CLASSIFICATION OF DWARF HEATH PLANT COMMUNITIES ON THE COASTAL BARRENS OF NOVA SCOTIA

By

Caitlin Porter

A Thesis submitted to

Saint Mary's University, Halifax, Nova Scotia

in Partial Fulfillment of the Requirements for

the Degree of Master of Science in Applied Science.

Halifax, Nova Scotia

Approved: Dr. Jeremy Lundholm
Supervisor

Approved: Sean Basquill, M.Sc.
Supervisory Committee

Approved: Dr. Danika van Proosdij
Supervisory Committee

Approved: Dr. Nick Hill
Supervisory Committee

ABSTRACT

Classification of Dwarf Heath Plant Communities on the Coastal Barrens of Nova Scotia

By Caitlin Porter

Abstract: Nova Scotia's coastal barrens are comprised predominantly of heathlands, a globally threatened community type. Coastal barrens provide habitat for a number of nationally rare species. Despite their ecological and cultural importance, Nova Scotia's coastal barrens are poorly described. My objectives were to classify and describe coastal dwarf heath plant communities and to quantify environmental factors that explain variation in their composition, diversity, and distribution. I sampled plant species abundance alongside comprehensive environmental and soils data across Nova Scotia. Using ordinations and cluster analyses combined, I numerically classified three distinctive plant communities. I inventoried 253 species of vascular plants, bryophytes and lichens, including several species of conservation concern. Environmental variables with significant influence on heathland vegetation structure included: moisture regime, fetch distance, soil depth, elevation, distance from the coast, and slope gradient. Future conservation efforts should prioritize rare species and evaluate habitat representivity using these quantitative community definitions in place of current qualitative approaches.

May, 2013.

DEDICATION

For my family for their love and support: Nan and Gramp, Aunt Joan, Mom and Dad and my brother Evan.

ACKNOWLEDGEMENTS

I would firstly like to thank my supervisor Dr. Jeremy Lundholm for his mentorship. Jeremy provided valuable guidance, insight and support while also enabling me to pursue research questions that I found personally rewarding. He provided me with many unique opportunities within and parallel to my thesis that greatly enriched my learning experience. Jeremy had faith in my abilities and has always been encouraging. His leadership also created a uniquely supportive and creative-thinking lab dynamic that I have enjoyed being a part of.

Sean Basquill is a committee member but also acted as my supervisor for 4 months of this thesis during my employment with NSDNR. My field experiences with Sean were challenging and among the best times of my life so far. I greatly appreciate his mentorship, encyclopedic ecological knowledge, and general support throughout the entire process of my thesis. Mentorship from both Jeremy and Sean provided me with even more opportunity to learn than I had expected of grad school.

I greatly appreciate Dr. Danika van Proosdij's broader contextual perspective, attention to detail and helpful feedback. Thanks to my external examiner, Nick Hill for providing perspective and insight, particularly in terms of ecological theory and as well from extensive field research experience in Nova Scotia.

Thank you also to Tony Bowron and Nancy Neat of CBWES for opportunities outside of my thesis and for being helpful and flexible supervisors.

This research would not be possible without all of the field support I received. Thanks to Brett Weddle for his field assistance and Lawrence Benjamin at NSDNR for field support and for introducing me to some very interesting rare plants. Thanks also to Kim Campbell and Rayna Ogilvie for field assistance. Thanks to Kevin Keys for guidance and input with respect to soils. Thanks to Terry Power for field support and he and Reg Newell for their local knowledge. Thanks to Ken Corkum for the lift.

Unknown vascular species were identified by Sean Blaney and David Mazerolle of the Atlantic Canada Conservation Data Center. Sarah Robinson of ACCDC also shared her reports on sand dunes in Nova Scotia. Unknown bryophyte specimens were identified by Bruce Bagnell of the New Brunswick Museum. Unknown lichens were identified by Frances Anderson of the Nova Scotia Museum of Natural History.

Thanks to Greg Baker for GIS help, mapping advice, and coding the fetch model for my thesis. Thanks also to Frances McKinnon at NSDNR for GIS support.

Thanks to Ben Lemieux and Chance Creelman for their friendship and thoughtful review of my thesis. Thanks to Jeff Barrell for support and also review of my final draft. Thanks to Rob William for helping me with public speaking, solidarity in late lab nights, and thanks to he, Amanda Lowe and Steph Tran for their friendship and support. Thanks to all my EPIC labmates, Amy Hiem and Stephanie Appleby-Jones for their friendship and support.

TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

Overarching relevance

Anthropogenic habitat destruction has been described as a global "crisis" (Hoekestra *et al.* 2005). Habitat destruction leads to loss of species and provision of ecosystem services (Dobson *et al.* 2006). These losses directly affect human welfare due to the reduction of economic and human health services ecosystems provide (Dobson *et al.* 2006; Blaikie and Jeanrenaud, 1996). Projected species extinction rates suggest that at least 10% of plant species currently face extinction (Pimm and Raven 2000).

Barrens are a habitat characterized by prevalence of Ericaceous vegetation and environmental extremes such as: shallow, acidic, and nutrient poor soil; wind and salt spray. Barren habitats belong to a biome subject to the highest global conservation risk because 48.5% of temperate grassland, savanna and shrubland have been subject to land conversion while only 4.6% of barrens habitats have been protected (Hoekestra *et al* 2005). Globally, heathland plant and animal communities face habitat loss and species extinctions (Clarkson *et al*. 2010). Projecting extinction rates or quantifying threats to individual species or groups of species is challenging, particularly because of inadequate data (Balmford *et al*. 2003). There has been very limited research on the coastal barrens in Nova Scotia, meaning scientific data and knowledge required for conservation and landscape management decision making are also limited.

European heathlands are relatively well understood, providing a strong research basis for conservation policy and management (Clarkson *et al*. 2010). A better understanding of barrens in Nova Scotia would have similar value in shaping policy and management decisions. One long term research objective of Nova Scotia Department of Natural Resources (NSDNR) is to determine the diversity, distribution, and conservation status of heathland (barren) ecosystems in Nova Scotia (Sean Basquill, personal communication). The Nova Scotia Department of Environment will protect 12% of Nova Scotia by 2015 under the Sustainable Prosperity Act, and a number of candidate sites are comprised of barrens habitat (NSE 2010; 2013).

Geography of Nova Scotia barrens

Barrens cover a significant portion of Nova Scotia. They are distributed across the entire Atlantic Coastline from Digby, through Southwestern Nova Scotia, the Eastern Shore, and Northern Cape Breton. There are also occurrences of barrens along the Northumberland Straight and Bay of Fundy. Barrens are concentrated in the Tobeatic region, along the South Shore, peninsulas south of Halifax, the Canso Peninsula, and Eastern Atlantic coast of Cape Breton (Figure 2). Nova Scotia Department of Natural Resources (NSDNR) has mapped barrens in the province based on interpretation of aerial photography. Proportional to other ecosystem types in Nova Scotia, barrens cover a relatively small but still significant area of the province (approximately 1200 km^2 or 2.17%), as shown in Figure 2.

Biogeography and classification of barren habitats

Barrens are generally described (or conceived) as terrestrial vegetation not dominated by trees. Heathland refers to barrens dominated by Ericaceous shrubs, typically growing on dry, acidic soils. Heathlands by definition do not typically include peat bogs or grassland areas (Gimingham 1972), both of which are intermittent to frequent, intergrade spatially and conceptually and are and even somewhat indistinguishable from barrens vegetation in Nova Scotia (Oberndorfer 2006). Barrens are highly diverse and occur across a global extent. Latham (2003) summarized a list of world heathlands into a number of biomes based on respective geography, environmental conditions and plant assemblages. This spectrum ranges broadly and is inclusive of such habitat types as the semi arid gypsum heathlands in Turkey (Akpulat and Celik 2005), rare New Zealand gumlands defined by deposits of amber-like resin from the kauri tree (Clarkson *et al*. 2010), and boggy maritime heathland moors in Scotland (Friedlander 1970; Gimingham 1972). The commonalities among these vastly different habitat types classified as heathlands are: stressful environmental conditions; acidic nutrient poor soils, and dominance of ericaceous vegetation (Webb 1998; Schmidt *et al*. 2004; Piessens *et al* 2006; Oberndorfer 2006).

Heathlands research has largely focused on the biology and ecology of European barrens (Clarkson 2010; Friedlander 1970; Gimingham 1972). These barrens have been broadly described and categorized based on soil drainage (Price 2003) into wet or dry heathlands (Nilsen *et al* 2005). In Europe, heathlands are traditionally sometimes categorized into dry heathland or heathland moors and, differentiated largely by their soil and moisture characteristics. Moors are defined by wet conditions, significant peat accumulation and increased abundance or dominance of graminoids such as *Trichophorum caespitosum* (Friedlander 1970). The terms heathland and moorland are sometimes used interchangeably though heathlands are broader in meaning (Price 2003). Ellenberg and Mueller-Dombois (1966); Fosberg (1967); Rodwell *et al.* (2000), are among the best known British works classifying specific species plant communities on barrens in Europe. Very general terms such as ‘sedge moor’ are sometimes used to describe heathland plant communities (Pearsall 1965).

North American barrens are represented by alpine, tundra, desert scrub and rock outcrop vegetation (Oberndorfer 2006). These habitats also occur worldwide, *e.g.* globally rare alvars are also found in Estonia (Pärtel *et al* 1999). In the Eastern United States, barrens are distributed along coastal New England, and inland, *e.g.* Pennsylvania and pine barrens of New Jersey (Clarke 1946; Dunwiddie 1989; Rhoades *et al* 2005; Elliman 2005; Foster and Motzkin 2003; Latham 2003). Coastal barrens in Eastern Canada are largely concentrated in Newfoundland where they comprise 20% of the province's land area (Meades, 1983).

Barrens in Newfoundland have been extensively studied. Meades (1983) classified Newfoundland barrens into a number of communities based on species composition, dominance and environmental factors. These categories include; Alpine, *Empetrum*, Moss, Limestone, Serpentine and *Kalmia* heaths. Species assemblages are further described into sub-associations, for example, *Kalmia* heaths are further differentiated into species assemblages commonly occurring in peaty depressions over humic gleysols, or distinct assemblages which occur on soils with a thin Iron (Fe) cemented layer (Meades 1983).

Ecological importance

Many rare vascular plants, bryophytes and lichens inhabit barrens in Nova Scotia. *Vaccinium corymbosum, Rubus chamaemorous* and *Cornus suecica* are among the rare plants locally abundant at specific barrens sites in Nova Scotia. *Hudsonia ericoides* is rare across North America but present on some barrens in Nova Scotia. The moss *Dicranum condensatum* and the shrubs *Vaccinium uliginosum* and *Betula michauxii* are among the rarest species in Nova Scotia and are found exclusively on barrens. *Corema conradii* is relatively common in Nova Scotia (S4) but rare or uncommon in all other parts of its North American range, and *Ilex glabra* is unique in Canada to Nova Scotian barrens, woodlands, and wetlands, where it is locally abundant and ranked common (S5) (ACCDC 2013; NatureServe 2013).

Our understanding of barrens in Nova Scotia is incomplete since research is limited and because new species are regularly discovered. Additions to the list of provincial lichens in Nova Scotia are occurring more frequently as coastal barrens are increasingly targeted for exploration (personal communication: Frances Anderson; Teuvo Ahti; David Richardson). The first documented observation of *Cladonia brevis* in Nova Scotia was made during 2010 field work. As part of another study, five new lichen species to Nova Scotia and one new species to North America were recently discovered on a coastal barren in Nova Scotia (Macdonald 2011). The reindeer lichen, *Cladonia oricola* is another species new to North America (Ahti 2008), recently discovered on one Nova Scotia coastal barren (unpublished data Teuvo Ahti and Frances Anderson, 2011).

In the Northeastern United States, many shrublands are habitat for rare animal species (Latham 2003). This may also be the case in Nova Scotia but this type of research on barrens is extremely limited. Scatarie Island, comprised largely of barrens, is a protected area and designated IBA (important bird area) by Bird Studies Canada. Transient species such as Whimbrels annually migrate through select coastal barrens in

Nova Scotia, feeding on crowberry fruits (personal communication, NS Department of Environment; Bird Studies Canada).

Moose, an endangered species in mainland Nova Scotia, previously thought to avoid barrens (Oberndorfer 2006; 2009), forage on shrubs and trees on the periphery of barrens (personal communication Sean Basquill, NSDNR). Moose have been sighted on barrens during moose fly-over surveys by NSDNR on the Chebucto Peninsula (personal communication Sarah Spencer, NSDNR). The Chebucto Peninsula supports an isolated population of 20-30 moose. In addition, the second largest population of moose (250-275 individuals) inhabits Southwestern Nova Scotia concentrated near the Tobeatic Wilderness area (NSDNR 2007). This area is characterized by expansive inland barrens. Moose require a number of different open and forested habitats (NSDNR 2007) present within occupied habitat. White-tailed deer and snowshoe hare also browse on tall shrubs and grassy areas on the barrens occasionally (personal observation). Over the winter, porquipine sometimes eat the inner bark of conifers regenerating on the barrens, for example at the barrens on Pennant Point (personal observation).

Threats to barrens

Coastal housing developments have destroyed a large portion of barrens along the Northeastern Seaboard of the United States (Dunwiddie, 1989). Similar development pressure is foreseeable in Nova Scotia. Development along much of Nova Scotia's scenic coastline for luxury homes especially, has been increasing steadily (CBCL 2009). Urban sprawl in Halifax County also pressures areas with large expanses of barren south of Halifax (personal observation; CBCL 2009).

Irresponsible ATV use is another major conservation concern for barrens habitat (Oberndorfer 2006). Conservation oriented Non-Governmental Organizations (NGOs) cite ATV use as a threat to conservation areas; for example Bird Studies Canada in their site summary documentation of Scatarie Island as an Important Bird Area. ATV damage can be visually prominent, even from aerial photographs (*e.g.* at Peggy's Cove Preservation Area). One of the largest impacts that ATV tracks have on barrens microhabitats is soil alteration: soil temperature is increased by two to three degrees, soils are also compacted and eroded in comparison with hiking trails or with undisturbed barrens soils. ATV tracks have been shown to reduce lichen abundance (cover) and crush vegetation; ingraining bare tracks over bedrock. Seedlings are able to geminate on ATV trails, but survival rates are low and species composition of seedlings is altered, *ie*. the species that germinate on ATV trails are significantly different than surrounding vegetation. Bogs, low shrub plant communities and rock crack microhabitats are most vulnerable on the coastal barrens in Nova Scotia (Simon 2012).

