Tundra transects at the Mealys study area. Transects are ordered with increasing elevation up the valley. Note the difference in scale of the y-axis for the first transect in the Forest section. See the caption for Figure 10 for details about interpreting position variance.
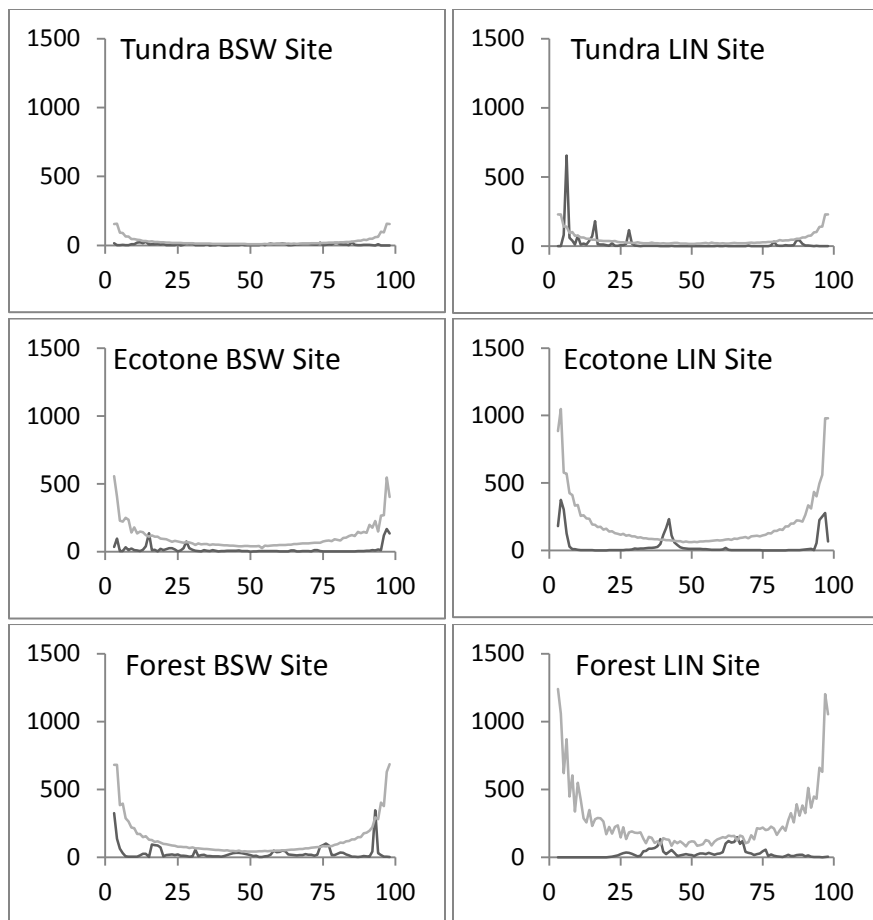
**Figure 14**: Position variance of *V.uliginosum* along Forest, Ecotone and Tundra transects at the Churchill study area. Note the difference in scale of the y-axis of the Forest BSW Site. See the caption for Figure 10 for details about interpreting position variance.
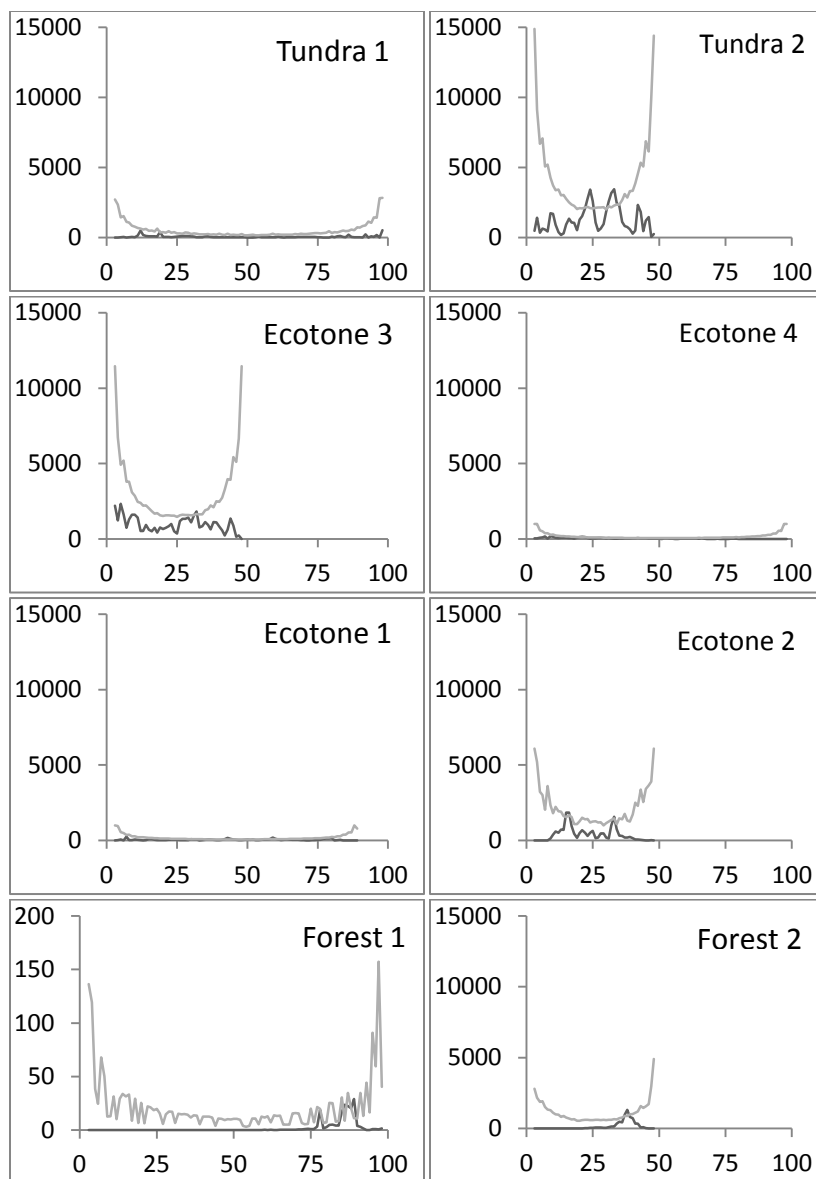
**Figure 15:** Position variance of *V. uliginosum* along Forest, Ecotone and Tundra transects in the Mealys study area. Transects are ordered with increasing elevation up the valley. Note the difference in scales of the y-axis. See the caption for Figure 10 for details about interpreting position variance.

