**Chapter 8. Trends in vegetation dynamics and impacts on berry productivity**

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**Abstract**

The vegetation of Nunavik and Nunatsiavut changes from treeline to arctic/alpine tundra moving northward and upwards in elevation. Current and predicted environmental changes promote shrub growth as well as treeline expansion, but not in a uniform way. Research has documented an increasing trend in birch and willow cover, as well as an altitudinal expansion of larch. With the improved growing conditions (such as increased summer temperatures and Growing Degree Days (GDD)) favouring increased viable seed production and seedling recruitment, trees are expected to gradually expand beyond current boundaries; however, given the highly variable nature of abiotic and biotic factors across the region, the extent and rate of treeline change is currently unknown. Changes in the distribution of shrubs are expected to alter snow distribution and its persistence on the land, affecting permafrost, feedback to the atmosphere (e.g. altered albedo), vegetation, wildlife and human transportation routes.

Warmer and longer growing seasons may not benefit the growth and productivity of all berry producing plants. Berry shrubs that have a prostrate or dwarf growth form will face increasing competition from taller erect shrubs such as birch and willow. The potential lack of moisture if summers become drier will also compromise their ability to produce large berry crops. Changes in precipitation across the region are uncertain, and berry productivity is sensitive to amount and timing of precipitation, as well as wind and extreme events (e.g. late frost events in the spring). Berry species that have highest productivity in full sun (especially partridgeberry/redberry and bog bilberry/blueberry) will most likely decline under an increased shrub cover, yet the patchy nature of arctic vegetation should enable other species more tolerant to partial shade such as black crowberry/blackberry and cloudberry/bakeapple to take advantage of the changing conditions.

Further research is necessary to understand feedbacks of treeline and shrubline changes on ecosystems and to evaluate how the disturbance regimes will vary in response to climate change, including if and how insect outbreaks and fires will increase. Major uncertainties exist regarding how environmental changes will impact biotic interactions between vegetation and animals, herbivores (both insects and vertebrates) and pollinators.

Northernners have observed changes in their environment both in the past and present and have adjusted their berry-picking activities to the high spatial and inter-annual variability in berry productivity. Community-based monitoring is an important tool to enable the collection of long-term data, crucial to understanding current uncertainties about berry productivity. Such long-term, sustained monitoring will enable Northernners to track environmental changes in their communities and tailor appropriate adaptation strategies for their region. Longer time series from a wide range of sites will benefit researchers and communities and greatly enhance scientific predictive abilities. This will in turn help to select areas to be protected from development, to ensure easy access to high quality sites for this culturally important activity.
8.1 Introduction

The vegetation of Nunavik and Nunatsiavut ranges from the northern limit of the boreal forest to the arctic tundra. The transition zone between forest and tundra moves from more abundant closed canopy forest to sparse forest patches then to isolated tree islands, and finally to krummholz, which are stunted shrub-like trees (Payette 1983). This complex transition zone is called the forest-tundra ecotone, and can either be sharply defined with an abrupt transition from forest to tundra, or gradual with forests changing to shrub tundra over long distances (Payette et al. 2001, Harsh et al. 2009). Climate controls on the position and character of the treeline increase in complexity nearer the coast, as exemplified by the treeline in Nunatsiavut (Payette 2007, Hallinger et al. 2010, Kennedy et al. 2010) (Figure 1).

The forest-tundra ecotone is highly sensitive to changes in environmental conditions (Payette and Lavoie 1994), with examples of trees and shrubs moving northward and upwards into the tundra zone across Canada in response to climate changes (Payette et al. 2001, Danby and Hik 2007, Harper et al. 2011). In the Arctic zones, shrubs increase in growth and density and are moving into herb tundra areas. Changes in the distribution of shrubs are expected to alter the way snow is distributed on the land and how long it stays, affecting permafrost, vegetation, wildlife and human transportation routes as well as having feedbacks to the atmosphere, for instance through the exchange of greenhouse gases.

Shrubs could act as “nurse” plants for trees, accelerating their spread into the tundra (Cranston 2009). However, shrubs can form dense thickets that may not be suitable for tree seedling establishment and survival. Taller shrubs such as dwarf birch (*Betula glandulosa*), alder (*Alnus spp.*) and willow (*Salix spp.*), can also shade out shorter shrubs such as berry plants, causing localised loss of species such as bog bilberry/blueberry (*Vaccinium uliginosum*) and partridgeberry/redberry (*Vaccinium vitis-idaea*), or affecting the berry productivity. Under thicker shrub cover, other shade-intolerant ground cover species, such as lichens, will also be lost which may have negative effects on caribou food supply. Besides shrub encroachment and expansion, other competitive species may change the vegetation dynamics. In open areas, tall grasses may invade and displace less competitive species such as *Rhodiola rosea* or cushion plants, like Lapland pin-cushion plant (*Diapensia lapponica*) and moss campion (*Silene acaulis*).

In Nunavik, Inuit have already noticed that tall shrubs are now invading some of their usual berry-picking spots, mostly where they used to find blueberries and black crowberry/blackberry (*Empetrum nigrum*) (Gérin-Lajoie et al. In Prep.). However, other species may become more abundant such as cloudberry/bakeapple (*Rubus chamaemorus*), reported in Kangiqsualujjuaq to have been mostly found among birches in the mountains in the past and now found growing everywhere. In addition, Elders from Umiujaq, Kangiqsujuapik and Kangiqsualujjuaq, are saying the permafrost is retaining less water (as discussed in chapter 6), resulting in lower water levels and plants invading dried up streams and lakes. This in turn has an impact on insect emergence and abundance as well as on fishing and travel on land.
In Nain, Nunatsiavut, community members have observed that trees and shrubs are more abundant now and are rapidly growing around their community and up the coast. Some individuals highlighted the difficulty in locating and using traveling routes because of their rapid infilling by shrubs. Community members have also indicated changes in berry crops, such as berries being less abundant, smaller and changing in taste. However, changes in berry crops were not linked explicitly with shrub expansion (L. Siegwart Collier, unpubl. data).