In Europe, atmospheric nutrient deposition has been extensively documented as a primary concern to species composition of bryophytes, lichens and vascular plant on barrens (Vagts and Kinder 1999; Roem *et al* 2002). Due to nutrient enrichment, heathlands are replaced by non-native grasses and Calluna dominated communities are entirely displaced (Roem 2002; Damman 1957; Gimingham 1981). Encroachment by nonnative species is a threat to native barren plant assemblages in Northeastern Kentucky, USA (Rhoades *et al.* 2005). Scots pine (*Pinus sylverstris)* invasion and displacement of native species on *Corema* dominated sand barrens in the Annapolis Valley, Nova Scotia is a previously documented conservation concern for these barrens (Catling and Carbyn

2005; Carbyn *et al*. 2006). *Sedum* spp. have been observed on coastal barrens as garden escapes, but currently invasive species do not appear to be a major threat to coastal barrens (unpublished data, Lundholm lab). Conversely, Garbary (2011), found the garden escape *Rosa rugosa* to spread rapidly and displace native coastal plant communities on dry coastal heathlands. Garbary suggests the species may prove to be a major threat; displacing coastal plant communities in the future. The barrens on Briar Island are relatively disturbed and fragmented by development in comparison with other locations in Nova Scotia (personal observation). *Rosa rugosa* has also recently been shown to displace a fragile native coastal sand dune community in Cape Breton, Nova Scotia (Hill *et al*. 2010). Heathlands disturbed by development are often fragmented, isolated and vulnerable to further anthropogenic disturbance and to weedy invasion (Clarkson *et al*. 2010). It is possible the threat of invasive species displacement of natives is a compound threat, becoming a more pressing concern as development pressures increase.

Scope of previous research on Nova Scotia barrens

Our understanding of barrens in Nova Scotia is limited, mainly qualitative and patchy in both distribution and coverage of the range of barrens in the province. The Nova Scotia Museum of Natural History (Davis and Browne 1996) classifies barrens broadly as “highland”, “inland” or “coastal”. Coastal barrens are further categorized as “granitic”, “pennant” and “Canso” barrens (Davis and Browne 1996). No justification is provided for this classification scheme though there is some supportive evidence for its legitimacy in a broad sense. Carbyn *et al*. (2006) describe that floristic vascular composition of granitic vs. sandy barrens in the province differs. Technical reports which include floristic surveys exist for a number of specific barrens sites protected by Nova Scotia Department of Environment or by conservation NGOs. These reports are further limited in that they are almost exclusively short term duration field surveys (1 or 2 days) limiting survey comprehensiveness.

Aside from technical reports, floristic composition has also been formally described for a select number of sites; a bog/barren complex at Western Head in Queens County (Damman and Dowhan 1980), Hall and Alders (1968) likewise describe two inland and highly disturbed sites, dominated by *Kalmia angustifolia* and *Vaccinium angustifolium*. Carbyn *et al*. (2006) described the vascular flora of Annapolis sand heathlands and noted their distinctness from other barrens in western Canada in species composition, distinctive patterns of variation for several species and presence of at risk species. The authors found that variation in species composition between sites on Annapolis sand barrens was attributable to disturbance and soil moisture. There is only one baseline study of coastal barrens in Nova Scotia. Oberndorfer and Lundholm 2009, described gradients of environmental influence and vegetation on coastal barrens in the province based on data from six field sites. They identified 173 species including 105 vascular plants, 41 macrolichens, and 27 mosses. Aside from this study, very little quantitative research has been conducted to date on coastal barrens in Nova Scotia.

Vegetation Classification

Within any area, the assemblage of plant species across a continuum does not preclude recognition of identifiable communities (van der Maarel and Franklin 2013). In order to study vegetation, plant ecologists need to categorize variation of plant communities (Miles 1979: in McCune and Grace 2002). This modern view of community classification does not polarize but instead synthesizes concepts of Gleason's continuum (Gleason, 1926) and Clemments' (1916) discrete community unit. Modern ecologists typically classify communities using a formalized numerical approach to classification, in contrast to older methodology which was biased by descriptions within existing literature or somewhat arbitrary classifications of table sorting by professional judgment (Ladislav 1997). At the same time, field observations and ecological theory also remain critical tools of classification practitioners in the interpretation of meaningful units. Here I adopt van der Maarel and Franklin (2013)'s definition of a plant community: "a plant community is generally recognized as a relatively uniform piece of vegetation in a uniform environment, with a recognizable floristic composition and structure, that is relatively distinct from the surrounding vegetation." While plant communities are human constructs, there is great value in classifying them in order to assess the relative abundance of different kinds of communities, to assign conservation priority to them, and to aid in the development of our understanding of plant ecology. The Government of Canada has implemented a standard (CNVC 2013) for classifying vegetation types, and provincial and sub-provincial classifications exists for many parts of Canada, however there has not been enough suitable data available to classify the coastal barrens of Nova Scotia.

NS coastal barren plant communities

Barrens in coastal Nova Scotia are comprised predominantly of shrubby vegetation that is frequently intermixed with *Sphagnum* dominated peatland. Plants are assembled across a wet-dry continuum such that the boundaries of barrens and peatland can be impossible to distinguish and delineate (Oberndorfer 2006). Tree cover is sparse, limited to sheltered depressions and tree islands associated with successional forest encroachment (Burley and Lundholm 2009). Plants also occupy the rocky salt spray zone at the edge of barrens (Lundholm lab, unpublished). Dominant plant species belong to the family Ericaceae, this includes the Empetraceae which is no longer recognized as a separate family (Gimingham 1972; Oberndorfer 2006).

Dwarf heath plant communities are thought to be the dominant coastal barrens vegetation type. Most of these plants belong to the heath family (Ericaceae), including the following genera: *Empetrum*, *Corema*, *Arctostaphylous, Juniperus, Vaccinium*, *Photinia,* and *Gaylussacia*. Several of the species are very low (≤ 15 cm) growing and often prostrate or trailing, woody plants while the remainder are dwarfed expressions of species that normally grow as larger shrub life forms (15 cm – 2 m) (Luttemerding et al 1990; Clarkson 2010). This vegetation includes dwarfed arctic species, trees and specimens of species usually considered tall shrubs (Luttmerding *et al.* 1990). The Nova Scotia Museum of Natural History list *Cladonia* spp. lichens and two dwarf shrubs *Corema conradii* and *Empetrum nigrum* as the 3 most dominant species on coastal barrens. All of the 10 most common species found by Oberndorfer and Lundholm (2009) can be considered typical of dwarf heath based on their sizes. Five of the ten most common species are always dwarfed in height; *Empetrum nigrum, Juniperus communis, Vaccinium angustifolium, Vaccinium vitis-idaea* and *Corema conradii,* three others are shrubs that do occur in dwarfed forms; *Kalmia angustifolia, Gaylussacia baccata,* and *Rhododendron groenlandicum.* The other two species are *Cladonia terrae-novae* and

Osmunda cinnamonea, a lichen and a fern that occur within the 2m stratum. For purposes of this study, woody vegetation under 15cm, typically considered within the herbaceous layer (Luttmerding *et al.* 1990) will be defined as dwarf heath because of the nature of its constituent species and their prevalence on barrens. Because dwarf heaths dominate barrens vegetation, they are the focus group of our classification project.

Though Dwarf Heath plant communities are widely considered the dominant vegetation type, barrens are comprised of a mix of different plant communities inhabiting a continuum of environmental gradients. Strang (1971) first subjectively described four vegetation types on inland barrens in Southwestern Nova Scotia according to dominant species. These are *Gaylussacia baccata, Corema conradii, Rhododendron canadense,* and mixed shrubs. Bogs and barrens intermix at various scales, and are often difficult to delineate. Damman and Dowhan (1980), describe ecological units within a bog/barren complex at Western Head, NS. Among these units are slope forest, fen, bog plateau and dwarf shrub heath. NSMNH (1996) describe the occurrence of krummholz, bog and scrubby tall shrubs across barrens. Krummholz refers to stunted and warped trees growing in extremely exposed environments. A comprehensive classification of barrens vegetation in Nova Scotia has not been attempted using modern numerical methods, impeding our understanding of the variation with barrens vegetation and our ability to assess the relative rarity and conservation priority of different types of barrens.

Coastal Barrens environment

The persistence of Coastal Barrens species is largely controlled by exposure to environmentally stressful growing conditions (Oberndorfer and Lundholm 2009). Driving factors behind the distribution of persistent shrub dominated ecosystems in Eastern and Central North America are salt spray, high elevation and extremely dry or extremely moist soil (Latham 2003). Wind exposure, cold and frost disturbance are also climatic extremes of influence to barrens vegetation communities in Nova Scotia (Glaser and Mooers 1989). Oberndorfer and Lundholm 2009 found four important environmental variables associated with gradients in vascular plant species abundances: soils sodium (Na), temporal mean substrate moisture, Potassium (K) and Iron (Fe), and also vegetation height. For mosses and lichens, the most important environmental variables were substrate moisture, vegetation height, average substrate depth, Fe and elevation. While encompasing a range of plant communities and environmental gradients, replication was low and geographical representation incomplete. There is great plant community variation even within a broad category of vegetation such as "barrens" or "bogs", and none of the previous work allows for an understanding of how this variation within a vegetation type is shaped by environmental factors.

Research Objectives

a) Describe and classify coastal dwarf heath community types of Nova Scotia and

b) Identify and quantify environmental factors that explain variation in coastal dwarf heath community composition, diversity, and distribution

METHODS

Study area

Geography: Area and distribution of barrens

I identified barrens using Nova Scotia's Spatially Related Forest Resources (SRFR) information system, which was derived from interpretations of aerial photographs acquired between 1995 and 2011 (NSDNR 2011). The SRFR differentiates barrens into Rock Barrens (ForNon type 84) and Barrens (ForNon type 85) defined respectively as:

"any area covered by at least 50% exposed rock outcrop and/or boulders with less than 25% live tree cover (Boulders being rock fragments over 60cm in diameter." and as " any area of less than 25% live tree cover containing "ericaceous" vegetation with less than 50% rock out crops and/or boulder cover and less than 50% other woody plant cover. Area is dry and firm in summer. Indicator plants: Bearberry, Rhodora, Blueberry, Huckleberry and Lambkill." (NSDNR 2011)

In this thesis I define Coastal Barrens as those barrens occurring directly adjacent to the ocean to those within 500m of the coast, sometimes extending several kilometers inland and with less than 10% tree cover (Oberndorfer and Lundholm 2009). Coastal barrens occur along the entire length of Nova Scotia's Atlantic coast largely on exposed headlands within the Atlantic Coast Theme Region (Davis and Browne 1996). Elsewhere in the province coastal barrens occur in Northern Cape Bretons Highland Region, and have a more limited and patchy distribution in the Carboniferous Lowlands of Cape Breton and Antigonish Counties. Though seldom recognized in a provincial context, coastal barrens also occur patchily along the outer Bay of Fundy coastline; including one larger site at Cape Chignecto and several from Digby neck to Briar Island.

Climate: Temperature, precipitation and growing season

Along the Atlantic coast, Carboniferous Lowlands and Bay of Fundy theme regions, freezing temperatures consistently occur from mid December and last through mid March in the south and later until April along the Eastern Shore. In summer, temperatures along the Atlantic coast are on 10 degrees cooler on average than elsewhere in Nova Scotia. Far north, in the Highlands region, daily temperatures range more widely and the growing season is considerably shorter and steeper (Davis and Browne 1996).

Total precipitation is least along the Northumberland plain; less than 1000mm annually. Precipitation ranges between 1200mm and 1400mm along the Atlantic Coast save for Queens, Lunenburg and Northern Halifax Counties where precipitation ranges 1400 to 1600mm. In Cape Breton, precipitation ranges from 1200mm to 1600mm in the West and exceeds 1600mm in the Highlands. Across the Atlantic Coastal Region only 15% of precipitation is snow (Davis and Browne 1996). Snowfall is greater in other regions and greatest in the highlands. Accumulation of snow can be limited on barrens by strong coastal winds (Glaser and Mooers 1989)**.** Fog is prevalent on all regions where coastal barrens occur. Along the Atlantic coast fog occurs 15-25% of the year. Yarmouth experiences the most fog, an average of 120 days per year (Davis and Browne 1996).

Climate: exposure

From the Nova Scotia wind atlas (NSE 2012) with 200m resolution, I obtained wind speeds at 30 meters in elevation within our 49 study sites. Wind speeds ranged from

4.5 to 8.5 meters per second with an average minimum of 6.8 meters per second and an average maximum of 7.5 meters per second (NSE, 2012). Wind direction is highly variable relative to Western Canada (Roland 1982). While storm winds can be Easterly, winds predominate from the West (Roland 1982) or South (Environment Canada Climate Normals hourly wind direction for 2010). This differs in the Cape Breton Highlands where winds frequently originate from the North (Davis and Browne 1996).

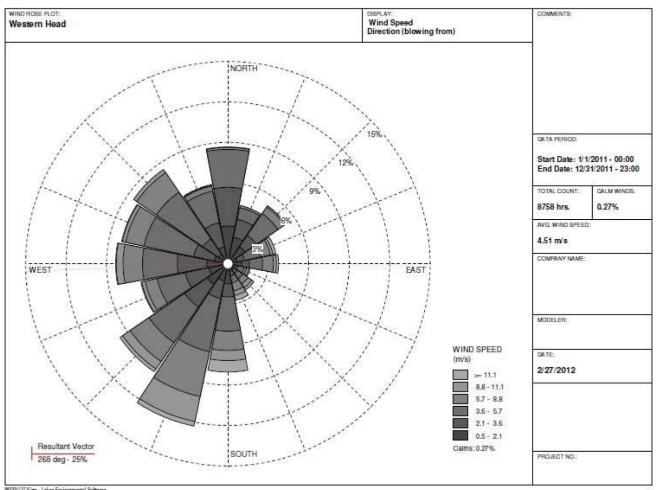

Figure 1. Wind Rose created from Environment Canada Climate Normals Hourly wind direction and speed data from 2010 collected from station located on our field site at Western Head, NS.

Long fetch distances create large swells and these combined with waves created by storm winds break over exposed coastal areas and wave energy is concentrated on headlands in Nova Scotia (Thurman and Trujillo 1999; Roland 1982). Northeastern and Southeastern Cape Breton are exposed to the open ocean, in Eastern Cape Breton exposure is greater than 500km. The Eastern shore of Nova Scotia is exposed to open ocean, as is the Western shore with local embayments. The South shore of Nova Scotia is largely sheltered (Davis and Browne 1996).

Bedrock

Hard bedrock types underlie the majority of barrens in Nova Scotia. Barrens surveyed for this study occur over bedrock belonging to Meguma group Halifax formations and Goldenville formations, the Pictou group and the Forchu group. These groups specifically include rock types such as shale and coal, slate, basalt, granite and greywacke. Granite appears to be the most common bedrock type underlying barrens in Nova Scotia, followed by greywacke (Keppie 2000).

Coastal processes are known to exert a massive force on the shoreline resulting in damaging effects such as erosion. Erosional effects vary based on surficial and bedrock geology. For example, the hardness and structure of granite makes it most resistant to erosion though boulders are often broken off and re-distributed (Roland 1982). Exposed granite outcrops are relatively unchanged compared with cliffs formed of softer bedrock types and continually eroded by wave action and frost heaving (Roland 1982; Davis and Browne 1996). Examples underlying barrens in Nova Scotia include cliffs of columnar basalt on Long Island; the sandstone, shale, coal and conglomerate cliffs near Donkin, Cape Breton undergoing cliff and cave formation originating from erosion, abrasion, and, depending on the rock type, dissolution; and, the slates and shales underlying the barrens in Lunenburg county (Roland 1982; Davis and Browne 1996; personal observation).

Nova Scotia was entirely glaciated as recently as 15,000 years ago (AGS 2001). Glaciation in the Quaternary period is responsible for many of Nova Scotia's current landscape features (Davis and Browne 1996). Glaciation has influenced the slope of exposed bedrock and has also deposited glacial eratics on exposed barrens (AGS 2001).