## 5.6 Summary of Results

The following is a brief summary of the results for each study species (Table 3). Overall, in Churchill, study species became less abundant but more clumped with smaller from the forest to the tundra. However, the amount of aggregation did not differ greatly between the forest and

ecotone. In the Mealys, study species became more abundant with larger patches from the forest to the tundra. Aggregation varied between species, but species were generally the most clumped in the ecotone or tundra. At both study areas, patches were furthest apart in the ecotone, excluding *Arctostaphylos spp*.

Both *B. glandulosa* and *E. nigrum* became less abundant and more clumped with smaller patches further apart from the forest to the ecotone or tundra in Churchill. In the Mealys, *B. glandulosa* was most abundant and clumped in the ecotone; patches became larger and further apart from the forest to the tundra. In the Mealys, *E. nigrum* became more abundant and clumped from the forest to the tundra, with the largest patches furthest apart in the ecotone.

*R. groenlandicum* and *V.uliginosum* became less abundant and more clumped, with larger patches closer together from the forest to the ecotone in Churchill. In the Mealys, *R. groenlandicum* became more abundant and clumped with smaller patches further apart in the ecotone. In the Mealys, *V. uliginosum* became more abundant and clumped, with patches getting larger and closer together from the forest to the tundra.

In Churchill, *V. vitis-idaea* became less abundant and clumped, with smaller patches distance further apart from the forest to the tundra. In the Mealys, *V. vitis-idaea* became more abundant and clumped, with smaller patch sizes located closer together from the forest to the tundra.

In Churchill and Mealys, *A. spp* became more abundant, with larger, more clumped, patches further apart from the forest to the tundra.

**Table 3:** A summary of the changes in abundance and spatial pattern of each species from the forest to the tundra in Churchill, Mealys, and Nansen. Note ↑ represents increasing and ↓ represents decreasing from the forest to the tundra.