Influenced by climatic factors, vegetation changes like treeline patterns affect animal distribution and, consequently, Inuit and Innu people have had to modify their travel routes to follow migration of animals (Fitzhugh 1977, 1997, Fitzhugh and Lamb 1985). Today, Inuit depend less on hunting, fishing and gathering activities for their survival, but going on the land remains a very important part of their activities and a way to obtain a supply of fresh and healthy country food, including berries which are a significant part of country food for Inuit and Northerners (see Chapter 5). Berries are a valuable source of vitamins and antioxidants and a natural treat for people of all ages. Berry picking is a traditional activity very much enjoyed by community members, particularly women and children. It promotes intergenerational and family relationships as well as sharing, both values that are very significant in the Inuit culture.

This chapter on vegetation dynamics will cover tree and erect shrub expansion, examining the ancient and actual trends at treeline interface as well as above treeline, the associated processes, conditions, disturbance regimes and their effects on the landscape. Secondly, berry shrub productivity, abundance, growth and antioxidant activity found in the berries will be reviewed. Thirdly, community-based environmental monitoring and associated ongoing initiatives will be presented. Conclusions and recommendations will complete the chapter.

### 8.2 Trees and erect shrub expansion

#### 8.2.1 Historical trends and current rate of change

**Vegetation changes observed at treeline interface**

Vegetation has always adapted to past climate variations over short and long time periods. The vegetation of Nunavik and Nunatsiavut was established following glacier retreat and soil development at the end of the last ice age (approx. 7000-8000 years ago) (Dyke and Prest 1987). Tree expansion reached its maximum during the warm interval known as the hypsithermal (Lamb 1985, Payette 2007, Bell et al. 2008). For instance, abundant subfossil tree remains (spruce, fir, larch) were found around the margins of shallow ponds above the treeline on the uplands of central Labrador (Photo 1); a random sampling of several of these trees provided C-14 dates of 3000-5000 years ago illustrating that trees grew higher during this period (Bell et al. 2008). The fragmented pattern of today’s forest-tundra ecotone in Nunavik is a consequence of forest fires that opened the landscape and the failure of the postfire forest recovery processes (Sirois and Payette 1991, Payette et al. 2001, Asselin and Payette 2005).

The most recent cooling ended in the mid 19th century and is referred to as the Little Ice Age (LIA). During this cooler period, shorter growing seasons certainly constrained seed production and plant growth as shown by the tree-ring records from some long-lived woody species and by the reconstruction of tree pollen records preserved in lakes and bogs (as mentioned in chapter 2). These changes possibly have imposed migration on Inuit and Innu people (Fitzhugh 2009). Fitzhugh (1977, 1997) and Fitzhugh and Lamb (1985) demonstrated how Aboriginal people in Labrador and the Eastern Subarctic have adapted their migration patterns to climate factors and treeline patterns. These studies exemplify the strong interrelation among Inuit lifestyle, climate change and vegetation patterns.
Since the end of the LIA, a general increase in erect shrub and tree abundance was expected as temperatures have been warming (Hallinger et al. 2010, Sturm et al. 2005a, Chapter 2). However, this warming trend was not constant but characterised by successions of warm and cool periods favourable or not for erect shrub and tree expansion. Such increases have been reported in Nunavik for green alder (*Alnus viridis* subsp. *crispa*) (Gilbert and Payette 1982) and for trees (white spruce (*Picea glauca*) and black spruce (*Picea mariana*)) in many areas including Nunatsiavut; sometime resulting in local rises of the altitudinal or latitudinal treelines (Payette and Filion 1985, Lavoie and Payette 1994, Lescop-Sinclair and Payette 1995, Caccianiga and Payette 2006, Payette 2007).

In the last 50 years there are indications of altitudinal rise of the treelines. In western Nunavik, Gamache and Payette (2005) documented a transect straddling the forest-tundra ecotone where black spruce increased through seedling establishment in the southern part of the transect and through vertical growth of stunted individuals in the northern part. Black spruce expansion near treeline was constrained by very limited seed viability in the past (Sirois 2000) but current results indicate a sharp increase in viability over the last 18 years (Dufour Tremblay and Boudreau 2011). A recent study in the vicinity of Kangiqsualujjuaq (George River, northeastern Nunavik) recorded abundant and recently established seedlings and saplings of eastern larch (*Larix laricina*) on hillsides above pre-existing woodlands, suggesting an ongoing rise of local altitudinal treelines (Tremblay et al., In press, see Photo 2). In 2008, the cone production of eastern larch in this area was remarkable and laboratory germination trials revealed very high proportions of viable seeds (E. Lévesque, pers. comm.). People from Kangiqsualujjuaq (Nunavik) reported that trees have been starting to grow...
on the coast since the 1990s and an Elder mentioned that balsam poplar (*Populus balsamifera*), very scarce in the 1940s, was now becoming more abundant (Gérin-Lajoie et al. in prep.). Kangiqsualujjuamiut have also mentioned the greater expansion of tamarack over black spruce, and some Elders have noticed that black spruce on hillsides facing the George River mouth were not seen some years before (Gérin-Lajoie et al. In prep.).