Surficial mineral deposits

Surficial mineral deposits on barrens are predominantly of glacial origin, often comprised of a thin discontinuous veneer of glacial till, residuum or colluvium over bedrock. This is the case on many of the largest coastal barrens; in the Cape Breton Highlands, Eastern Cape Breton, the Canso Peninsula and the Chebucto Peninsula (Davis and Browne 1996). Elsewhere, surficial deposits underlying coastal barrens are comprised of glacial advance deposits made up of stony, silty till. Sand dunes are not as extensive or well developed in Nova Scotia as in some other regions of Eastern Canada (*e.g*, Prince Edward Island). This is due to a high energy in the Atlantic coastal environment and the lower relative availability of deposits eroded from less resistant bedrock types. Barrier beaches occur at locations where unconsolidated materials are more abundant. At these specific locations, sand exists as a relict of deglaciation. At other sand dune and beach complexes, deposition originates from active erosion where material is actively transported by wind and marine processes and anchored to headlands or accumulated in sheltered coves (Davis and Browne 1996).

Soil

Barrens occur in Nova Scotia across a spectrum of humus forms and mineral soils that are generally coarser grained, shallow and of moderately to excessively stony; sometimes with a cemented layer. Rockland is the most frequent mapped soil series underlying barrens in Nova Scotia and also the least described (MacDougall *et al* 1963).

Nova Scotias coastal barrens are typically underlain by shallow, acidic and nutrient poor soils, and these are generally recognized as a defining characteristic of barrens ecosystems (Macdonald *et al*. 2011; Oberndorfer and Lundholm 2009). Soil depths are shallow on average but highly variable. Barren vegetation is frequently interrupted by exposed bedrock yet wetland peat on the barrens can exceed a meter in depth (personal observation).

Study site selection

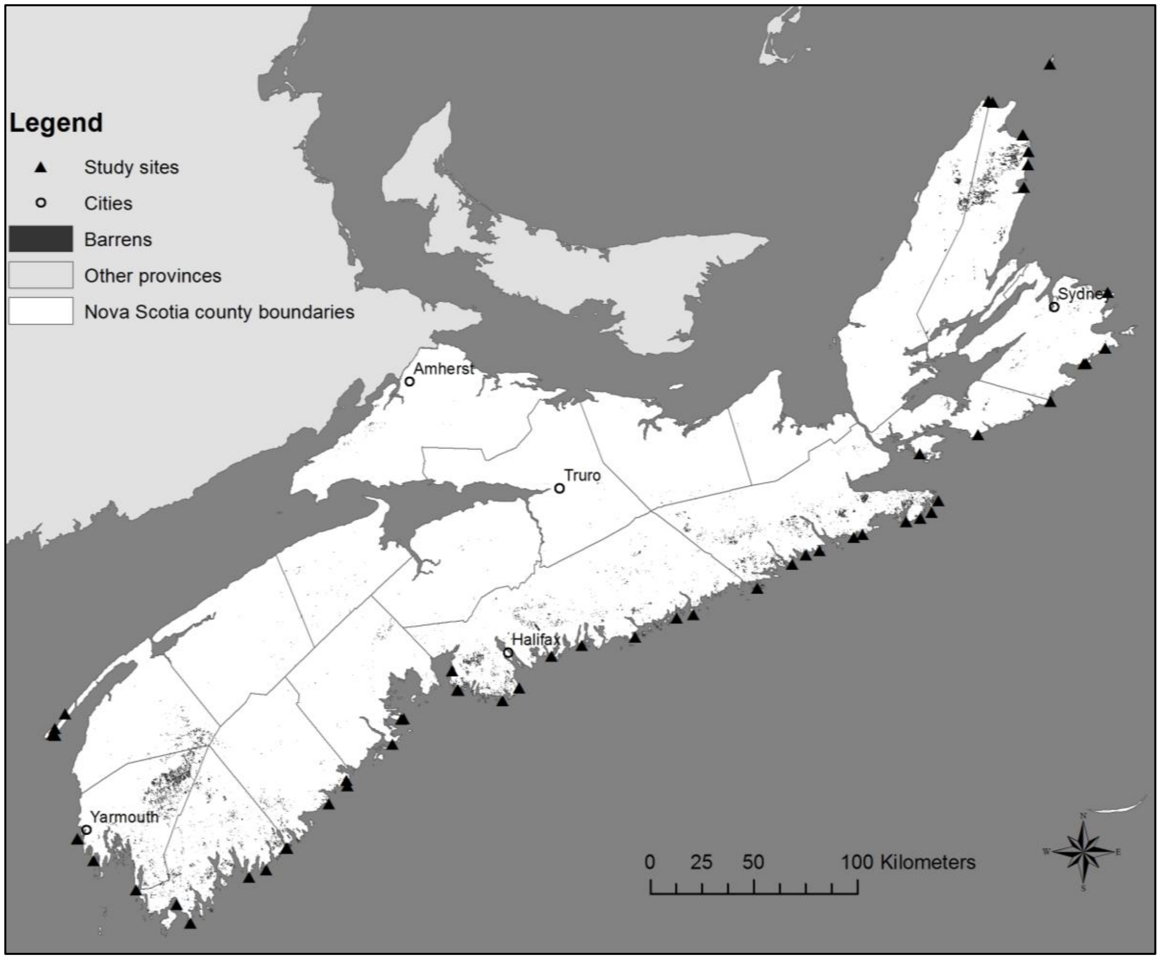

Figure 2. Map of Nova Scotia with study sites represented by black triangles and the area of barrens in Nova Scotia shaded grey. The area of barrens is derived from NSDNR SRFR GIS data. Coastal barrens are found along the perimeter of Nova Scotia save for sheltered reaches of the Bay of Fundy and also the Northumberland Shore.

We selected study sites for representation of the geographical range and plant community variability of dwarf heath on coastal barrens within Nova Scotia. Candidate study sites were preliminarily identified based on a review of Nova Scotia's Spatially Related Forest Resources (SRFR) information system (NSDNR 2011), maps of sand dune heaths by Hales, (1992) and species records from the Atlantic Canada Conservation Data

Center and Nova Scotia Museum of Natural History. Local knowledge was also useful in identifying candidate study sites. Using these data, aerial photos, and reconnaissance surveys, 69 accessible and relatively undisturbed dwarf heath coastal barren sites were selected for study. Since some sites were environmentally sensitive and/or protected, soil pit excavation and specimen sampling was deemed inappropriate; we surveyed 49 sites in completeness. Data from Saint Paul's Island, Meat Cove, Green Cove, Middle Head and White Point in Cape Breton, Briar and Long Island, and also from Cape Chignecto was collected in 2011 by Sean Basquill and Lawrence Benjamin at Nova Scotia Department of Natural Resources and shared with me for purposes of this research.

A small number of sites encountered during reconnaissance surveys contained mainly herbaceous vegetation (*e.g.*., natural grasslands and forblands, abandoned coastal pastures, and old buildings sites) or were comprised exclusively of tall shrubs thereby precluding their inclusion in the pool of suitable sample sites. Sites heavily impacted by recent anthropogenic disturbances such as ATV traffic or housing development were avoided. Contiguous tracts of barrens were selected and those highly fragmented by road, development or forested areas of >10% canopy cover were ommited. Sites inaccessible by four wheel drive vehicle and a 10km hike were excluded except in the case of Guysborough County where the majority of suitable barrens sites are inaccessible. In this case, I visited the sites by helicopter.

Sample unit (plots)

In order to capture species composition variability, I collected data from one to five sample plots at each study site. Selection of sampling location and number of plots within a site was informed by the range of environmental conditions occurring on the site assessed by casual observation: areas with greater variability in dwarf heath communities and/or environmental conditions received more sampling plots in order to capture the range of conditions present. I followed ecosystem description methodology by Luttemerding *et al* (1990) and collected measurements from sample plots uniform in species composition and with consistence of environmental variables, based on visual observation.

I chose a plot size of 4x4m (Kent and Cooker 1992) or 5x5m (FGDC 2008). This plot size varied depending on homogeneity of the community with the objective of efficiently capturing most of the species regularly occurring throughout a local dwarf heath community (akin to a forest stand) but small enough to avoid capture of adjacent vegetation types at the scale of environmental variables measured. I placed sample plots at least (generally farther) 50 meters from access points such as footpaths and animal trails that may have compacted the soil, subjected the community to trampling or introduced non-native plants, and with at least 5m spacing from any marine debris (fishing equipment that washed ashore).

Vegetation survey

Vegetation surveys were performed between May and November 2010 and 2011, when vascular plants were in leaf. Species abundances were quantified by visual estimate of percentage cover within each sample plot. Vegetation height was measured at five representative locations within a plot so that an accurate mean could be obtained. All vascular plants, bryophytes and lichens were identified to species with the exception of crustose lichens and some rarely encountered epiphytic lichens. Vascular plants were identified using primarily Roland's Flora of Nova Scotia (Roland and Zinck 1998) and the Flora of New Brunswick (Hinds 2000).

Environmental Characteristics and Soil

Geographical features

At each plot, Universal Transverse Mercator (UTM) coordinates were determined using a Garmin E-trex model handheld Global Positioning System (GPS) with horizontal accuracy of approximately 6m. Elevation was corrected using NDSNR 1:10,000 Digital Elevation Model (DEM) and the "extract values to point locations" tool in ArcGIS10 (ESRI 201X). The DEM has a vertical accuracy better than 1m, and pixel resolution of 20m. Values were interpolated to point location for best resolution.The 'near' tool in ArcGIS 10.0 was used to determine the distance from NSDNR's mapped coastline to sample plots. The measure tool in ArcGIS 10.0 was used to determine site area from the SRFR map.

Meso slope position and microtopography of the survey area were described using a standard approach to ecosystem description based on classes assigned by Luttemerding *et al.* (1990). The relevance of slope to our study specifically relates mainly to wind exposure (Quine and Gardiner 2007) and soil characteristics, *e.g.* formation and depth, also moisture and nutrient composition (Keys 2007; Tedrow 2003; Bonan 2002). Microtopography is similarly relevant at a smaller scale influencing abiotic heterogeneity of relevance to small plant communities (Crawley 1997), for example the reduction of wind on sand dunes (Miyanishi and Johnson 2007).

For purposes of analysis, categorical scales described above were converted to a numerical scale (Table 1). Class values were assigned to our categorical data as described and modified as follows; *Site Position Meso:* Lower slope and toe slope position were collapsed into one category due to the low occurrence of toe slopes in survey data and because of their ecological similarity. Depression and level slope positions were also merged for similar reasons. *Microtopography;* extremely mounded and ultramounded conditions were not encountered. For purposes of analysis, these scales were converted to a numerical scale (Table 1).

Table 1. Categorical variables that quantify aspects of topography according to Luttmerding *et al.*1990, and associated numerical scale

Categorical Variable		**Value**
Site position meso	crest	1
	upper slope	2
	middle slope	3
	lower slope and toe	4
	depression and level	5
Microtopography	smooth	0
	micromounded	1
	slightly mounded	2
	moderately mounded	3
	strongly mounded	4
	severely mounded	5

Slope and aspect were measured in the field in degrees using a compass with a clinometer. Slope degrees were converted to Slope gradient (%) by taking the tangent of radian slope value multiplied by 100. Aspect was converted to indices of Eastness and Northness; divided by 360, and the cosine and sine were respectively taken of these converted radian values that were then multiplied by 2pi. Slope length is defined by Luttmerding *et al.* (1990): "the estimated or measured distance (in meteres) between upper and lower extremities of the site position meso associated with the site. It is the total length of the slope defining the catchment area in which subsurface water is transmitted through the landscape." I estimated slope by classes developed for this research project in consultation with Kevin Keys at NSDNR: 0 -10m, 10 - 25m, 25 -50m, 50 - 100m, 100 - 500m, 500+m, based on provincial standards for ecosystem classification and previous knowledge of soil characteristics in Nova Scotia. For purposes of analysis, I assigned a median of each class to represent slope length. This better suited the data than class categories since classes differed in scale.

Substrate

Percent cover was estimated for exposed substrates including surface rocks, bedrock, mineral soil, organic matter, decaying wood, and water.

Exposure

Maximum and minimum wind speeds were determined using Nova Scotia department of Energy Wind Atlas model (NSE 2012) at lowest (30m) elevation for which data was available. Using ArcGIS 10.0 to determine the closest weather station to nearest survey points, hourly wind speed and direction were obtained from Environment Canada Climate Normals website (EC 2012). Weather stations with significant missing data, located far from the coast, or where only historical data was available were not used. Lakes Environmental WRPLOT version 7.0.0 was used to generate frequency tables of wind speed and direction and resulting wind roses for stations. A vector of mean wind direction was determined. The most frequent wind direction was also extracted. Frequency was determined according to 16 categories of conventional compass aspects (*i.e.* N, NNE, NE, etc). Most frequent wind direction explained a minimum of approximately 10% of wind direction variation.

Fetch was determined for both mean and most frequent wind directions using a model developed by Geomatics Technician Greg Baker, Research Instrument Technician at the Maritime Provinces Spatial Analysis Research Centre, SMU. The model runs from Script in Python version 6 on ArcMap10 (ESRI). The code extracts topographical data points at 30m sample intervals from NSDNR digital elevation model (DEM), of 20m resolution, until a point of elevation that is higher than the elevation of my sample plot interrupted prevailing wind. The geographical boundaries in any given direction were approximately 400Km on average, sometimes shorter. This limited our maximum fetch distance to approximately 400Km. In instances where fetch exceeded the boundaries of the DEM, the model provided a "greater than" value and therefore statistics involving fetch generally represented a minimum distance.

Soil survey included complete soil pits at each sample plot

Soil series were first identified using Nova Scotia Soil Survey Maps (e.g, MacDougall *et al.* 1963). Soil pits were excavated within each tract of sampled vegetation to the depth of bedrock or to 30 cm from the mineral soil surface. For deep upland or wetland humus, pits were excavated to 1m depth. Excavated pits and dominant and or characteristic soil horizons were photographed. The depth of each horizon was measured; horizon soil colours were determined using a Munsell colour chart. Humus form was classified according to Green *et al.* (1993). A simple key was used to define mineral soil texture, based on the System of Soil Classification for Canada, Canada Department of

Agriculture (1971). Drainage type was described according to provincial ecosystem description methodology (Keys *et al.* 2009; 2010) using key modified from Jones *et al*. 1983 and descriptors by ECSS 1983, also consistent with Luttmerding *et al* (1990). For purposes of analysis, drainage class was converted to a numerical value such that : rapid (1), well drained (2), moderately well drained (3), imperfectly drained (4), poorly drained (5), very poorly drained (6) (Table 2). Depth of REDOX features such as mottling was recorded, as per Keys *et al.* (2009, 2010). Bedrock geology was noted and coarse fragment lithology was described where possible. Coarse fragment volume (% composition of fragments > 2mm dia) was estimated for each horizon. Moisture class was adapted from Luttemerding *et al* (1999). Associated factors for consideration included plots' meso slope position and slope angle, soil depth, humus thickness, drainage class, mineral soil texture, humus type and field observations from soil pits including the presence of seepage, the depth of REDOX features (such as mottling) within soil horizons, and coarse fragment volume were additional considerations. For purposes of analysis a number was assigned to each moisture class such that: xeric(1), sub xeric(2), sub mesic(3) mesic(4), subhygric(5),hygric(6), sub hydric(7) Table 2).