| Species | Study Area | | |
|---|---|---|---|
| | **Churchill** | **Mealys** | **Nansen** |
| *B. glandulosa* | ↓ Abundance, patch size<br><br>↕ Scale in E<br><br>↑ Aggregation | ↑ Abundance in E, patch size & scale<br><br>↓ Aggregation in the T | ↑ Abundance |
| *E. nigrum* | ↓ Abundance<br><br>- Largest patch size in F, smallest in E<br>- Largest scale in E, smallest in T<br><br>↑ Aggregation | ↑ Abundance<br><br>- Largest patch size in E, smallest in F<br>- Largest scale in E, smallest in F<br><br>↑ Aggregation | ↑ Abundance |
| *R. groenlandicum* | ↓ Abundance & aggregation<br><br>↑ Patch size & scale | ↑ Abundance, scale & aggregation in E<br><br>↑ Increased patch size | ↓ Abundance |
| *V. uliginosum* | ↓ Abundance<br><br>- Largest patch size in E, smallest in T<br>- Largest scale in E, smallest in F<br>- Highest aggregation in T, lowest in E | ↑ Abundance , patch size, & aggregation<br><br>↓ Scale from E to T | ↑ Abundance in E |
| *V. vitis-idaea* | ↓ Abundance, patch size & aggregation<br><br>↑ Scale from F to E | ↑ Abundance & aggregation<br><br>↓ Patch size (not present in F)<br><br>↓ Scale from E to T | N/A |
| *Arctostaphylos* spp. | ↑ Abundance, patch size, scale & aggregation | ↑ Abundance, patch size, scale & aggregation | ↓ Abundance |

**6.0 Discussion**

In this study, I examined the distribution of shrubs used by indigenous and local peoples across the forest-tundra ecotone in Canada.  For my first objective of determining how the abundance of shrubs varied across the forest-tundra ecotone, I found that the species abundance decreased from the forest to the tundra in Churchill but increased in abundance at the two mountainous study areas, Mealys and Nansen. For my second objective, where I investigated the current spatial patterns of the species, I found that patch size was the greatest in the forest at Churchill, but in the tundra at Mealys. Scale (distance between patches) was generally the greatest in the ecotone across all species and study areas, and aggregation (the amount of clumping) varied across study areas and species. My results indicate that there is substantial variation in the abundance and spatial pattern of shrubs used by indigenous and local peoples across the Canadian forest-tundra ecotone.

It is important to acknowledge that only a few transects were analyzed at three study areas within the vast forest–tundra ecotone across Canada. Thus, although the study design by PPS Arctic Canada included a breadth of study areas, this study only looked at three, and they also lacked depth at individual sites (Harper et al., 2011a).Nonetheless, despite few sites, some general trends across the forest–tundra ecotone were apparent.

Although trends in abundance and patch size differed in Churchill and Mealys, the tall shrub *B. glandulosa* and dwarf shrubs (i.e., *V. vitis-idaea*) followed the same pattern within each study area as they decreased in abundance and patch size from the forest to the tundra in Churchill, but increased in the Mealys. These results differed from a study conducted by Lantz et al. (2010) with aerial photography which observed a northward decrease in abundance and patch size of tall shrubs (i.e., *B. glandulosa*), which corresponded to a northward increase in the

abundance and patch size of dwarf shrubs (i.e., *V. vitis-idaea*, *Arctostaphylos*, *R. groenlandicum*) in the Mackenzie Delta region of the Northwest Territories. Patterns of abundance and patch size from the forest to the tundra did not differ between tall shrubs and dwarf shrubs as was expected from the Lantz et al. (2010) study. However, as predicted, substantial variation in abundance and spatial pattern was discovered among the study areas (Harper et al., 2011a).

**6.1 Insight into Factors Affecting Abundance and Spatial Patterns of Shrubs**

The interaction between shrubs and trees could provide an explanation to why the abundance of shrub species in the Mealys forest was lower than in Churchill as berry plants are generally intolerant to shading (Siegwart-Collier et al., 2012). The Mealys has approximately twice the abundance (highest average cover ~ 40 %) of trees in the forest than Churchill (Harper et al., 2011a) which could hinder the structure of the shrub community below.

Changes in shrub cover in Arctic and subarctic region are likely to be spatially heterogeneous (Ropars and Boudreau, 2012). Minor differences in the abiotic environment (such as local topography) could translate into important differences in shrub survival, growth and reproduction. The two study areas (Mealys and Nansen) located in mountainous regions demonstrated an opposite pattern of shrub abundance and patch size than Churchill. This could be because local topography can influence variables such as snow accumulation, duration of snow cover, nutrient availability, soil moisture and soil temperature which all have major impacts on plant growth and reproduction (Ropars and Boudreau, 2012).

Across the forest-tundra ecotone Dwarf Birch (*B. glandulosa*) had a higher abundance in the Mealys compared to Churchill. Some shrub species have a competitive advantage over other plants. For example, in warming and fertilization experiments woody deciduous shrubs (e.g., *B.*

*glandulosa*) have been reported to increase in canopy cover and height to dominate treatment plots (Myers-Smith et al., 2011).