In coastal areas of southern Nunatsiavut, Payette (2007) found that treelines (mainly white spruce) advanced northward and that seedling establishment has increased in upland tundra ecosystems since the 20th century. Invading white spruces were observed several meters above current altitudinal and latitudinal treelines, suggesting that spruce is infilling suitable and unoccupied sites. An abundance of white spruce seedlings has also been observed in the Labrador interior at Mistastin Lake, about 25 km south of the northern tree limit (T. Trant and J. D. Jacobs, unpubl. data, pers. comm.). In Nain, observations by local Elders suggest that trees (mostly spruce) and shrubs have been spreading and advancing upslope into upland tundra, expanding around their community and throughout their traditional harvesting/traveling areas (L. Siegwart Collier, unpubl. data, pers. comm., see Photo 3).

**Vegetation changes observed above treeline**

A recent study in tundra areas surrounding Kangiqsualujjuaq using past and recent aerial photos showed a substantial increase of erect woody vegetation from 1964 to 2003, attributed mainly to dwarf birch (Tremblay et al. In press). During the 40 years spanning the two photo series, more than half the area available to erect woody vegetation was affected by new colonization or infilling of dwarf birch. Expansion of dwarf birch was most prominent on mid to upper slopes with southerly and easterly exposures. The drivers of this change may be a combination of warmer

Photo 2. Hillside northeast of Kangiqsualujjuaq, Nunavik, showing abundant eastern larch saplings recently established above the treeline, suggesting that local altitudinal treeline is rising. Source: Benoît Tremblay.
long-lived woody species and by the reconstruction of tree pollen records preserved in lakes and bogs (as mentioned in chapter 2). These changes possibly have imposed migration to Inuit and Innu people (Fitzhugh 2009). Fitzhugh (1977, 1997) and Fitzhugh and Lamb (1985) demonstrated how First Nation people in Labrador and Eastern Subarctic have adapted their migration patterns to climate factors and treeline patterns. These studies exemplify the strong interrelation among Inuit lifestyle, climate change and vegetation patterns.

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In the last 50 years there are indications of altitudinal rise of the treelines. In western Nunavik, Gamache and Payette (2005) documented a transect straddling the forest-tundra ecotone where black spruce increased through seedling establishment in the southern part of the transect and through vertical growth of stunted individuals in the northern part. Black spruce expansion

Photo 3. North-facing (foreground) and South-facing (nearground) hillside slopes surrounding the community of Nain, Nunatsiavut. Photo depicts the abundant and widespread distribution of predominantly spruce (Picea spp.), tamarack (Larix laricina) and dwarf birch (Betula glandulosa) surrounding the community. Source: Laura Siegwart Collier, 2009.

Photo 4. Repeated ground photography of a landscape near Kangiqsualujjuaq, Nunavik. View is from the east side of Akilasakallak Bay and shows substantial colonization of palsa summits by erect shrubs and trees in only 20 years. The 1988 photo was graciously provided by Marcel Blondeau and was taken at the end of July. The 2008 photo was taken August 7th. Source: Benoît Tremblay.
temperatures during the last two decades, coupled with a destruction of lichen cover associated with trampling and grazing by caribou during high density years. This increase of erect woody vegetation is consistent with a marked rise in mean annual temperatures in the Canadian Eastern Arctic since the beginning of the 1990s (Figure 2) and is further supported by repeated ground photography (Photo 4) and regional-scale NDVI analysis (W. Chen, unpubl. data, pers. comm.) as well as local ecological knowledge. Indeed, people have reported a “greening” of the area, mostly due to shrubs growing much more than before (Gérin-Lajoie et al. in prep.). The rings of some larch trees and saplings that were analysed showed an increase of annual growth since 1990 as was suggested by the deceased Willie Emudluk from Kangiqsualujjuaq (see Box 1). Further analyses are in progress to document treeline dynamics at this site. In Western Nunavik, along the Boniface River, shrub cover (mainly *Betula glandulosa*) has increased significantly over the last 50 years. This increase could also be linked to warmer temperatures and caribou disturbances as in the case in Kangiqsualujjuaq. However, the absence of tree regeneration following forest fires over the last thousand years has resulted in the progressive opening of the forested landscape (Sirois and Payette 1991, Payette et al. 2001). Such lack of tree regeneration could have contributed to creation of a suitable landscape for shrub expansion.

Figure 2. Mean annual temperatures of six eastern Canadian Arctic localities: Nain (Labrador, 56°33’N-61°41’W; 1927-2009 with incomplete data from 1927 to 1984), Kuujjuarapik (Quebec, 55°17’N-77°45’W; 1926-2009 with incomplete data from 1937 to 1957, 2002 to 2004 and 2006 to 2008), Kuujjuaq (Quebec, 58°06’N-68°25’W; 1948-2009), Kangiqsualujjuaq (Quebec, 58°43’N-66°00’W; 1993-2008), Iqaluit (Nunavut, 63°45’N-68°33’W; 1947-2009 with missing data for a few years) and Coral Harbour (Nunavut, 64°11’N-83°22’W; 1946-2009 with missing data for a few years). Source of raw data is Centre d’études nordiques (Laval University) for Kangiqsualujjuaq and Environment Canada for all other localities. Parallelism of all the curves is remarkable and they all show a similar trend of higher mean annual temperatures since 1993.
Near Umiujaq along the eastern shore of Hudson Bay, community members have reported increased shrub growth, especially of birches becoming more abundant and willows growing taller (Gérin-Lajoie et al. in prep.). Preliminary results from the comparison of 1990 aerial photographs and 2004 satellite images confirm such an increase in erect shrub distribution. Changes happened mainly in coastal lowlands, in openings in protected valley bottoms and on the tops of palsas. These changes were essentially due to dwarf birch and, to a lesser degree, to Labrador tea (Rhododendron groenlandicum). No tree saplings were found at this site (E. Lévesque, pers. comm.). As for Nunatsiavut, M. Upshall and A. Simms (unpubl. data, pers. comm.) found, using Landsat images from 1985 and a SPOT image from 2008, that erect deciduous shrubs such as dwarf birch have spread from river valleys in the southern Torngat Mountains into the tundra, increasing in height and density. Further modelling exercises to predict future changes are underway.