Table 2. Drainage and moisture classes according to Luttmerding *et al.* 1990 were assigned a numerical value for purposes of statistical analyses.

Variable	Class	Value
Drainage	rapid	1
	well	2
	moderately well	3
	imperfect	4
	poor	5
	very poor	6
Moisture regime	xeric	1
	sub xeric	2
	sub mesic	3
	mesic	4
	subhygric	5
	hygric	6
	sub hydric	7

Presence and/or depth of charcoal, rooting, stone layer, cemented layer or lithic contact were also measured. A 500 mL sample was collected from each of the dominant humus layer and mineral horizon in each sample plot using methodology adapted from Luttmerding *et al.* (1990) and Keys *et al.* (2010). Frequently, only thin humus horizons were encountered. Comprehensive chemistry of the dominant horizon of rooting was analyzed at the University of Prince Edward Island analytical laboratory. Relevant variables were determined based on relevant literature (e.g., Green *et al.* 1993, Luttmerding *et al.* 1990, Klinka *et al.* 1981, Oberndorfer and Lundholm, 2009); those used in our analysis included: pH, salinity, cation exchange capacity(CEC), exchangeable base cations (Ca, M, K, Na), Total C, Total N, minerizable N, total Fe, and Mg.

Statistical methods of numerical classification

I preformed two separate but complimentary ordination techniques to accomplish two distinct objectives:

1.) I used Principal Components Analysis (PCA) to explore multivariate relationships among: a) vegetation species composition, and b) environmental variables.

2.) I used Redundancy Analysis (RDA) to find correlations between vegetation species composition and environmental factors.

In order to classify the plant communities in the sample sites, using techniques independent from the ordination procedures described above, I performed a Ward's Cluster Analysis on species abundance data. The resulting dendrogram output is an unbiased, numerically established topology (architecture of connections) of plant community groups derived from strictly floristic criteria. Using these plant community groups, I then conducted indicator species analysis according to Dufrêne and Legendre, (1997), who define indicator species as those species possessing greatest abundance and/or specificity and fidelity to a pre-defined community. To describe each dwarf heath plant community group in terms of both the species that characterize it and the environmental variables that correlated with each group, I synthesized the results of both ordination and cluster analyses. All analyses were performed using the open source software R, version 2.15.0.

Principal Components Analysis (PCA)

I explored multivariate relationships in plant species composition by ordinating Hellinger's transformed species abundance data using Principal Components Analysis (PCA). PCA is an unconstrained ordination technique that projects correlated species in proximity to one-another and dissimilar species orthogonaly in Euclidean space: such that variance is maximized along each axis. (Borcard *et al.* 2011; Legendre and Legendre 1998; Wildi 2010).

Rationale for selection of Principal Components Analysis (PCA)

While several techniques can provide similar projections of species coordinates in multivariate space using the same data set (Wildi 2010), PCA was best suited for our analyses because of its high resolution (lack of distortion) and solution (outcome of analyses) stability. Iterative Nonmetric Multidimensional Scaling (NMDS) routines were not considered because this technique provides results that are inconsistent between runs, computers, and software packages (Wildi 2010; Borcard *et al.* 2011). PCA was a better fit for our analyses compared to either Principal Coordinates Analysis (PCoA) or Correspondence Analysis (CA) because of the improved clarity it ensured; PCA provides less distortion than PCoA and better 2-dimensional resolution with less sensitivity to outliers than CA (Wildi 2010).

Most importantly, PCA avoids the risk of uncontrolled alteration to the similarity pattern caused by detrending procedures of Detrended Correspondence Analysis (DCA) (Wildi 2010). Specifically, detrending by segments (Hill and Gauch 1980) provides "meaningless" solutions that would not be possible to interpret ecologically (Legendre and Legendre 1998 p 467-472, and ter Braak 1987c in: Legendre and Legendre 1998) and detrending by polynomials (Hill and Gauch 1980; ter Braak 1987c in: Legendre and Legendre 1998) imposes a model onto the data which may not fit, and which also fails to resolve the issue of site compression along axes (Legendre and Legendre 1998). Those problems are considered significant enough that despite its popularity and ease of recognition, DCA is strongly discouraged for use, by Borcard *et al.* (2011) with reference to discussion by Legendre and Legendre (1998). These recommendations, in addition to complimentarity of use with Redundancy Analysis (RDA) are our primary rationale for the choice of PCA as our ordination technique.

Hellingers transformation definition and rationale for use

Hellinger's transformation makes PCA an appropriate method for use with species abundance data when otherwise the PCA model would be inappropriate (Legendre and Legendre 1998; Legendre and Gallagher 2001; Borcard *et al.* 2011). Hellinger's distance, described by Rao (1995), is a metric distance coefficient and an optimal alternative to Chi-square distance measures used within canonical analyses. The algorithm of Hellinger's transformation involves a square root of species abundance data (row sums, row totals) and relies on vectors in species abundance transformed into Euclidean distance (Rao 1995; Legendre and Legendre 1998; Legendre and Gallagher 2001). For further explanation, see Rao (1995) and Legendre and Legendre (1998).

Hellinger's transformation is applied to species abundance data to overcome limitations related to linear assumptions and circumvent problems with Euclidean distance models inherent in both PCA and RDA models (Legendre & Gallagher 2001).

Hellinger's transformation has been recommended for ordinations of community composition, (Legendre & Gallagher 2001; Borcard *et al.* 2011), especially when those data are heterogeneous (Borcard *et al.* 2011). In addition to more general recommendations, Rao (1995), and Legendre and Legendre (1998) conclude that Hellinger transformed data is the best performer of other transformative options for use with linear based ordination.

Procedure for conducting a PCA

I first applied Hellinger's Transformation on our species abundance data matrix using the R package VEGAN before ordination. Following transformation, I conducted PCA for the species abundance data and separately for the environmental variables each using VEGAN package with a scaling of two because species were of interest (Borcard *et al.* 2011). Axes with eigenvalues greater than one were considered significant.

Redundancy Analysis (RDA)

To investigate the expression of plant species composition in response to environmental factors, I then tested for correlations between plant species and environmental variable matrices using Redundancy Analysis (RDA). RDA is a constrained ordination technique complimentary to PCA in its linear correlation algorithm (Wildi 2010). I first applied Hellinger's Transformation on our species abundance data matrix, and I standardized the environmental data using VEGAN.

I employed a scaling of two to produce a correlation biplot addressing our main question; to identify correlations between species and environmental variables. I also explored the relationships among study sites through a distance biplot with scaling set at one (Borcard *et al.* 2011). I adjusted my R^2 value according to Ezekiels formula (Ezekiel 1930), to avoid inflation inherent in the RDA model (Borcard *et al* 2011; Legendre *et al* 2011).

My environmental matrix was comprised of 31 environmental variables with strong linear dependencies recognizable within the RDA and PCA graphs and from performing Pearson's correlations. Interpretation of the ordinations was therefore difficult and it is also known that the regression coefficients of collinear variables within an RDA can be unstable (Borcard *et al* 2001). I sought parsimony and a better understanding of the primary variables responsible for species patterns in performing both a Variance Inflation Test and a Forward Selection procedure on my explanatory (environmental) matrix.

First, I used VEGAN to identify Variance Inflation Factors (VIFs) and I identified nine variables with VIF values between 21 and 515. I removed the inflated variables strongly correlated with others: average minimum wind speed (correlated with maximum wind speed), Sodium concentration of soil (correlated with salt and had a greater VIF than salt), Calcium and Magnesium concentration of soil (correlated with CEC), and the Easting UTM coordinate (correlated with Northing). Three variables had variance inflation factors less than 20 but more than 10; of these I removed Potassium and Sulphur from analyses since they were also correlated with CEC. After removal of these variables, a new variance inflation factor test showed no environmental parameters with VIF values greater than 10. Though 10 is the threshold (Borcard *et al* 2011), the greatest VIF was actually only 5.45 following this procedure.

I then used a recent (2012) version of PACKFOR to compute a Forward Selection on the reduced environmental matrix to identify the most important environmental variables (Dray *et al* 2007). Recent versions of PACKFOR use global testing values to prevent overly liberal designation of significant variables or high variance by including too many variables into the model (Borcard *et al* 2011). A double stopping criterion (Blanchet *et al*. 2008) is used in recent versions of PACKFOR to reduce error. The R^2 and the traditional α level of significance are used as stopping criterion for selection of significant variables (Borcard *et al* 2011).

When redundancy analysis provides a limited number of canonical axes, it may not be necessary to test significance of those axes. It may not be necessary to explore axes that explain low proportions of variance (*e.g* 1% or even 5%), even if those axes are significant (Legendre *et al.* 2011). I completed a permutation test with 1000 permutations to test significance of axes (Borcard *et al.* 2011), but also observed variance explained by each axis was sufficiently high to warrant interpretation, *i.e.* that axes were meaningful.

Cluster Analyses

To identify distinct dwarf heath plant communities from vegetation plot data, I performed a floristic cluster analysis on standardized species abundance data using the Ward's method of Minimum Variance Clustering method as employed using the Stats Package for R. Ward's Minimum Variance method establishes a floristic topology by numerically clustering plots through the linear model criterion of least squares that minimizes the within-group sum of squares (Borcard *et al.* 2011).

To standardize species abundance data, I used VEGAN package's "normalize" transformation which makes margin sum of squares equal to one and uses a Euclidean distance measure. I preformed my actual cluster analyses using the Stats package, described earlier. A meaningful level of cutting was determined quantitatively rather than through professional judgment or arbitrary methods. To establish our first criteria for cutting (identifying split points among clusters), I plotted Fusion levels and identified the range where clear jumps between levels occurred. Next, I plotted Silhouette widths and determined the optimal number of clusters according to the Rouseeuw quality index (Rousseeuw 1987). I then created a Silhouette plot of the final partition and assessed group membership and misclassifications through associated Si values; a measure of grouping validity and relative strength. I graphically plotted the square roots of fusion levels to avoid distension of the dendrogram but without altering topology, as recommended by Borcard *et al.* (2011). In interpretation, I adhered to Wildi (2011)'s general rule of thumb that an adequate sample size is at least five plots per group. Following classification of plant communities, I assigned indicator species to each of those pre-decided groups using the indval function in labdsv package of R.

Plant Community Concept

I adopted van der Maarel and Franklin (2013)'s definition of a plant community: "a plant community is generally recognized as a relatively uniform piece of vegetation in a uniform environment, with a recognizable floristic composition and structure, that is relatively distinct from the surrounding vegetation." This unit concept embodies a modern synthesis of Gleason's Continuum theory (Gleason 1926) and Clements' (1916) community unit concept, thereby embracing the idea that vegetation communities comprise a continuum in species composition but with the understanding that this does not preclude recognition of identifiable communities (van der Maarel and Franklin *2013)*. My interpretation of a community recognizes that similar species recur from stand to stand but that no two stands are exactly alike (Mueller-Dombois and Ellenberg 1974). Classification breakpoints were assigned numerically using solely statistical techniques. Ward's Classification assigns groups floristically using species abundance dataII

The relationships between species and the environment were identified through Redundancy Analysis and then described in the context of, and as they apply to, the plant communities assigned by Ward's Classification and their indicator species. Environmental factors were not breakpoints in the assignment of plant communities although correlative relationships were apparent within each community type and were subsequently described.

For purposes of unambiguous naming, I use naming standards of the CNVC. Our "base unit" is defined at the CNVC hierarchical level of the Association. The CNVC (2013) defines the association as: "a plant community type at the lowest level of the CNVC hierarchy, with consistency of species dominance and overall floristic composition, as well as having a clearly interpretable ecological context in terms of site-scale climate, soil and/or hydrology conditions, moisture/nutrient factors and disturbance regimes, as expressed by diagnostic indicator species."

RESULTS

Flora

Dwarf heath flora was comprised of 253 species of vascular plants, lichens, mosses and liverworts (Appendix 1). Species richness was distributed throughout 66 families such that 57.7% of all species (146 species) were concentrated within ten families, and the remaining 56 families contained less than 5 species each. The most species rich family is Cladoniacea (lichens) and represents 12% of total richness, containing 29 species. The second most species rich family is Asteraceae (vascular plants), which contained 24 (9.7%) species. Three families contain 18 (7.3%) species each; Ericaceae, Poaceae, and Rosaceae. Fewer species belong to remaining families; nine species belong to Dicranaceae, Parmeliaceae and Sphagnaceae, representing 3.6% of total species richness, seven species belong to Scrophulariaceae (2.8%) and only five to Caryophyllaceae (2%).

Frequency and abundance of species

Relatively few (103) species were found in more than three sample plots. More than half of all species identified were uncommon: 98 or 37% of species were exclusive to one sample plot, 37 or 14% of species were found in only two sample plots, 28 or 11% species were found in three sample plots. The 15 most frequent and abundant species found across all sample plots were (respectively): *Empetrum nigrum, Juniperus communis, Symphyotrichum novi-belgii, Morella pensylvanica, Sibbaldiopsis tridentata, Festuca rubra, Vaccinium angustifolium, Danthonia spicata, Agrostis scabra, Cladonia* *mitis* , *Kalmia angustifolia*, *Cladonia terrae-novae* (*Cladonia boryi*, *Cladonia rangiferina* (Table 3).

Table 3. The most frequent and abundant (mean percent cover where found) species across all sample plots.

Species	Frequency	Abundance
Empetrum nigrum	59	45.8
Juniperus communis	49	11.2
Symphyotrichum novi-belgii	47	1.1
Morella pensylvanica	43	9.6
Sibbaldiopsis tridentata	39	2.6
Vaccinium vitis-idaea	37	2.3
Festuca rubra	36	5.1
Vaccinium angustifolium	33	1.8
Danthonia spicata	30	2.0
Agrostis scabra	30	0.3
Cladonia mitis	27	5.3
Kalmia angustifolia	27	3.7
Cladonia terrae-novae	27	2.0
Cladonia boryi	20	4.3
Cladonia rangiferina	20	3.0

Several infrequent species were abundant where they were found. Save for *Empetrum nigrum* which was the most frequent and abundant species, the ten most abundant species where found, independent of frequency were: *Ammophila breviligulata, Sphagnum papillosum, Arctostaphylos uva-ursi, Corema conradii, Sphagnum flavicomans, Sphagnum magellanicum, Juniperus communis*.

Rare species

Thirteen species of conservation concern, as defined by the Atlantic Canada Conservation Data Centre,were identified within our sample plots, two of which represent new additions to the provincial bryophyte and lichen lists; the moss, *Dicranum condensatum* and the lichen *Cladonia brevis* (Appendix 2). One lichen species we identified represents the third finding within North America. *Cladonia oricola* was only recently identified in Newfoundland (Ahti, 2011) with one other unpublished finding in Nova Scotia, incidentally located at one of our field sites. 14 species within our inventory are ranked at S4 or of longer term concern within Nova Scotia. 34 other species are ranked S4S5; belonging to a watch list of some districts only. An additional 15 species within our total inventory have not been ranked for their conservation status within Nova Scotia. This may be as likely a reflection of under-collection as it is an index of rarity.