*B. glandulosa* has been identified as one of the key species in pan-Arctic shrub densification. Dwarf birch can take advantage of more favorable growing conditions, such as an increase in air temperature and nitrogen by rapidly elongating their long leaf-producing shoots (Tape et al., 2006; Ropar and Boudreau, 2012). It can also reproduce asexually via clonal growth, with stems producing advantageous roots when over-grown by adjacent vegetation. *B. glandulosa* also produces an abundant seed rain, and seed germination is higher under experimental warming (Ropar and Boudreau, 2012) which suggests that densification may continue if the climate continues to warm. Accordingly, the high abundance of *B. glandulosa* at Mealys could be facilitated by microclimate, as it has higher air temperature and snowfall in comparison to Churchill. The temperature-nutrient hypothesis states that higher temperatures and deeper snow packs promote increased microbial activity, which in turn increases the availability of nutrients in the soil (Sturm et al., 2005; Tape et al., 2006). The increased abundance of *B .glandulosa* could be a positive response to the climate in Labrador. Increased nutrients in the soil provided by *B. glandulosa* leaf litter in the Ecotone and Tundra may also explain the increased abundance of other shrub species in the area whose growth may be limited by nutrient availability.

Results showed that in general the scale (distance between patches) and aggregation of shrub species increased from the forest to the ecotone at both Churchill and Mealys. De Fields (2009) states that patches or aggregations of shrubs should be found in areas where it is more advantageous for shrubs to establish close to one another as compared to further apart. It is advantageous for shrubs to not only be low-growing but also more clumped in the tundra due to

its harsh growing conditions - such as permafrost, low temperatures, a short growing season, and wind (University of California, 2012).

## 6.2 Implications for Climate Change

Trends in shrub spatial pattern across the forest-tundra ecotone provide some insight into how the configuration may change with a changing climate. With a warming climate, the spatial patterns within the Tundra could transition to that in the Ecotone, and the patterns within the Ecotone could transition into that of the Forest. For example, the ecotone in the Mealys has a high abundance of tall shrubs, the average total cover of all tall shrubs reaches nearly 45 % compared to 5% in Churchill (Harper et al., 2011b.). *B. glandulosa* alone has an average percent cover of 30% in the ecotone at the Mealys; however, as seen from the original data, cover can range up to 60 to 90% in many quadrats. Given the assumption that climatic warming will continue, *B. glandulosa* could increase in abundance through the expansion of existing patches, or the establishment of new individuals in areas where it is already growing, referred to as 'filling in' (Myers-Smith, 2011) which would cause an increase in aggregation and thus a dense canopy cover. There is evidence that *B. glandulosa* has started to encroach upon the tundra. If these patches continue to fill in, this could result in ecosystem and habitat changes, possibly affecting regional biodiversity (i.e., decreases in the high abundance of dwarf shrub species, lichens, and moss) and northern peoples way of life (discussed in further detail below) (Parlee et al., 2006). However, if the forest encroaches into the Ecotone, the abundance of *B. glandulosa* (and other shrub species) and patch size will likely significantly decrease as the Mealys forest has substantially lower shrub cover. However, the patches would become aggregated, possibly leaving some areas more species diverse than others.

If the Ecotone were to transition into the Forest at Churchill, the abundance and patch size of shrub species would decrease. This decrease in abundance and size of shrub patches (particularly, berries) and the increase in distance between them could be detrimental for northern peoples who travel long distances to pick berries (Karst, 2010).

**6.3 Implications for Northern Peoples**

With climate warming in the Arctic already occurring, productive berry patches will likely undergo changes in abundance and spatial pattern. For example, my results indicate that patches in the ecotone at both sites are the furthest apart. With climate warming, the tundra will likely transition into the ecotone and as a consequence the distance between patches may increase, making it more difficult to pick the same amount of berries as people may remain at one patch for a longer period of time, collecting fewer berries, due to the increased distance between patches. These areas where individuals harvest berries are dependent on family ties and friendships or personal knowledge, as some individuals pick in the same location where their parents and grandparents picked berries which serves as a base of knowledge for harvesters (Parlee et al. 2006; Thornton, 1999). However, this knowledge is not historical or fixed, but continues to develop each season through observation and interpretation (Parlee et al., 2006).

The practice of observation or 'checking the berries' provide women with insight into where and when they can find the best berries. Harvesters will first visit places where they know there have been berries before, if conditions are poor in their usual picking areas, harvesters will rely on information from family members and friends in the community or other parts of the region. Specific observations about conditions from year to year, and from patch to patch are generally communicated informally between friends and family (Parlee et al., 2006).

It is through these 'information sharing networks' that harvesters have been able to deal with seasonal variability in the abundance and distribution of berries through increasing or decreasing the geographic extent of their picking areas in the past, and will ultimately be essential in adapting to more long-term changes in spatial patterns across the forest-tundra ecotone due to climate change.