Box 1. Look at the trees!

During an interview on climate change, Willie Emudluk from Kangiqsualujjuaq told us that the trees were growing more, both in height and diameter. To support what he had said, he encouraged us to measure the growth rings of both larch and spruce.

He said: “If you cut a tree and examine the lines, you will find that trunks of trees have grown wider. Look at the trees!”.

Born on January 17, 1924 in Old Kuujjuaq, he passed away in Kangiqsualujjuaq on September 21, 2009. Willie Emudluk was an important figure in Nunavik, particularly in the Ungava region. Well respected, he worked towards the foundation of Inuit cooperatives in the hamlets of Nunavik, originally created for selling fish and wood. He possessed a good knowledge of animals, plants, Inuit territory and the history of his community. He was interviewed numerous times and was always willing to collaborate with researchers and share his expertise. It is important for us to honour his memory and to pay tribute to his open-mind, his humility, his passion for Nature as well as his generosity. Nakurmmimaluluk Willie!

Willie Emudluk interviewed by Alain Cuerrier and José Gérin-Lajoie in 2007.
The situation of erect shrub cover in areas underlain by continuous permafrost associated with the herb and shrub tundra vegetation subzones is poorly known. During interviews, people from Kangiqsujuaq on Hudson Strait, have reported that since the 1980s, shrubs, especially willows, are growing everywhere, getting taller and bearing bigger leaves (Gérin-Lajoie et al. in prep.). The comparison of 1987-2001 Landsat images around this community revealed a slight increase of shrub-herb-like vegetation by approx. 3%, in valleys (W. Chen, unpubl. data, pers. comm.). No fine-scale study or ground truthing work has been done in this area to further support these results. However, a fine-scale study of erect shrub cover change using aerial photographs and high resolution satellite images is underway in the Deception Bay area, about 60 km east of Salluit.

A large part of the continuous permafrost zone of Nunavik is under the influence of the Rivière-aux-Feuilles caribou herd (presented hereafter in chapter 9), a population which has greatly increased in recent years (over 600,000 individuals according to the 2001 census, Gouvernement du Québec, 2008). Erect shrub increase in this area may be hindered by high grazing pressure, particularly in tundra ecosystems where erect shrub abundance was initially very low (herb tundra subzone). High caribou grazing counteracting the positive effects of warmer temperatures on shrubs is suggested by a recent study in northern Sweden (Pajunen 2009).

In the Torngat Mountains, the alpine /coastal arctic tundra is dominated by short/prostrate shrubs that occur at low densities, including dwarf birch, northern Labrador tea (Rhododendron tomentosum ssp. decumbens) and bog bilberry/blueberry. The predicted changes in vertical structure may lead to loss of shade-sensitive species such as ground lichens (Cornelissen et al. 2006, Walker et al. 2006), which may have negative consequences for caribou especially in winter. In study sites near Nakvak Brook (Nunatsiavut), dry sites support a high lichen cover, while wet sites support high moss and graminoid cover. Shrubs and graminoid species play an important role in structur-
viable seed production (R. Jameson, unpubl. data, pers. comm.). In another study from this location, it was found that while there were negligible effects of nurse plants on growth in the first growing season, it was not until late in the second growing season that survival and growth rates began to show a positive association with their nurse plants. This suggests a weak net positive association between nurse shrubs and beneficiary seedlings during the first crucial life history stages (Cranston 2009). The documented impact was probably due to facilitation by seedbed species. Facilitation between the feathermoss (Pleurozium schreberi) and black spruce was observed as seedling growth and survival were highest on this seedbed and herbivory, seed predation and overwinter mortality were overall lower in feathermoss versus both reindeer lichens (Cladonia spp.) and bare ground seedbeds. The physical structure of the feathermoss likely reduces seedling exposure, and protects from temperature extremes and predators (Wheeler et al. 2011). In western Nunavik however, black spruce seedling establishment appears to be higher in sites disturbed by caribou (destruction of the lichen cover and exposition of mineral soil) (Dufour Tremblay and Boudreau 2011). Therefore, climate warming and caribou activity could act synergistically to increase black spruce regeneration. The expansion of trees into areas above current treelines of the forest-tundra ecotone, may be facilitated or “nursed” by shrub species. The shrubs could ameliorate harsh environments by providing shelter for tree seedlings (Sturm et al. 2005b).

In the Nunavik forest-tundra ecotone, sites with an increase in erect woody vegetation have been linked to variation in biogeographical, edaphic (soil related) and climatic factors. For instance, erect shrub increase is more or less restricted to lowland openings around Umiujaq on the east coast of Hudson Bay. At this location, further expansion on hillsides and hilltops, mostly made up of rock outcrops, may be impeded by rugged topography coupled with lack of loose substrate. In fact, tree abundance increase seems nonexistent or negligible around Umiujaq and changes may be in the form of loss of stunted growth of black spruce krummholz and through radial growth increase of pre-established individuals. Larch is sparse around Lac Guillaume-Delisle where it is near its northern distributional limit at this longitude (Boniface River). This is not the case around Kangiqsualujjuaq where hillsides and hilltop plateaus are usually covered with till of varying thickness, facilitating an increase in tree cover through abundant larch recruits. Regional differences will influence vegetation processes, for instance, in western Nunavik, tree species associated with altitudinal and latitudinal treeline dynamics are mainly spruces (mostly black spruce) whereas in eastern Nunavik and Nunatsiavut, at least in coastal areas, larch probably plays a greater role in current changes.