Our study is also the first to inventory liverworts of the dwarf heaths on coastal barrens in Nova Scotia. Seven percent (18 species) of total species richness across the dwarf heath was comprised of liverworts. Approximately one third (20 of 69 or 29% of sample plots) contained one to four species of liverwort. *Ptilidium ciliare* was the most frequently occurring liverwort, occurring in four sample plots. All other species occurred three or less times. Liverworts were low in abundance, ranging from trace occurrences intertwined with *Sphagnum* spp. in boggier plots to a maximum of 0.33% cover within sample plots. Outside of sample plots I also observed at least one occurrence of the liverwort *Frullania tamarisci subsp. asagrayana* growing as a mat on humus substrate on Little Dover White Head Island. This species is typically epiphytic but known to grow on humus in coastal areas in Europe (BBS 2012; Crandall-Stotler *et al,* 1987).

Exotic species

We encountered 20 exotic species (not considered native to Nova Scotia) across 18 field sites (20 sample plots). Exotic species were found in greatest density (four to ten species) at four sites, all within Cape Breton: Meat cove (ten species), Big Cove (six species), Flour cove (five species), Louisbourg (four species). Two exotic species were found at Donkin, Middle Head, Cape Forchu, Green Cove and Saint Pauls Island. At Freeport, Point Michaud, Martinique, Dartmouth Point, Taylors Head, Sandhills, Freeport and Black Point, only one exotic species was indentified within sample plots. Mean abundance for exotic species was always less than 1% across all plots, and less than 1% across all plots where the species was found with the exception of three species; *Carex panacea* which made up 9% in one sample plot, *Anthoxanthum odoratum*, which had a mean abundance of 2.66% across the five plots it was found within, and *Hieracium* caespitosum Dumort., which made up 1% cover in one plot.

Principal Components Analysis (PCA) of species

The PCA model was found to explain 56.48% of species variance (total unconstrained inertia). Broken stick and Kaiser-Guttman plots reveal eight interpretable axes but the first four axes represent cumulatively 45.36% of the variation, with subsequent axes explaining proportionally less variance per axis. The majority of species (132 or 90%) are projected in close association near the center of Axis 1 and 2; 0.5 and center 0 on axis 1 and axis 2, showing little differentiation on either axis (Figure 3).

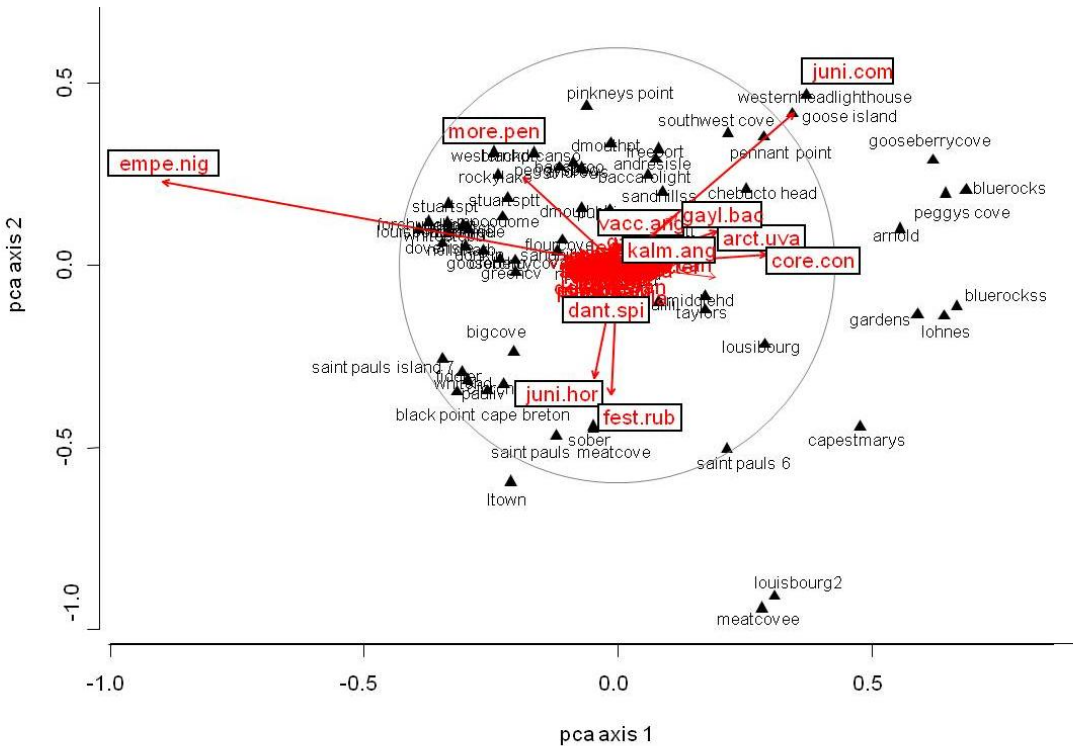

Figure 3. PCA graph of axes 1 and 2. Similarity is shown by Euclidean distance. Circle of equilibrium is shaded grey. The centroids of sites are represented by triangles. Names of most sites are slightly offset for clarity. Most species names were also slightly offset and the species *Cladonia mitis, Cladonia boryi, Cladonia arbuscula* were removed for clarity. Species vectors are unchanged and arrowheads approximate species centroids. Empe.nig= *Empetrum nigrum,* juni.com = *Juniperus communis,* fest.rub= *Festuca rubra,* juni.hor = *Juniperus horizontalis,* more.pen = *Morella pensylvanica,* kalm.ang= *Kalmia angustifolia*, vacc.ang= *Vaccinium angustifolium, gayl.bac=Gaylussacia baccata,* core.con= *Corema conradii,,* dant.spi= *Danthonia spicata*

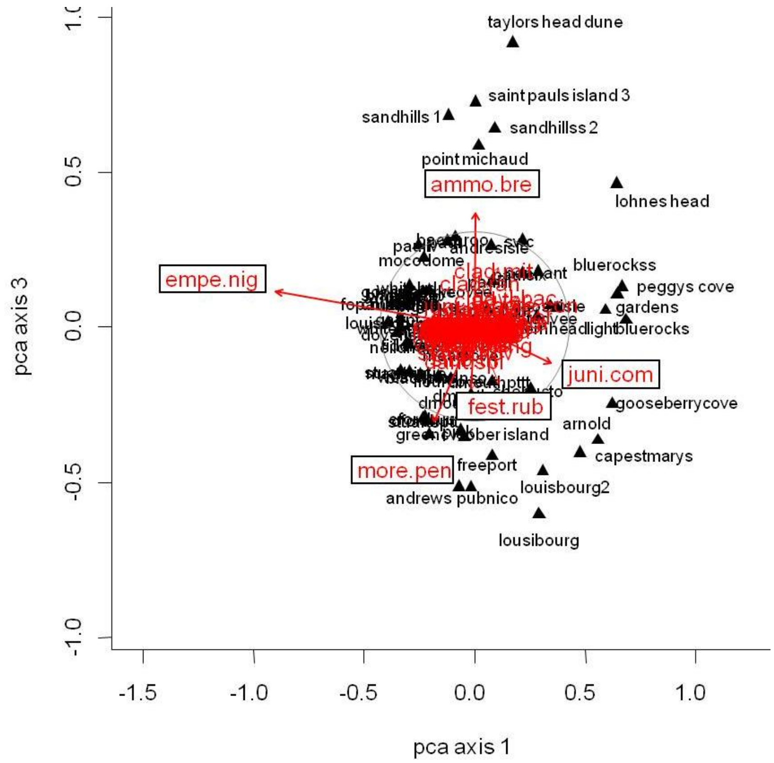

Figure 4 PCA graph of axes 1 and 3. Similarity is shown by Euclidean distance. Circle of equilibrium is shaded grey. Names of most sites and species were offset for clarity. Vectors are unchanged and arrowheads (species) and triangles (sites) approximate centroids. Empe.nig= *Empetrum nigrum*, ammo.bre = *Ammophila breviligulata*, juni.com = *Juniperus communis*, fest.rub= *Festuca rubra*, more.pen = *Morella pensylvanica*.

Five species showed greatest relevance, being consistently projected with wide separation along each significant axis: *Juniperus communis, Juniperus horizontalis, Festuca rubra, Morella pensylvanica,* and *Empetrum nigrum* (Figure 1,2)**.** With the exception of *Juniperus horizontalis* these were some of the most frequent and abundant species encountered throughout our study. The configuration of these five species rotates between axes, but their constant presence as those with greatest separation remains unchanged, thus dwarf heath communities differ mainly in the abundances of these species.

Nine (6.1%) additional species project in the near periphery of the central point cloud, illustrating some differentiation from the majority of species: *Kalmia angustifolia*, *Cladonia mitis*, Vaccinium *angustifolium, Gaylussacia baccata, Corema conradii*, *Cladonia boryi*, Danthonia *spicata, Cladonia arbuscula, and Picea glauca.*

Redundancy Analysis (RDA)

My RDA model represents between 19% and 67% of variance expressed by species in response to environmental variables (whereas other types of ordination may express variance of species independent of environmental variables). These percentages are the constrained proportions of total variance. I report a range rather than one concrete value because 19% represents our adjusted R^2value. The adjusted value is overly overly conservative because the number of environmental variables (23) is greater than half of our tested sample size (22.5) (Borcard *et al*, 2011). The upper value; 67%, represents RDA's inherently inflated estimation.

Eight canonical axes explain this range of species variance in response to environmental conditions we measured. 35 residual axes show variation not captured within our data. In permutation tests of all environmental variables save for VIFs, only the first three axes were significant when Pr (>f) = 0. When only the variables determined by forward selection (results below) to be significant are included, only the first two axes are significant when Pr (>f) = 0. Axis 3 is also significant when n Pr (>f) = 0.001. Subsequent axes are non-significant but also provide little insight because they represent only 5% to less than 1% of species variance explained by environmental variables included in the RDA.

My next step was to conduct forward selection on the reduced set of environmental variables after removing those with high variance inflation factors. This resulted in a final set of eight variables: **moisture class, fetch of the most frequent wind direction, soil depth, elevation, distance from the coast, slope, humus thickness, and soil's iron content.** This parsimonious model selected explained somewhat less variation: between 10.6% (adjusted R^2) and 40% , where the first two axes explained 68.8% of that variance and a third axis increased this to 78.2%. Overall architecture of the RDA is maintained whether the analysis is completed with all variables (save for VIFs) or with the most parsimonious data set.

Axis 1 is associated with fetch of most frequent wind direction, distance to coast, elevation and slope at the positive end, meaning conditions relatively inland, with higher elevations and steeper slopes (Figure 5a). The species associated with this end of axis one include *Corema conradii*, *Juniperus communis*, *Gaylussacia baccata*, *Arctostaphylos uva-ursi*, *Cladonia boryii*, *Kalmia angustifolia*, and *Cladonia mitis*. The other extreme of axis 1 (negative scores) was associated with humus thickness, moisture class, soil iron content, and soil depth, so associated plots and species occur in areas of deep humus, wetter conditions, and high iron content. Species associated with these conditions include *Empetrum nigrum*, *Morella pennsylvanica*, and *Festuca rubra*. Many species were associated with intermediate values of Axis one, and these tended to be uncommon (i.e., found in few sample plots); some of the more frequent include *Iris versicolor*, *Rosa carolina*, *Drosera rotundifolia*, *Dicranum* spp. and *Solidago bicolor* and *S. sempervirens*.

High axis 2 scores are associated with deeper soils (Figure 5b); low axis 2 scores are associated with moisture class, humus thickness, elevation, iron content, slope and distance to coast. Species associated with high values of Axis 2 include *Ammophila breviligulata*, *Cladonia rangiferina*, and *C. mitis*; there were few species associated with negative values of axis 2 but the species with the most negative scores included *Corema conradii*, *Morella pennsylvanica*, and *Arctostaphylos uva-ursi*. Many other species were associated with intermediate (close to zero) values of this axis and are also associated with intermediate values of Axis 1, described above.

High axis 3 scores were associated with high iron content, high elevations and steeper slopes and had species such as *Corema conradii*, *Danthonia spicata*, *Arctostaphylos uva-ursi*, and *Cladoia boryii*. The other end of axis 3 was associated with wetter conditions (moisture class), deeper humus, high fetch, greater distances to the coast and deeper soil, with species such as *Kalmia angustifolia*, *Cladonia mitis*, *Sphagnum fallax*, and *Chamaedaphne calyculata*.

High axis 4 scores are associated with fetch of most frequent wind direction, greater distance to coast, thick humus and high elevation. Associated species include *Gaylusaccia bacata*, *Cladonia mitis* and *Juniper horizontalis*. On the opposite end of axis 4, steep slope, wetter conditions (moisture class), deep soil and iron content were closely associated with negative scores and the species *Juniper communis*, *Vaccinium macrocarpon* and *Sphagnum fallax*.

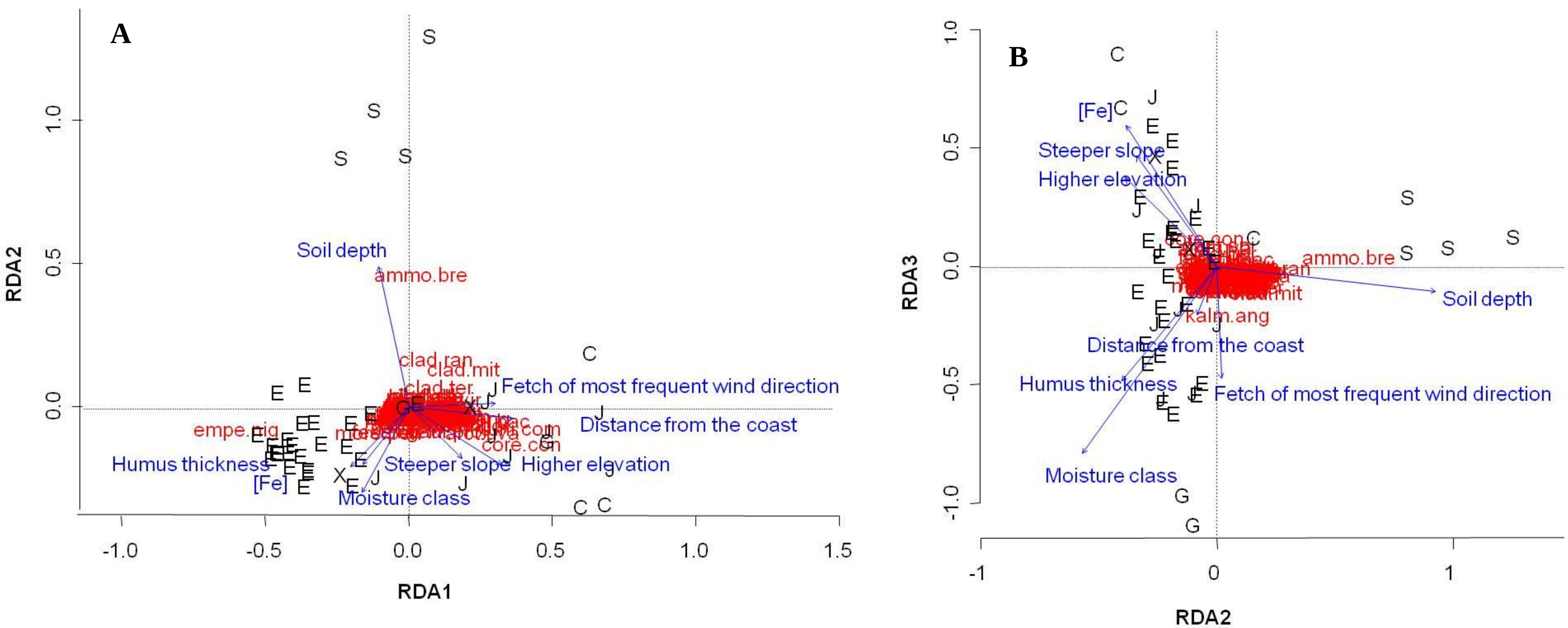

Figure 5. RDA of significant axes and environmental variables only. Interpret similarity by vectors. Positions of names have been moved for clarity, vectors are consistent. **5a** displays axes 1v2, **5b** displays axes 2v3.