As discussed in section 6.3, *B. glandulosa* poses a threat to the diversity and abundance of berry-producing shrubs in the Mealys if the climate continues to warm. As noted in previous studies, woody shrubs (e.g., *B. glandulosa*) and berry plants (e.g., *E. nigrum*) are commonly associated in tundra plant communities, however, the increasing dominance of woody shrubs has been documented to change the distribution of berry plants and reduce the quantity and quality of berries produced, as berry plants are commonly intolerant to shading (Parlee et al., 2006; Johnson, 2008; Myers-Smith et al., 2011; Siegwart-Collier et al., 2012).

A decrease in berry-producing shrubs could alter indigenous peoples 'way of life'. Gathering berries is thought to be about more than survival, it brings families together - any sense of alienation and isolation quickly dissolves as people actively engage in conservation while picking berries (Mitchell, 2009). Intentional conservation and resource management of edible shrubs has already been observed and documented in previous studies. Thornton (1999) found evidence that indigenous peoples in Alaska have manipulated ecological succession (e.g., the use of fire to control forest succession), reduced competition (e.g., weeding), and added inputs (e.g., irrigation or fertilizer) in order to increase the productivity of berry patches. For example, he states that one middle aged man remembers being instructed by his elders to clear alder and other brush from favored strawberry patches to prevent fruits from being choked off by the competition which is similar to what was documented by Parlee et al. (2006). These

strategies currently in place could be used by northern peoples to cope with permanent changes in the spatial patterns of berry-producing shrubs.

## 7.0 Conclusions and Recommendations

My results suggest that trends in abundance and spatial pattern and the potential factors affecting shrub establishment within the forest-tundra ecotone are site specific. Factors such as the width of the forest–tundra gradient, tree and shrub species present, microclimate, and local topography likely affect the configuration of shrubs in the forest–tundra ecotone and the development of the pattern of the forest–tundra ecotone with climate change. Resource management strategies (e.g., clearing tall shrubs) and information sharing networks that are currently being used by northern peoples may help them adapt to a warming climate by increasing the productivity of favorite berry-producing shrub patches, or helping to find alternative berry patches, respectively. Response to climate change will vary across Canada and consequently adaptation of northern communities to change must be tailored to individual areas.

This study looked at the fine-scale spatial patterns of six shrub species in the Mt. Nansen region of the Yukon; Churchill, Manitoba and Mealy Mountains, Labrador during 2007-2008. In order to determine whether the spatial patterns are changing transects should be repeated in the area every 10-15 years. I suggest increasing the number of transects within the Forest, Ecotone, and Tundra sections as the spatial pattern often varied along each transect. Additional studies could be conducted on fine-scale spatial patterns of shrubs across the Arctic and sub-arctic to gain further understanding of how site-specific attributes affect shrub establishment. Also, further studies could investigate thresholds for woody shrub abundance and/or canopy cover before being detrimental for understory species (i.e., berry-producing shrubs).

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**Table 2.** Summary of study species and their human use (Porsild, 1953; Aiken et al., 2003; Crewe and Johnstone, 2008; Karst, 2010).

| Common name | Scientific name | Human uses | | |
|---|---|---|---|---|
| | | **Food** | **Medicinal** | **Other** |
| American dwarf birch/Resin birch | *Betula glandulosa* | **N/A** | **N/A** | **Branches:** bedding, fishing spears, firewood, flooring in tents |
| Bearberry | *Arctostaphylos spp.* | **N/A** | **Juice/Tea** (whole plant or berries): chest pains, stomach aches, infections | **N/A** |
| Black crowberry | *Empetrum nigrum* | **Berries:** eaten alone, or mixed; used in jams | **Tea** (roots, berries, and stems): stomach aches and/or bad cold | **Branches:** mattress; cleaning out gun barrel |
| Bog blueberry/ Bilberry | *Vaccinium uliginosum* | **Berries:** used in jams, pies, muffins | **Tea** (stems): cold symptoms | **Branches:** remove stains ordinary soap could not |
| Low bush cranberry/ Lingonberry | *Vaccinium vitis-idaea* | **Berries:** used in jams, pies, muffins, breads, puddings | **Juice** (raw or boiled): kidney problems, urinary tract and mouth infections, loss of appetite, digestion, sore throats, coughing | **Berries**: source of red dye for clothes, porcupine quills |
| Labrador tea | *Rhododendron groenlandicum* | **N/A** | **Tea** (leaves): stomach aches, sore throats, relaxation, congestion (inhale steam)<br><br>**Chewed leaves**: ointment, tooth aches, eye disorders | **N/A** |