8.2.3 Impact of increasing shrub cover on the landscape

Impact on snow distribution and ecosystem processes

Increasing shrub cover has profound consequences on many ecological factors, such as decreased albedo and heightened sensible heat flux to the atmosphere and ground (Sturm et al. 2005a) as well as greater snow accumulation, active layer depth and summer evapotranspiration (Sturm et al. 2001, Pomeroy et al. 2006, Strack et al. 2007) (Photo 5). A decreased albedo of the tundra surface will result in greater absorption of radiation and atmospheric warming (Chapin et al. 2005). Furthermore, soil nutrient cycling is altered through changes in production and accumulation of woody material (carbon sequestration), through higher amounts of organic debris retained during transit (Fahnestock et al. 2000) and through warmer winter soil temperatures. The latter enhances decomposition (Grogan and Chapin 2000, Schimel et al. 2004, Sturm et al. 2005b), which in turn may promote spring and summer growth. The microclimate of taller shrub communities will also influence recruitment and establishment of vegetation through reduced airflow, warmer soil temperatures, and changes in moisture availability (Jessen Graae et al. 2009). On the other hand, there are some indications that increased soil shading by higher and denser shrub canopy might decrease heat transfer to the ground during summer
and thus counteract warmer temperatures (Walker et al. 2003). Further studies are needed to better understand the impact of shrub cover changes on soil properties, particularly to identify winter conditions favouring a warming of permafrost and summer conditions leading to soil shading and cooling of permafrost.

Community members from Umiujaq, Kangiqsujuaq and Kangiqsualujjuaq are noticing shallower snow depths, partly due to later snowfalls (delayed from October to December) and more wind blowing snow accumulations almost immediately after snowfall. In addition, erosion phenomena are more frequently observed in Nunavik. For example, community members are reporting permafrost thawing and more landslides in Kangiqsualujjuaq, rock sliding in Kangiqsujuaq as well as beach and river bank erosion in Umiujaq (Gérin-Lajoie et al. in prep.).

In Nain, community members are reporting later arrival of snow (delayed from October to late December), lower abundance and reduced snow quality. In winter months, wet snow and rain are becoming more common, having a detrimental effect on both inland and offshore ice conditions (L. Siegwart Collier, unpubl. data, pers. comm.). These trends are wide-spread across Nunavik and Nunatsiavut and are projected to continue for the next 40-50 years with earlier snowmelt (by 3-11 days), later onset of winter snow (by 5-16 days later), and warmer winter temperatures (3-5°C increase; Chapter 2). However, the snow-elevation dynamic is a complicating factor. The relatively warm winter 2009-2010 in Labrador was characterised by more snowfall in higher elevations (e.g. above 600 m), but by rain and winter thaw events at low elevation. More landscape-scale snow cover data are needed. These conditions compromised the ability of Nunatsiavut residents to travel, either by boat or snowmobile (L. Siegwart Collier, unpubl. data).

Disturbance regimes in a changing climate

In the context of a warming tundra and associated changing vegetation, it is expected that the impacts and nature of disturbances could change and then further modify the vegetation and landscape dynamics. In the boreal forest,
fire is the most pervasive large scale disturbance agent in closed canopy black spruce dominated stands. Biotic interactions (insect outbreaks, herbivory and fungal attacks) also play a major role in the overall dynamics of these forested ecosystems where they are interacting with fire (McCulloch et al. 1998, Malmström and Raffa 2000, Cairns and Moen 2004). Due to the low abundance of fuel provided by the patchy shrub/conifer cover in northern forest-tundra and shrub tundra, fire has lesser impact (0.4 fire/yr and 80 ha) than in the closed northern boreal forest (0.7 fire/yr and 8000ha; Payette et al. 1989). Similarly, fire was found to be very uncommon in central Labrador and usually associated with single trees, probably a result of very rare lightening strikes (Trindade et al. 2011). Although model projections show an increase in annual precipitation of 10 to 20% (see chapter 2), this projected trend may not be sufficient to maintain soil moisture given the expected rise in growing season temperatures (2°C by 2050; see chapter 2) and the corresponding increases in evapotranspiration. Consequently, with an increased vegetation cover, it is hypothesized that fire could be favoured and may become a more important driver of change in the North (Payette et al. 2001).

The impact of defoliating insects on erect shrubs and trees in Nunavik and Nunatsiavut, as well as frequency and extent of outbreaks, is poorly known. Near treeline in western Nunavik, the role of insect outbreak (particularly bark beetle) was important at the local scale and may explain the high mortality of the oldest cohorts of white spruce (Caccianiga et al. 2008). In central Labrador, larch sawfly is one of the defoliating insects that causes decreased tree growth and increased tree mortality (A. Trant, pers. comm.). However, impact of insect outbreaks in the forest-tundra ecotone might be minimal due to cold weather but also to patchy distribution and small extent of wooded areas. Current environmental changes could have major impacts on insect numbers and vegetation.

The interrelations between climate change, fire and biotic disturbances require more studies to better predict vegetation dynamics. For instance, fires can favour forest regeneration if sufficient viable seeds are dispersed. Warmer conditions are expected to favour seed production in treeline trees. On the other hand, fires can destroy isolated forest patches and slow down tree expansion (Payette et al. 2001), especially if differential mortality of older, seed bearing trees linked with insect outbreak (Caccianiga et al. 2008) further reduces the seed rain.