Community types are represented symbols: **S** = *Ammophila breviligulata* dwarf heath, **J**= *Juniperus communis – Arctostaphylos uva-ursi* dwarf heath, **E** = *Empetrum nigrum* dwarf heath, **X=***Festuca rubra – Sibbaldiopsis tridentata*, **G=**Herbaceous and grassland communities, **C=** *Corema conradii - Gaylussacia baccata.*

Species are represented by abbreviated code: ammo.bre = *Ammophila breviligulata*, clad.ran = *Cladonia rangiferina.* clad.mit = *Cladonia mitis*, clad.ter = *Cladonia terrae- novae* empe.nig = *Empetrum nigrum*, core.con = *Corema conradii*, juni.com= *Juniperus communis*, kalm.ang = *Kalmia angustifolia*, more.pen=*Morella pensylvanica.*

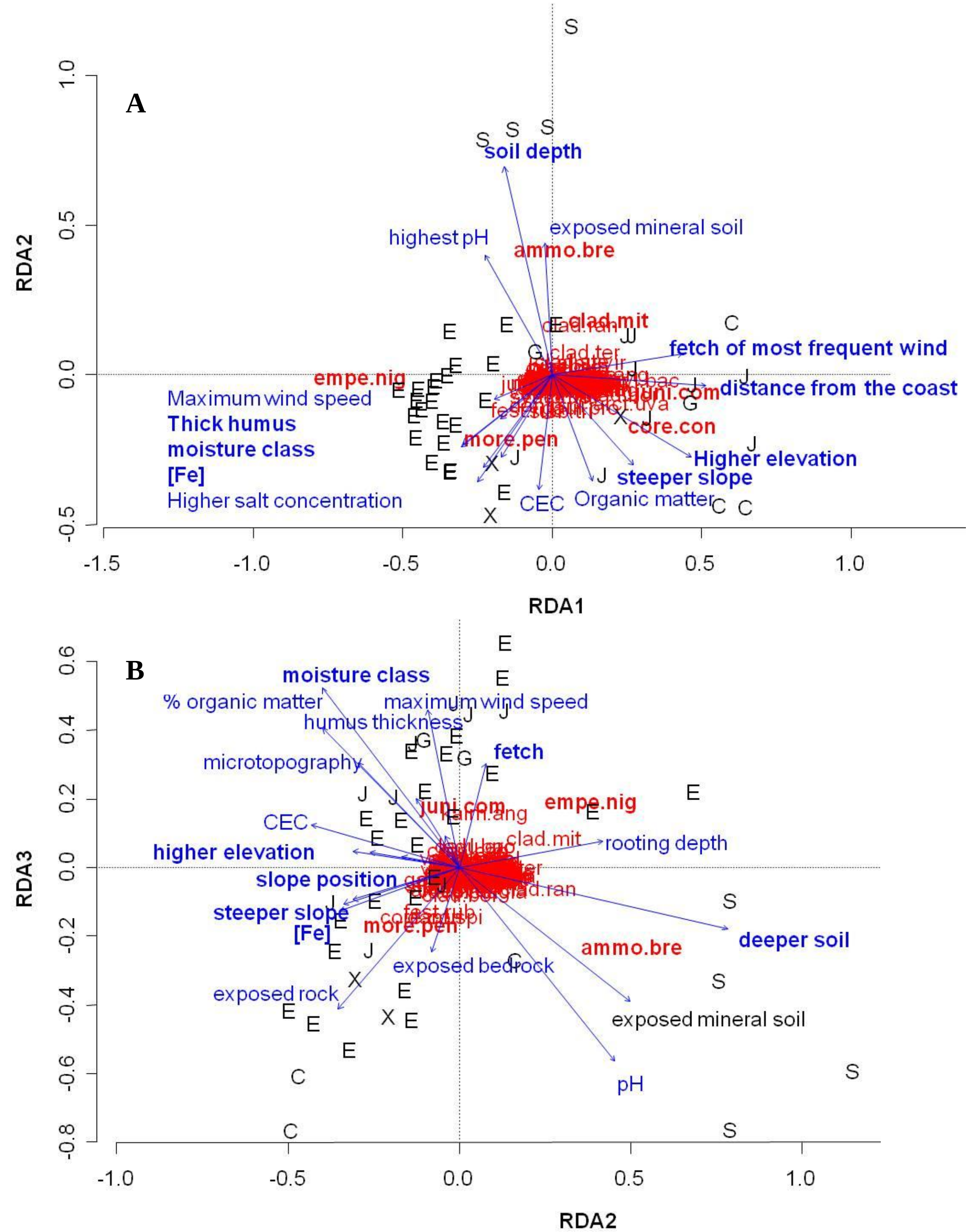

Figure 6. RDA of all environmental variables with VIFs removed. Significant variables are in bold font. Positions of variable names have been moved for clarity, vectors are consistent. 6A = RDA axes 1v2, B. 6B= RDA axes 2v3. Symbols for community types and species names are consistent with figure 5.

Environment of the dwarf heaths across all sample plots

Means will be reported throughout this thesis with both standard deviation (SD) and standard error of the mean (SEM). Across all of my sample plots and study sites, the average height of vegetation was 13.2 cm (± SD= 7.4cm; SEM= 1 cm).

On average, my field sites were 123.5 ha (± SD=215.9ha; SEM=29.4ha) in area. Mean elevation of sample plots was 10 m ± (SD=10m; SEM=1.3m). Average meso slope position was between upper to middle slope (2.5 ± SD=1.8; SEM=0.2 in class). Meso slope positions were variable, ranging from depression to crest. Dwarf heaths in general are not restricted to one slope position. Mean slope gradient was a variable 14% (± SD=16.8%; SEM=2.1%). Microtopography was also varied but was slightly to moderately mounded (2.5 ± SD=1.1; SEM= 0.1) on average.

Average fetch distance in the direction of most frequent wind was > 58.9km (± SD= >120km; SEM= >15.6km). Average fetch distance of mean wind direction was 12km (± SD = > 57.5km; SEM=7.5km). Fourteen sample plots had fetch distances of less than 1km in either the most frequent or mean direction of wind. Thirty eight percent of sample plots had fetch distances that were larger than measurable by our model (greater than 12 to 400km). When fetch distances were small for the most frequent wind direction, they were often large in the mean direction of wind and vice versa.

Wind speeds at sites (30m elevation off the ground) ranged from a minimum average of 7.5m/s (± SD= 1.2m/s; SEM= 0.1 m/s) to a maximum average wind speed of 8m/s (± SD= 0.9m/s; SEM= 0.1m/s). These speeds represent moderately breezy on the

Beaufort scale (NMLA 2011). This average does not preclude much higher speeds during storms.

In terms of exposed substrates, exposed rock and bedrock were most frequent and organic soil was rarely exposed in sample plots. Exposed bedrock occurred in 13 sample plots where it comprised an average of 15% cover ± (SD= 14.3%; SEM=4.18%). Exposed rock was found in 27 sample plots where it comprised an average of 6.9% cover (± SD=8.9%; SEM=1.74%). Mineral soil was exposed in 10 sample plots where it comprised an average of 10.5% cover (± SD=13.2%; SEM=4.38%). Organic soil was exposed in only 2 sample plots, where it comprised 1% cover in each.

Table 4. Summary statistics of dwarf heath environmental characteristics across all study sites, where n represents the number of samples collected in total, SD represents the standard deviation and SEM represents the standard error of the mean.

	n	**Mean**	**SD**	**SEM**
Average minimum wind speed (m/s)	67	7.5	1.2	0.1
Average maximum wind speed (m/s)	67	8.0	0.9	0.1
Vegetation height (cm)	51	13.2	7.4	1.0
Slope length (m)	47	52.0	71.6	10.4
Fetch: most frequent wind (km)	60	58.9	120.0	15.6
Fetch: mean wind (km)	60	12.5	57.5	7.5
Site area (ha)	54	123.5	215.9	29.4
Elevation (m)	66	10.0	10.2	1.3
Distance from coast (m)	66	75.7	61.3	7.6
Slope gradient (%)	66	14.0	16.8	2.1
Aspect: North	45	5.2	0.9	0.1
Aspect: East	45	3.1	1.4	0.2
Meso slope position (class)	65	2.5	1.8	0.2
Microtopography (class)	62	2.5	1.1	0.1
Exposed bedrock (% cover)	13	13	14.3	4.1
Exposed rock (% cover)	27	27	8.9	1.8
Exposed mineral soil (% cover)	10	10	13.2	4.4
Exposed organic soil (% cover)	2	2	0.0	0

Dwarf heath soils

Average soil depth within our sample plots was 31.1cm (± SD=19.9cm; SE=3.3cm). Rooting depth was on average 24.5cm ± (SD =17.8cm; SEM=2.4cm). Humus thickness was on average 23.9cm ± (SD=19.5cm; SEM=3.2cm) in depth.

Soils were rapidly to very poorly drained, but most frequently they were rapidly drained. On average, drainage class was approximately well drained with a standard deviation of approximately 2 classes and a standard error of 0.2 classes. Moisture class ranged from xeric to sub hydric. On average, moisture class was between sub mesic and mesic, but with a standard deviation of 2 classes and standard error of less than 1 class.

Humus forms included six mors: four fibrimors, eight hemimors, 25 humimors, one hydromor, mesimor, and six resimors. There were three moders including three mormoders and one mullmoder and one leptomoder. Four soil pits occurring on sand dunes were comprised exclusively of sandy soils with only litter and organic staining and no developed humus layer. Only from these sandy soils was the predominant rooting zone within mineral soil.

Table 5. Humus forms classified within the dwarf heaths include six mors and three moders. Four additional sample plots were from sand dunes and comprised exclusively of sand with no developed humus layer. Humimor was the most frequent humus form, having more than twice as many occurrences than any other. n represents the number of samples of each humus form.

Mor	n	Moder	n
Fibrimor	4	Mormoder	3
Hemimor	8	Mullmoder	1
Humimor	25	Leptomoder	1
Hydromor	1		
Mesimor	1		
Resimor	6		

Soils were acidic with a mean pH of 4.2 ± (SD=0.6;SEM=0.1). Total salt concentration calculated from conductivity was 0.5 mS/cm (±SD=0.5 mS/cm;SE=0.1 mS/cm). Sodium (Na) was present on average in 270.9ppm ± (SD=341.9ppm, SE=51.5ppm). Cation exchange capability (CEC) was on average 90.4 Meq/100g (± SD=4.5 Meq/100g SE=0.7 Meq/100g). Table 6 provides detailed soil characteristics inclusive of al sample plots.

Table 6. Soil depth, chemistry and drainage condition summarizing the dwarf heaths. Soil pits and chemistry were taken from a subset of sample plots. n represents the number of samples collected per variable, SD represents the standard deviation and SEM represents the standard error of the mean.

Soil depth (cm)	**n**	**mean**	**SD**	**SEM**
Soil depth (cm)	37	31.1	19.9	3.3
Rooting depth (cm)	44	24.5	17.8	2.4
Humus thickness (cm)	38	23.9	19.5	3.2
Soil chemistry	**n**	**mean**	**SD**	**SEM**
Organic Matter	44	51.4	30.9	4.7
Na (ppm)	44	270.9	341.9	51.5
K (ppm)	44	123.1	73.0	11.0
S (ppm)	44	23.3	18.1	2.7
Mg (ppm)	44	327.3	237.8	35.8
Fe (ppm)	44	212.1	167.7	25.3
N (%)	44	1.1	0.6	0.1
Ca (ppm)	44	451.7	383.3	57.8
pH	44	4.2	0.6	0.1
Salt (mS/cm)	44	0.5	0.5	0.1
CEC (Meq/100g)	44	90.4	4.5	0.7
Drainage condition	**n**	**mean**	**SD**	**SEM**
Drainage class	44	2.3	1.7	0.2
Moisture class	44	3.55	1.78	0.27

Cluster Analysis

The Cophenetic correlation coefficient of my cluster analyses was 0.61. Cophenetic correlation is a Pearson's *r* correlation between the dissimilarity matrix and the cophenetic dendrogram. Broadly speaking, this is a measure of how well the dendrogram models the data. Though the cophenetic correlation is not a test of significance (due to interdependence of matrices and method of clustering), this value quantifies the fit. Just like a linear correlation coefficient, 0.61 is relatively high since a value of 1 would be perfect.

I decided upon the number of community associations to select from the dendrogram based on statistical criteria. Firstly, fusion level (*i.e.* dissimilarity values where two branches meet) plotting exhibited obvious clear jumps for up to six groups, where node height approached 1.7 in dissimilarity value. I chose a height of cutting above this threshold. I then used the CLUSTER package in R to construct a bar plot of silhouette height that provided the Silhouette optimal number of clusters: 4 groups for the final partition, this having an average Silhouette width of 0.31.

Group Si similarity indices are specified within figure 7. Si is a measure of how similar the group is to itself such that the closer Si is to 1, the stronger the fit as a clusterIf the values are close to 0 but still positive, it means they are a fit but more similar as well to other groups. Similarity values were high (0.19 to 0.49) for 3 of 4 classification groups, suggesting a strong fit for these groups. *Empetrum nigrum* and *Ammophila breviligulata* associations had the strongest Si values with no misclassified plots. The *Juniperus communis-Arctostaphylos uva-ursi* association had a moderately high Si score with few (2 of 12) plots misclassified. The *Festuca rubra- Coptis trifolia* community demonstrated a negative Si score and high percentage of misclassifications. This suggests included plots do not share a consistent plant species association.

Because Ward’s cluster analysis relies on floristic data alone, I was able to include all sample plots (n=68) in the analyses. Soil pits were dug at only 44 sample plots, hence the difference in sample size between the cluster analyses and RDA analyses. The sample size of each variable is indicated within subsequent tables and summary statistics describing clustered communities.

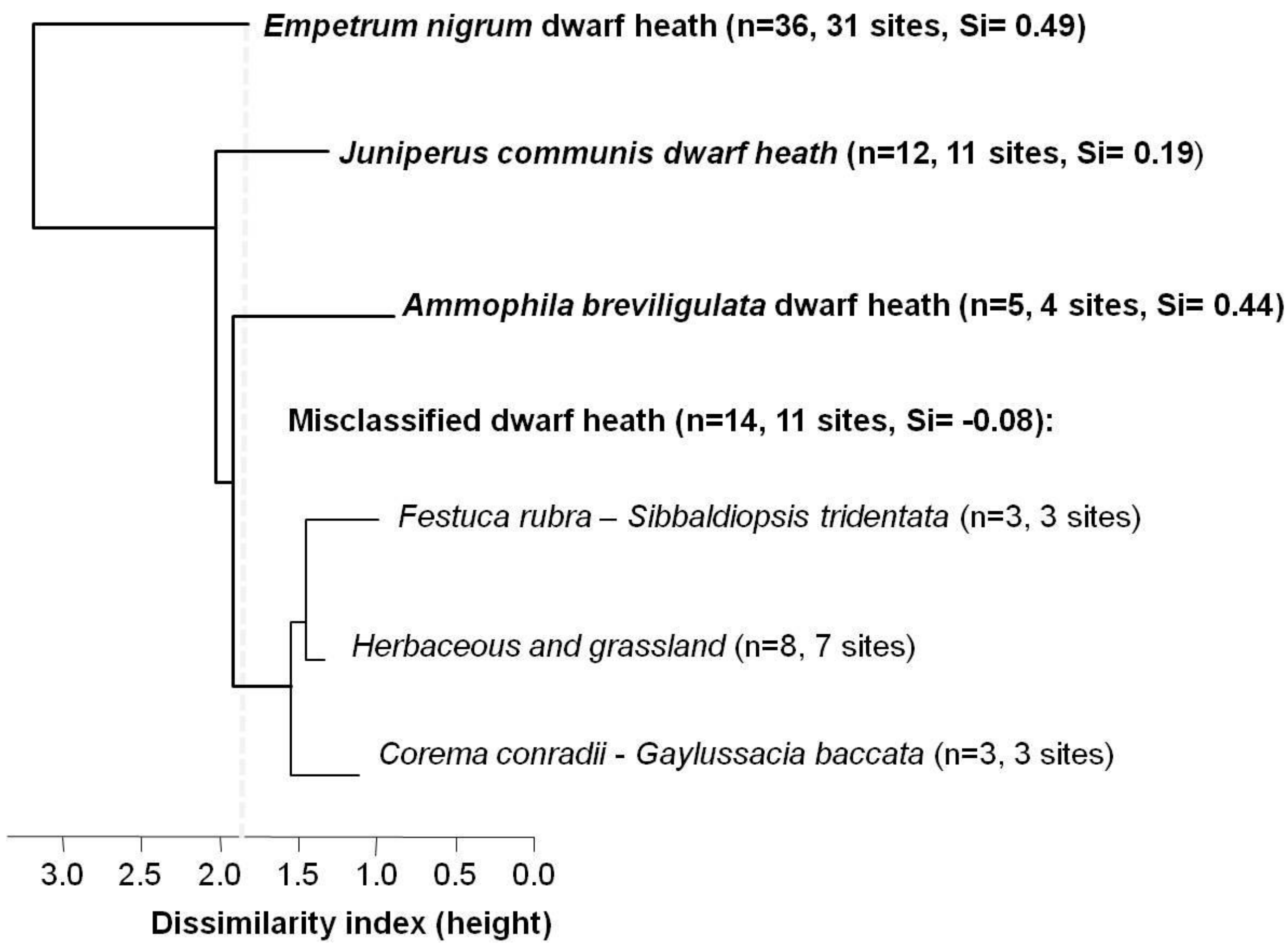

Figure 7. Wards Minimum Variance Clustering Dendrogram illustrating three associations and one misclassified branch divided into three community types. Dotted grey line represents height of cutting. Sample size and Si score are provided in parentheses.

Table 7. Summary of primary environmental characteristics that distinguish dwarf heath associations, including significant variables from RDA analyses and also details in summary statistics of measured variables.

Association	Related Environmental Variables
***Empetrum nigrum* dwarf heath** Average species richness: 19.6 species/plot	High maximum average wind speed, greatest fetch distance of mean wind direction, thickest humus on average; diverse in form, widest moisture gradient, higher plant nutrient concentrations and CEC
***Juniperus communis* dwarf heath** Average species richness: ten (10) species/plot	Sites largely central to south in distribution and of largest sites (area). Plots farther from coast, on longer and steeper upper to middle slopes, higher elevation, greatest fetch distance in the most frequent wind direction, lower average wind speed, more rapidly drained soils, shallow soil, thin humus, shallow rooting, slightly more acidic pH, higher [Fe]
***Ammophila breviligulata* dwarf heath**	Sites were sand dunes and sandy marine deposits. Plots were at lower elevation, of deepest soil; coarse sand with deep rooting and most basic (still acidic) pH, lower nutrients and lower salinity

Table 8. Summary of primary environmental characteristics of misclassified dwarf heath communities (n=14, 11 sites, Si= -0.08)

Community	Related Environmental Variables
Festuca rubra – Sibbaldiopsis tridentata	Small sized sites. Plots on shallow slopes with aspects facing the coast, nearest distance to coast, lower elevation, higher nutrient concentration especially [Mg] and [Ca], exposed rock, extreme highest salinity
Herbaceous and grassland 22.9 species/ plot, highest proportion of rare and exotic species	Almost exclusively sites in the Northern extreme of Nova Scotia save for two peninsular South NS sites. Fetch values by far the largest. Average wind speeds the fastest; fresh breeze in Beaufort scale. Highest elevation, farther from the coast
Corema conradii - Gaylussacia baccata	Sites located in Southern half of province. Plots are further from the coast, have taller vegetation, steep upper to crest slopes, soils thin to negligible, high rock exposure, low Magnesium, occasional charcoal, low salinity.

Empetrum nigrum dwarf heath association (n=36, 31 study sites, Si=0.49)

Table 9. IndVal test shows *Empetrum nigrum* as the sole indicator species, significant where P<0.001. An IndVal closer to 1 represents a species with large mean abundance within an association (specificity), and presence within most sites of the association (fidelity). P represents the probability of finding a higher indicator in random permutations.

Indicator species	IndVal	P-value
Empetrum nigrum	0.45	0.001

This association is characterized by dominance of the indicator species *Empetrum nigrum*, present within every plot with mean cover of 59.6% (± SD= 5.9%, SEM= 3.83%). While ubiquitous across the dwarf heaths, *Empetrum nigrum* was most abundant within this association. *Symphyotrichum novi-belgii* is the next most frequent species, occurring in 30/36 sample plots, with mean abundance of only 1% cover (± SD=1.9%, SEM= 0.34%). *Morella pensylvanica* was the third most frequent and second most abundant species of this association. It occurred in 29/36 plots with mean abundance of 10.5% cover (± SD=13.5%; SEM =2.6%). *Juniperus communis* was present in 24/36 plots and had a mean abundance of 4.6% cover (± SD=4.6%; SEM = 1.43%). *Festuca rubra* was also relatively common, present in 21/36 plots, but with low mean abundance of 4.1% cover (± SD=5.7%; SEM= 1.27%).

Table 10. Most frequent and abundant species of *Empetrum nigrum* association. n represents frequency of species occurrence, % cover is a measure of species abundance, means are provided with standard error of the mean (%SEM) and also standard deviation (%SD).

Species	n	%cover	SD	SEM
Empetrum nigrum	36	59.61	22.69	3.84
Symphyotrichum novi-belgii	30	1.05	1.91	0.35
Morella pensylvanica	29	10.50	13.53	2.56
Juniperus communis	24	4.61	6.87	1.43
Festuca rubra	21	4.12	5.67	1.27
Sibbaldiopsis tridentata	21	2.19	3.74	0.84
Vaccinium vitis-idaea	21	1.54	2.18	0.49
Danthonia spicata	19	2.32	4.13	0.97
Vaccinium angustifolium	15	1.28	1.42	0.38
Agrostis scabra	15	0.37	0.37	0.10
Cladina mitis	13	2.03	2.48	0.71
Deschampsia flexuosa	13	1.67	2.83	0.82
Juniperus horizontalis	11	10.38	14.68	4.64
Kalmia angustifolia	11	2.62	2.47	0.78
Photinia melanocarpa	11	0.69	0.73	0.23
Vaccinium oxycoccos	11	0.35	0.61	0.19
Plantago maritima	9	1.37	1.63	0.58
Cladina terrae-novae	9	1.29	1.10	0.39
Achillea millefolium	9	0.62	0.83	0.30
Vaccinium macrocarpon	8	4.70	8.86	3.35
Cladonia arbuscula	7	2.00	2.14	0.87
Ledum groenlandicum	7	1.29	1.09	0.44
Cladina rangiferina	7	1.24	1.19	0.48
Picea glauca	7	0.51	0.54	0.22
Solidago puberula	7	0.51	0.73	0.30
Hypogymnia physodes	7	0.37	0.72	0.29
Iris versicolor	7	0.29	0.20	0.08
Dicranum scoparium	7	0.08	0.04	0.01

Mean plot richness for this group was 19.6 species/plot, slightly less than the overall mean across all groups of 22 species/plot. Mean vegetation height was 12.4cm (± SD=6.7cm; SEM=1.3cm), slightly shorter than the mean of all sample plots (13.2cm).

Environmental characteristics of *Empetrum nigrum* association

On RDA axis 1 (Figure 5a) *Empetrum nigrum* is closely associated with negative RDA axis 1 scores and soils characteristics of thick humus, poorer drainage condition and greater moisture class. *Empetrum nigrum* and *Morella pensylvanica* are projected at negative RDA1 and negative RDA 2 scores, associated with the greatest maximum average wind speeds, greatest salt content (both total salts from conductivity and [Na]), greatest fetch distance of mean wind direction and soils with greatest CEC value.

Environmental characteristics of this association are summarized in table 11. Study sites were slightly smaller on average: 104ha (± SD=237.9ha; SEM=44.2ha). Sample plots were widespread and not restricted in geographical range. Mean elevation was 7.92m (± SD=9m; SEM=1.52m). On average, slope length falls within the 50-100m category, this is also the average across all sample plots. Slope position was highly variable. Though the average was mid slope (class =2.71± SD= 1.96 ; SEM=0.34), sample plots of the association were located at all slope positions. Slope gradient was 10.7% (± SD=13.2%; SEM = 2.3%); this is relatively shallower in comparison with other sample plots. Microtopography was on average moderately mounded.

Consistent with the RDA, fetch distance of the mean wind direction was greater than average: >19.7Km (±SD=>77.1Km; SEM= >13.6Km) vs. the mean of all plots of >12.5Km. Fetch distance of the most frequent wind direction appears very much less than average: at least 13.9km (± SD=33.4Km; SEM= 5.9Km) for the association, compared with 58.9Km for all sample plots. The mean of the average maximum wind speed was 8.1m/s (± SD= 0.9m/s; SEM=0.2m/s), this represents moderate wind on the Beaufort scale and is just slightly greater than winds at other sample plots. Plots were located 56.3m from the coast on average, (± SD=53.1; SEM= 9.0m), nearer than for other sites.

Exposed rock, bedrock and soil were each less frequent in comparison with other sample plots outside of this association, but for exposed bedrock and rock, abundances were higher on average. Exposed bedrock was present in only seven of 36 sample plots but represented on average 22.7% cover (± SD=15.9% ;SEM=6.5%) within those seven plots. Exposed rock was observed in 16 of 36 sample plots and represented 6.4% cover (± SD=8.5%, SEM= 2.2%) where observed. Exposed soil was rarely observed (Table 10); mean exposed mineral soil was minimal (0.44% cover), relative to overall site averages (7.55% cover) and mean exposed humus percent cover was slightly greater (28.7% cover vs 23.9% cover).

Table 11. Environmental characteristics of 36 sample plots comprising the *Empetrum nigrum* association. n represents number of observations collected for each variable. Note sample plot at Gaff point had shaley coarse fragments in the soil pit, differing from the bedrock type at that site.

	N	Mean	SD	SEM
Mean Vegetation height (cm)	29	12.4	6.7	1.3
Mean site area (ha)	30	104.2	237.8	44.2
Easting (UTM)	28	485819.3	184593.9	35525.1
Northing (UTM)	28	4952210.9	88163.3	16967.0
Aspect (East)	22	5.2	0.9	0.2
Aspect (North)	22	3.1	1.6	0.3
Elevation (m)	36	7.9	9.0	1.5
median slope length (m)	27	33.0	38.7	7.6
Slope position (class)	35	2.7	2.0	0.3
Slope (%)	35	10.7	13.2	2.3
Microtopography (class)	33	2.6	1.2	0.2
Average average minimum wind speed (m/s)	36	7.5	1.2	0.2
Average average maximum wind speed (m/s)	36	8.1	0.9	0.2
Fetch: most frequent wind (Km)	33	13.9	33.4	5.9
Fetch: mean wind (Km)	33	19.7	77.1	13.6
Distance from coast (m)	36	56.3	53.1	9.0
Exposed bedrock (%)	7	22.7	15.9	6.5
Exposed rock (%)	16	6.4	8.5	2.2
Exposed mineral soil (%)	4	4.0	1.4	0.8
Exposed organic soil (%)	2	1.0	0.0	0.0
Bedrock lithology	Meguma group: Halifax and Goldenville formations, Pictou Group, Forchu Group			

Soil characteristics of *Empetrum nigrum* association

In addition to differences in the environmental conditions represented at *Empetrum nigrum* sample plots, soil variables largely characterize this association (Table 12 and Table 13)

Soil depth was on average 34.7cm (± SD=23.1cm, SEM=5cm), greater than the mean across all study sites. Average rooting depth was 24.3cm (±SD=16.4cm; SEM=3.1cm), only 0.2cm different from the mean across all sites. Humus thickness was greater than average, 28.7cm (±SD=23.5cm; SEM=5.1cm). The greatest range of humus forms were classified from sample plots of the *Empetrum nigrum* association. (Table 4). Sample plots spanned the full range of drainage conditions from rapidly to very poorly drained sites. Organic soil concentrations (56.9%± SD=26.8%; SEM=5.6%) were higher than average (51.3%). CEC and the concentrations of all nutrients with the exception of Calcium were higher in soil in comparison with means across all other sample plots (Table 3). Mean pH was acidic: 4.13, near overall site average: 4.18. Charcoal was found in three soil pits belonging to this association, representing 75% of occurrences of charcoal within our study. Drainage condition was on average moderately well drained, but this was highly variable such that several plots were rapid or very poorly drained (class mean: 2.77 ± SD=1.9 ; SEM=0.35).

Table 12. Soil characteristics of 36 sample plots where 29 soil pits were dug. All variables were measured for 24 soil pits, *i.e*. soil chemistry data was not obtained from every pit. n represents the number of samples collected for each parameter. Salt value is based on conductivity lab testing.

Soil depth (cm)	**N**	**Mean**	**SD**	**SEM**
Soil depth	22	34.7	23.1	5.0
Rooting depth	29	24.3	16.4	3.1
Humus thickness	22	28.7	23.5	5.1
Soil chemistry	**N**	**Mean**	**SD**	**SEM**
% Organic matter	24	56.9	26.8	5.6
CEC (Meq/100g)	24	91.1	4.6	1.0
K (ppm)	24	135.3	79.2	16.5
S (ppm)	24	28.6	21.7	4.5
Mg (ppm)	24	375.1	234.4	48.9
Fe (ppm)	24	237.8	180.5	37.6
N (%)	24	1.2	0.6	0.1
Ca (ppm)	24	431.3	281.3	58.7
pH	24	4.1	0.6	0.1
Na (ppm)	24	349.8	391.6	81.7
Salt (mS/cm)	24	0.6	0.6	0.1
Drainage condition	**N**	**Mean**	**SD**	**SEM**
Drainage Class	31	2.8	1.9	0.4
Moisture class	24	4.1	1.7	0.4
Presence of charcoal	3	N/A	N/A	N/A

Table 13. Humus form was classified at 27 of 29 soil pits of the *Empetrum nigrum* dwarf heath association and includes five mors and two moders. n represents the number of soil pits where a given humus form was classified. The percentage of each humus form within the association represented by n sample size is also provided.