8.3 Berry shrub productivity, abundance and growth

In general, experimental warming of tundra plots favours increasing cover and/or height of shrub species (Walker et al. 2006, Chapin et al. 1995). In addition, growth and reproductive phenology of tundra vegetation (i.e. green-up, bud burst and flowering) is shifting due to climate warming, and observations of these shifts have been verified by long-term passive warming experiments (Walker et al. 2006, Henry and Molau 1997). Shifts in flowering phenology may affect pollination success, influencing fruit production, seed ripening and dispersal (Fitter and Fitter 2002, Memmott et al. 2007, Galloway and Burgess 2009, Jentsch et al. 2009). Recent studies in Europe comparing simulated and natural extreme winter warming events have shown a significant reduction in flower and berry production, primarily due to damage to previous year buds (Bokhorst et al. 2008, Bokhorst et al. 2009). Similar impacts in Nunavik and Nunatsiavut may be expected as projections show similar increases in winter temperatures (3-5°C) in the region (Chapter 2). In addition, increased variability in late spring frost days may result in flower drop and loss of berry crops. Damage could be related to premature induction of flowering hormones, rendering buds or flowers vulnerable when seasonal weather conditions return.

While we know that warming-induced shading from upright shrubs reduces non-vascular plant cover and biodiversity (Cornelissen et al. 2006, Walker et al. 2006), there are few if any studies linking the effects of upright shrub expansion (shading) to variation in growth and re-
production of dwarf berry shrubs such as alpine bearberry (*Arctous alpina*), bog bilberry/blueberry, partridgeberry/redberry, black crowberry/blackberry and cloudberry/bakeapple (Photos 6 to 10).

Naturally variable in time and space, the number of berries produced depends on weather and successful pollination. Yet, very little is known about pollinators in the Arctic and Subarctic, nor about predation of flowers and/or fruits, especially by insects. Berry production and insect activity are influenced by spring and summer rainfalls and by seasonal temperatures that contribute to the timing of thawing and growing degree days. Using an 11 year dataset from the Yukon boreal forest, Krebs et al. (2009) found that, in a given summer, rainfall and temperature two years prior can be significant predictors of tundra berry plant yield. Growth and productivity of previous years can also impact current year growth and berry production in ericaceous shrubs (e.g. *Vaccinium* spp.) (Krebs et al. 2009). Current climate warming scenarios predict changes in timing and total amount of thawing degree-days (increase by 30-60%; Chap 2) that will certainly influence berry productivity. In this context, it is even more urgent to improve our understanding of factors influencing this inter-annual variability. Community-based monitoring of berry productivity and phenology events associated with climate monitoring is being developed to help address this issue.

In the Torngat Mountains, experimental warming using Open Top Chambers (OTCs) indicates an increase in shrub height and density in dry and wet tundra plots; changes in shrub height may occur in dry sites before wet sites. The results suggest that mesic shrubs (growing in average moisture conditions) such as dwarf birch and bog bilberry/blueberry will respond positively to warming across both wet and dry habitats (Hermanutz et al., unpubl. data). In Kangiqsualujjuaq, preliminary results of berry shrub growth assessed in a range of habitat types, from open tundra to continuous tree cover (C. Lavallée, unpubl. data, pers. comm.) confirm that bog bilberry/blueberry, partridgeberry/redberry and black crowberry/blackberry plants were significantly shorter in open environments suggesting that plants modify their growing pattern under shrub or tree cover. In addition, the annual elongation of black crowberry/blackberry was measured.

*Photo 6. Alpine bearberry (*Arctous alpina*). Source: José Gérin-Lajoie.*

Photo 8. Partridgeberry/redberry (Vaccinium vitis-idaea). Source: José Gérin-Lajoie.

retrospectively using leaf scars up to 20 years; growth increased significantly over the last 10 years regardless of cover type (C. Lavallée, unpubl. data, pers. comm.) suggesting a response to the recent climate warming in this region. Similar results were seen in Sweden for *Empetrum hermaphroditum* and *Vaccinium uliginosum* when growing under a stand of *Betula nana* (Fletcher et al. 2010). Warming effects are more conspicuous in early Spring and might disappear during Summer. Efforts are being made in evaluating early growth in OTCs in relation to control plots near Nain, and then, re-measuring the same ramets (branches) in order to understand if differences will be blurred by later growth (L. Siegwart Collier, unpubl. data).

Analysis of vegetation cover and berry productivity data from recently established experimental warming sites (2008-2009) in Nunavut (Qamani’tuq/Baker Lake), Nunavik (Kangiqsualujjuaq, Kangiqsualujjuaq) and Nuna-tsiavut (Saglek, Nain) suggests that site characteristics play a very important role in berry production (Siegwart Collier et al., unpubl. data). Dwarf birch heights (ranging from 3-19 cm) had a strong negative effect on black crowberry/blackberry fruit set. More berries were found in open environments and under continuous tree cover and fewer under shrubs (Table 1). Birch height also had a weak negative effect on bog bilberry/blueberry and partridgeberry/redberry production. Regardless of shrub species, productivity of these three berry species was significantly higher in open environments (C. Lavallée, unpubl. data, pers. comm.). As for bog bilberry/blueberry, productivity under tree cover was even lower than under shrub cover.

With further warming as predicted in Chapter 2, it is expected that in areas where erect shrubs and trees are present, berry shrubs will need to invest more energy in growth to compete with taller shrubs for light. This may result in an overall decrease in berry productivity among sites. On the other hand, in open habitats, warmer conditions may increase berry productivity if moisture remains sufficient and pollinating insects abundant.

Northern communities are concerned about changes in berry shrub growth and productivity because of the importance of berries in tundra ecosystems to wildlife, human health and indigenous culture and identity. Interviews with community members in Nain suggest that berries are less abundant and smaller than in previous years. People also identified that the taste of berries has changed.

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>LATIN NAME</th>
<th>BERRY PRODUCTIVITY (g/m²)</th>
<th>OPEN HABITAT</th>
<th>SHRUB COVER</th>
<th>TREE COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black crowberry/Blackberry</td>
<td><em>Empetrum nigrum</em></td>
<td>++</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Partridgeberry/Redberry</td>
<td><em>Vaccinium vitis-idaea</em></td>
<td>++</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Bog bilberry/Blueberry</td>
<td><em>Vaccinium uliginosum</em></td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. Berry productivity (g/m²) in Kangiqsualujjuaq, Nunavik, in relation to shrub height and various habitats from open to shrub cover to tree cover.
and that the leaves and berries of berry plants sometimes appear “burnt” (L. Siegwart Collier, unpubl. data, pers. comm.). In Kangiqsualujjuaq, community members have noticed that the berries start to grow, bloom and ripen earlier in the season. In Kangiqsujuaq, people have already observed that greater snow accumulations mean lots of berries the following summer (Gérin-Lajoie et al. in prep.).

8.3.1 Antioxidant activity and phenolic compounds in berries

Berries around the world are rich in antioxidants and phenolic compounds. In the North, despite their important role in the diet, few studies have quantified antioxidant activity. Preliminary results obtained from Kangiqsualujjuaq and Kangiqsujuaq suggest that black crowberry/blackberry and partridgeberry/redberry are the two species with the highest antioxidant capacity and total phenolic compounds while bog bilberry/blueberry has lower antioxidant activity and total phenolic compounds (C. Lavallée, unpubl. data, pers. comm.) (Table 2). Harris et al. (in prep.) had comparable results from samples taken from boreal forest and the Eastern Subarctic, with black crowberry/blackberry having higher antioxidant activity after juniper berries with partridgeberry/redberry close in antioxidant activity. Samples of bog bilberry/blueberry harvested from different localities gave lesser activity, although they are still good candidates as antioxidants. Northerners are interested in studies on the importance of latitudinal gradient in antioxidant as well as gene expression linked to substances known to possess antioxidant potential. Results demonstrate that coastal and more northerly samples are generally more active. (Fraser et al. 2007, Downing et al. in prep.).

Climate change will impact berry producing plants and in turn will modify the antioxidant activity of their berries. It is still unclear how berries will be affected. Factors are numerous and complex: temperature, shading, soil, rain pattern, photoperiod, even plant genetics as well as diseases and insects will contribute to the production of antioxidant substances in berries. Because northerly individuals tend to produce more phenolic compounds to cope with low temperature and long photoperiod, warming may bring the plant to produce less of those protective compounds that have medicinal value. In Finland, Kahkonen et al. (2001) and other researchers measured phenolic compounds and antioxidant activity of common berries and apples. All species showed some antioxidant activity, especially black crowberry/blackberry and partridgeberry/redberry. Similar studies in Alaska indicate that results are comparable (Leiner et al. 2006, Kellogg et al. 2010). Both black crowberry/blackberry and partridgeberry/redberry seem to be the best berries in terms of antioxidants. Beaulieu et al. (2010) also showed that partridgeberry/redberry is a potentially good antidiabetic plant and this correlates with its antioxidant activity. Harris et al. (in prep.) further analysed a number of berries and came to the same conclusion: berries are a healthy

Table 2. Antioxidant capacity (µmol Trolox equivalents/g FW) and total phenolic compounds (mg Tannic acid/g FW) analysed in berries from Kangiqsualujjuaq and Kangiqsujuaq, Nunavik, summer 2009.

<table>
<thead>
<tr>
<th>Common names</th>
<th>Latin names</th>
<th>Kangirsualujjuaq</th>
<th>Kangirsujuaq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Antioxidant capacity</td>
<td>Total phenolic compounds</td>
</tr>
<tr>
<td>Black crowberry/blackberry</td>
<td><em>Empetrum nigrum</em></td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Partridgeberry/redberry</td>
<td><em>Vaccinium vitis-idaea</em></td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Bog bilberry/blueberry</td>
<td><em>Vaccinium uliginosum</em></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
food and contain medicinal agents. Members of different communities in Nunavik and Nunatsiavut have mentioned the importance of berries for health (Gérin-Lajoie et al. in prep., L. Siegwart Collier, unpubl. data, pers. comm., Cuerrier and Elders of Kangiqsujuaq, 2005).

There are potential positive and negative effects of warming on antioxidant concentration in berry plants. Further research is needed to document the relation between latitudinal gradient (or warming) and the berry’s nutritive quality.

8.4 Community-based monitoring

Throughout the world, berry productivity is known to be variable in time and space and the Arctic is no exception. However, this variability has rarely been documented in the Canadian Arctic and Subarctic despite the importance of berry-picking activities for Inuit culture and health. Through joint IPY and ArcticNet efforts, we presently collaborate with 3 Secondary schools in Nunavik (Umiujaq, Kangiqsujuaq and Kangiqsualujjuaq) to collect data about annual berry productivity, snow depth and various

Box 2. Community-based monitoring

Given the importance of berry picking activities to Inuit culture and health, researchers and high school teachers and students from three communities in Nunavik (Umiujaq, Kangiqsujuaq and Kangiqsualujjuaq) help collect information annually on the main berry species consumed by Inuit in areas easily accessible from the communities and representative of community gathering grounds.

Climate data from the local meteorological stations are also compiled and local students hired for snow measurements throughout the winter (Kangiqsujuaq and Kangiqsualujjuaq). In addition, an observation calendar was designed to collect dates and locations of various environmental and ecological phenomena, including phenological events for plants and insects.

This integrated approach is supported by Kativik School Board and a collaborative project is currently developing scientific learning activities using standard protocols to monitor berries. These educational activities are designed to be embedded in the Nunavik Science and Technology curriculum. Part of a larger initiative involving other communities in Nunavut (Kugluktuk, Baker Lake, Iqaluit, Pangnirtung, Pond Inlet), this contributes to capacity-building in science among Inuit Youth, and greatly enhances the understanding of berry productivity variability. Activities and protocols for monitoring other important ecological factors are also under preparation, such as snow depth variations, ice freeze-up and break-up and phenological observations.
phenological observations: blooming, green-down, berry ripening, insect emergence, sea and lake freeze-up/break-up, etc. This initiative was part of a larger effort across a broad East-West gradient, involving other communities in Nunavut (Kugluktuk, Baker Lake, Iqaluit, Pangnirtung, Pond Inlet) and Nunatsiavut (Nain), as well as two field research sites (Daring Lake, Bylot Island) (Lévesque et al. 2009). Using a simple standard protocol, researchers, teachers and their students as well as various other interested individuals help collect berries (Box 2).

Long term data series are essential to understanding such naturally variable systems and even more so to detecting changing trends. The collaboration with community members greatly enhances our ability to understand northern environments since we can get information year round from people most concerned about this information. In addition, this initiative will contribute to capacity-building in science among Inuit youth, and favour exchanges between scientists and Northerners that may raise issues or phenomena not anticipated.

**8.5 Conclusions and recommendations**

Vegetation is already changing in Nunavik and Nunatsiavut. Conditions predicted by climate models, especially increased growing season length (11 to 27 days, Chapter 2) and growing degree-days (50% to 150%, Chapter 2) will promote erect shrub species establishment and growth. Their cover and height are predicted to continue to increase throughout the area except on bedrock outcrops. Currently the herb tundra zone has not been greatly colonised by shrubs, but birch and some willows are expected to expand even in these zones.

With the improved conditions favouring increased viable seed production, and seedling establishment, trees are expected to gradually expand beyond current treelines. At this stage, it is impossible to predict the level of change by 2050 according to the climate projections presented in Chapter 2. Models are being developed to address this issue. Further research is necessary to understand feedbacks of these vegetation changes on the ecosystem and to evaluate how the disturbance regimes will vary in response to climate change, including if and how insect infestations and fire will increase.

Warmer and longer growing seasons may not benefit berry producing plants which will face increasing competition from taller shrubs, and potentially lack of moisture if summers are dryer. Changes in precipitation are expected to increase (Chapter 2) but remain uncertain due to the great spatial and temporal variability of precipitation. Berry productivity is sensitive to the abundance and timing of precipitation and extreme events (e.g. late frost in the spring). Berry species producing best in full sun (especially partridgeberry/redberry and bog bilberry/blueberry), will most likely decline under shrub cover, yet the patchy nature of arctic vegetation should enable other species more tolerant to partial shade such as black crowberry/blackberry and cloudberry/bakeapple to take advantage of the changing conditions.

Migration and/or expansion of boreal species (e.g. raspberries) are to be expected in the southern portion of the studied area. Some raspberries were reported near Umiujaq, but not in large abundance, and plumboy (*Rubus arcticus* subsp. *acaulis*) was newly observed in Kangiqsualujuaq (Kennedy et al. 2010). Raspberries are also thriving in the latter community, but they seem not to produce berries, which was also the case in Umiujaq in 2005 (A. Cuerrier, pers. comm.).

Major uncertainties relate to the impact of environmental changes on biotic interactions between vegetation and animals, herbivores (both insects and vertebrates) and pollinators. Warmer and longer growing seasons will affect food abundance and quality, as well as change the distribution, diversity and emergence patterns of insects. Changes in pollinator fauna and/or herbivorous insects may also affect berry production as insect distributions shift northwards and/or insect emergence occurs earlier.
during warmer seasons. Further studies are needed to document these biotic interactions.

Community-based monitoring will contribute to Northerners’ awareness of environmental changes and their capacity to document them. Longer time series from a wide range of sites will benefit communities and researchers and greatly enhance our predictive abilities.

In addition to their competitive impact on berry producing species and other plants, including lichens, taller shrub species (e.g. willow and birch) may affect traveling routes as well as traditional activities like berry picking. In winter, snow deposition patterns are being altered by taller shrubs and in summer, denser and taller vegetation can also restrict movements (see also Chapter 5).

Even if erect shrub growth (including berry producing shrubs) may be limited by grazing (in areas with high caribou density), by dryer conditions, or by other factors, warmer conditions may favour the expansion of species at their northern distribution limit, such as cloudberries and raspberries. All these changes will likely affect berry productivity but not in a uniform way, depending on species’ ecology (e.g. shade-tolerant species, pollination), substrate characteristics and availability, pollinators as well as local climatic conditions, topography and perturbations.

Northerners have observed changes in their environment both in the past and present (Nickels et al. 2005), and have adjusted their berry-picking activities to the high spatial and inter-annual variability in berry productivity. Additional changes are expected and models are currently under development to integrate the climate and biotic factors to help predict areas most likely to change in berry productivity. This should be helpful in the future when selecting areas to be protected from additional stress, such as community or industrial developments to ensure easy access to high quality sites for this culturally important activity.
8.6 References


Cranston, B. 2009. The Stress Gradient Hypothesis: plant facilitation at the forest-tundra transition (Mealy Mountains, Labrador, Canada). M.Sc. Thesis, Department of Biology, Memorial University of Newfoundland, St. John’s, NL, 81pp.


Harris, C. S., Lamont, E., Cuerrier, A., Haddad, P. S., Arn-
-nason, J. T., Bennett S. A. L., and Johns, T. Investigating wild berries as a dietary approach to reducing the formation of advanced glycation endproducts: Correlation with in vitro antioxidant activity. In prep.


Tremblay, B., Lévesque E., and Boudreau, S. Recent expansion of erect woody vegetation in the Canadian Eastern Low Arctic. under revision for Arctic Alpine and Antarctic research.