Mor	**n**	**%**	**Moder**	**n**	**%**
Hemimor	4	14.8	Leptomoder	1	3.70
Humimor	13	48.1	Mormoder	2	7.4
Resimor	3	11.1			
Fibrimor	3	11.1			
Mesimor	1	3.7			

Juniperus communis dwarf heath association (n=12 plots, 11 sites, Si=0.19)

Table 14. IndVal indicator species with associated p-values for the *Juniper communis* association. An IndVal closer to 1 represents a species with large mean abundance within an association (specificity), and presence within most sites of the association (fidelity). P represents the probability of finding a higher indicator in random permutations.

Indicator	IndVal	p-value
Juniperus communis	0.74	0.001
Trientalis borealis	0.29	0.03
Cladonia squamosa	0.25	0.018
Racomitrium lanuginosum	0.25	0.022
Arctostaphylos uva-ursi	0.23	0.036

The strongest indicator of this association is high abundance of *Juniperus communis.* Although this species was widely present (in 49 plots) throughout our study, it occurred in every sample plot of this association, in relatively high abundance. Mean abundance of *Juniperus communis* within the association is 32% cover (± SD= 14.5%; SEM= 4.38 %.)

The indicator species *Arctostaphylos uva-ursi* occurs with high abundance and exclusivity to this association, though it was not present in every sample plot. Three of four occurrences of the species throughout our study belong to this association. *Arctostaphylos uva-ursi* was recorded in mean abundance of 23.3% cover (± SD=7.6%; SEM= 5.4%).

Three indicator species are nearly exclusive to this association. Three of seven occurrences of the herb *Trientalis borealis* belong to this association, it had low mean abundance of 0.1% cover (±SD=0.06%; SEM= 0.04%). The lichen *Cladonia squamosa* was exclusively found within this association, where it occurred in 0.1% cover within each of the three plots. Similarly, all three occurrences of the moss *Racomitrium* *lanuginosum* belong to this community type. *Racomitrium lanuginosum* had a mean abundance of 0.4% cover (± SD=0.32%; SEM= 0.23%) in plots where it was found.

The second most abundant and frequent species of this association is (the ubiquitous) *Empetrum nigrum*, found in ten (10/12 total) plots, with high mean abundance: 30.1% cover (± SD= 17.6%; SEM= 5.9%). *Vaccinium angustifolium* and *Sibbaldiopsis tridentata* were both as frequent within this association as *Empetrum nigrum*, but occurred with lower mean abundance: 2.2% cover (± SD= 3.4%; SEM= 1.1%) and 0.9% cover (± SD= 0.95%; SEM= 0.31%) respectively. *Morella pensylvanica* is fifth most frequent and abundant species, found in nine of twelve plots and comprised 6.6% of cover (± SD=8.82%, SEM= 3.12%) within those plots. *Cladonia boryi* and *Kalmia angustifolia* were found as often as Morella but both were less abundant: found at 3.9% cover (± SD=8.14% ; SEM= 2.88%) and 2.8% cover ± (SD= 3.67% ; SEM= 1.3%) respectively. The most frequent and abundant species are listed in Table 15.

Several species were uncommon, but highly abundant. *Gaylussacia baccata* was found in 6 of 12 plots with mean abundance of 13.4% cover (± SD =16.4%; SE 7.33%). *Cladonia mitis* was found in 6 plots with mean abundance of 6.7% cover (± SD= 7.52% SEM= 3.36%). *Empetrum eamesii* was found in only one sample plot of this association, where it occurred in 12% cover. *Corema conradii* was found at 5 plots and had 10.4% mean cover (± SD=8.23%; SEM= 4.11%). The only occurrence of *Comptonia peregrina* in any dwarf heath plot was at our Blue Rocks site, where it had an abundance of 6.5% in that plot. Two of four occurrences of *Picea mariana* within our study belong to this association, occurring in 5.1% cover (± SD=7% SEM= 7%).

All other species were less frequent and/or abundant: occurring in less than 3% of sample plots and in low abundance of less than 5% mean cover. 119 species were identified in total, 62 of those occurred in only one sample plot. Average sample plot richness is only ten (10) species; less than half the average across all dwarf heath plots (22 species/plot). Mean vegetation height is 13.9cm± SD=6.5cm; SEM= 2.3cm, near the overall average across all sites of 13.2cm.

Table 15. Most frequent and abundant species of *Juniperus communis* association. SD represents the standard deviation of abundance, SEM represents the standard error of the mean abundance for each species. Eight (6.7%) species occur faithfully (8 or more times), 34 (29%) species are reoccurring (occur 3 – 8 times), 12 (10%) of species occur three times, 15 (12.6%) of species occur twice, and most species; 62 (52%) occur only once.

Species	**Frequency** n =12 plots	**Abundance (% cover)** mean	SD	SEM
Juniperus communis	12	32	14.52	4.38
Empetrum nigrum	10	30.05	17.56	5.85
Vaccinium angustifolium	10	2.15	3.44	1.15
Sibbaldiopsis tridentata	10	0.85	0.95	0.32
Morella pensylvanica	9	6.58	8.83	3.12
Cladonia boryi	9	3.88	8.15	2.88
Kalmia angustifolia	9	2.76	3.67	1.30
Cladina terrae-novae	8	1.93	3.33	1.26
Alnus viridis	7	2.83	3.09	1.26
Vaccinium vitis-idaea	7	1.73	3.66	1.49
Symphyotrichum novi-belgii	7	0.83	0.86	0.35
Agrostis scabra	7	0.23	0.22	0.09

Environmental characteristics of *Juniperus communis* association

The indicator species *Juniperus communis* and *Arctostaphylos uva-ursi* and also the species *Gaylussacia baccata* and *Corema conradii* and sample plots of this association are closely associated with each other and with positive RDA 1 scores, and negative RDA 2 scores. The most significant associated environmental conditions are greatest distances to coast, longest fetch distance from the most frequent wind direction, highest elevation, and steepest slopes. Exposed bedrock and increased area of study site are also associated variables. Along positive RDA 3, these plots and species are additionally associated with high iron content of soils.

Table 16 provides summary statistics of each measured environmental variable. Average site area was 223 ha (± SD=248.5ha; SEM= 82.8ha), representing nearly twice as large as mean across all sites; 123.5ha (± SD=216ha; SEM= 29.4ha). Plots were primarily located within Central Halifax County (along South-Eastern Shore) through Southwestern shoreline of Nova Scotia. This is not an entirely exclusive distribution though, since one of the 12 sample plots was at Gooseberry Cove, Cape Breton. It should be noted there was no *Corema* in that sample plot. There was little difference in the aspect compared with other sample plots, though they faced slightly more North than at other sample plots in our study.

Mean elevation for this group was 11.7m (± SD=4.58m; SEM=1.38m), which is 1.7m above the overall dwarf heath average of 10m (± SD=10.2m; SEM= 1.38m). On average plots were located in upper to middle slope positions, (mean 2.5 ± SD=0.93; SEM= 0.29), but one plot was on the crest of a hill and two lower to toe slope positions. No plots were located in depressions or on a level slope. Mean gradient of slopes were 20.1% (± SD=13.7%; SEM=4.3%); this is steeper than the mean across all sites of 14%(± SD=16.8%; SEM 2.06%). Slope length was about twice as long as other sample plots on average and fall into the 50-100m and 100m-500m classes (Table 16). Plots ranged in microptpography from slightly to strongly mounded, on average they were moderately mounded (3.2± SD=0.72 SEM=0.22).

The fetch distance of most frequent wind direction appears to be approximately two and a half times greater that of all sample plots; at least 146.2km (± SD=165.9Km; SEM= 8.7Km). Fetch distance in the mean wind direction was at least 4.3km (± SD=52.5km; SEM= 2.0km), far less than the average across all dwarf heaths. Average maximum and minimum wind speeds were lowest for this association, ranging between 7m/s and 7.7m/s on average with less than 1m/s SD or SEM.

Plots were considerably farther from the coast than those within other associations; 99.5m ±61m SE=18.4m on average for *Juniperus communis* dwarf heaths, compared to overall mean across all plots of 75.7±61.3m SE 7.55m.

Exposed substrates represented lesser cover values in comparison with other sample plots outside this association. No exposed organic soil was observed and exposed mineral soil occurred in only one sample plot where it represented 5% cover. Bedrock was exposed in five sample plots representing on average 5.4% cover (± SD=4.7%; SEM=2.4%). Rock was exposed in three sample plots where it comprised on average 3% abundance (± SD=2.1%; SEM=1.5%).

Table 16. Environmental characteristics of *Juniperus communis* association. n represents number of observations collected from the 36 sample plots comprising this association. SD represents the standard deviation and SEM represents the standard error of the mean.

	n	Mean	SD	SEM
Mean Vegetation height (cm)	9	13.9	6.5	2.3
Mean site area (ha)	10	223.0	248.5	82.8
Easting (UTM)	12	407835.4	157047.4	47351.6
Northing (UTM)	12	4928811.3	61561.7	18561.5
Aspect (North)	11	5.3	0.8	0.2
Aspect (East)	11	3.1	1.2	0.4
Elevation (m)	12	11.7	4.6	1.4
Median slope length (m)	8	99.7	111.7	42.2
Slope position (class)	11	2.5	0.9	0.3
Slope (%)	11	20.1	13.7	4.3
Microtopography (class)	12	3.2	0.7	0.2
Average average minimum	12	7.0	0.8	0.3
Average average maximum	12	7.7	0.7	0.2
Fetch: most frequent wind	11	146.2	165.9	8.7
Fetch: mean wind (Km)	11	4.3	52.5	2.0
Distance from coast (m)	12	99.5	61.0	18.4
Exposed bedrock (%)	5	5.4	4.7	2.4
Exposed rock (%)	3	3.3	2.1	1.5
Exposed mineral soil (%)	1	5.0	N/A	N/A
Exposed organic soil (%)	0	N/A	N/A	N/A
Bedrock lithology	Meguma group: Halifax formation and Goldenville formation, Forchu group			

Soil characteristics of the *Juniperus communis* association

Summary statistics of soil variables are provided in table 17 and table 18. Mean soil depth was 25.3cm (± SD=13.7cm; SEM= 4.8cm), about 5cm shallower on average than across the mean of all sample plots (mean was 31cm ±19.9cm SE 3.26cm.) Rooting depth was also shallower; 13.5cm (±9.9cm; SEM= 3.0cm) versus that across all plots (24.5cm ±17.8cm SE 2.4cm). Humus thickness was also shallower at 16.7cm (± SD=8.6cm SEM=3cm) on average.

Percentage of organic matter of the dominant soil horizon was 59.1% (± SD= 27.4%; SEM=9.7%) , greater than average of all soil pits. pH was slightly more acidic than average (3.99 vs 4.18). Nutrient concentrations were slightly higher than average for Calcium (Ca), Potassium (K), Iron (Fe) and lower for Magnesium (Mg), and Sulphur (S), Cation Exchange Capacity was near average (Table 17) Sodium (Na) concentrations in soil were a low 65.4 ppm (± SD=89.1ppm; SEM=31.5ppm); slightly more than half (61% of) the overall average across all plots.

Drainage class was more rapid than average. The majority of plots (9/12 or 75%) were rapidly drained, two plots were well drained and one plot was moderately well drained. Moisture class was variable however, on average mesic (3.2 ± SD=1.6; SEM= 0.58), but one plot was xeric and another hygric.

Five humus forms were classified; mainly mors and two moders. 6 (50%) of plots were classified as Humimors, 2 (17%) plots were classified as Resimors and Hemimors each, one plot (8%) was classified as a Mormoder and one as a Mullmoder.

Table 17. Soil characteristics of 12 sample plots where 12 soil pits were dug. All variables were measured for 12 soil pits, *i.e.* soil chemistry data was not obtained from every pit. n represents the number of samples collected for each parameter. Salt value is based on conductivity lab testing.

Soil depth (cm)	**n**	**mean**	**SD**	**SEM**
Soil depth	9	25.3	13.7	4.8
Rooting depth	12	13.5	9.9	3.0
Humus thickness	9	16.7	8.4	3.0
Soil chemistry	**n**	**mean**	**SD**	**SEM**
% Organic matter	9	59.1	27.4	9.7
K (ppm)	9	132.7	39.9	14.1
S (ppm)	9	19.0	6.3	2.2
Mg (ppm)	9	290.8	142.8	50.5
Fe (ppm)	9	214.2	191.6	67.7
Ca (ppm)	9	617.8	584.9	206.8
N (%)	9	1.25	0.49	0.17
pH	9	4.0	0.5	0.2
Na (ppm)	9	165.4	89.1	31.5
Salt (mS/cm)	9	0.4	0.2	0.1
CEC (Meq/100g)	9	90.6	2.9	1.0
Drainage condition	**n**	**mean**	**SD**	**SEM**
Moisture class	9	2.9	1.3	0.4
Drainage class	12	1.3	0.7	0.2

Table 18. Humus form was classified at all 12 soil pits of the *Juniperus communis* dwarf heath association, including three mors and two moders. n represents the number of soil pits where a given humus form was classified. The percentage of each humus form within the association represented by n sample size is also provided.

mor	**n**	**moder**	**n**
Humimor	6	Mormoder	1
Resimor	2	Mullmoder	1
Hemimor	2		

Ammophila breviligulata dwarf heath association (n=5 plots, 4 sites, Si=0.44)

This association is most distinctive from the others in floristic species composition. The association is characterized by 15 indicator species and by high abundance of the species *Ammophila breviligulata*, *Empetrum nigrum* and several of *Cladonia* sp. lichens as well as the presence of the forbs *Hieracium* and *Lathyrus japonicas,* the mosses *Polytrichum piliferum* and *Ceratodon purpureus* and the sedge *Carex silicea.* Table 19 provides a list of indicator species and their respective frequency and abundance within the association.

Table 19. Indicator species of the *Ammophila breviligulata* association. An IndVal closer to 1 represents a species with large mean abundance within an association (specificity), and presence within most sites of the association (fidelity). P represents the probability of finding a higher indicator in random permutations. % cover values represent abundance of each species where SD represents the standard deviation and SEM represents the standard error of each mean cover value of the association. n represents species occurrences from plots belonging to this association. n - all represents the number of species occurrences across the entire study. Both the number of occurrences of species within the association and the number of occurrences of species within the total study are provided to highlight exclusivity of a number of species to this association.

Species			frequency		abundance (% cover)		
	indval	pvalue	n - all	n	mean	SD	SEM
Ammophila breviligulata	1.00	0.001	6	4	38.75	27.80	16.05
Cladina rangiferina	0.86	0.001	20	4	9.1	11.47	6.62
Cladonia gracilis	0.80	0.001	4	4	0.1	0	0
Cladonia crispata	0.69	0.002	6	4	0.1	0	0
Hieracium pilosella	0.63	0.001	9	4	0.45	0.40	0.23
Cladonia cristatella	0.60	0.001	3	3	0.2	0.17	0.12
Carex silicea	0.60	0.001	3	3	0.3	0.35	0.24
Ceratodon purpureus	0.60	0.001	4	3	0.4	0.52	0.37
Hieracium sp.	0.40	0.012	2	2	0.1	0	0
Cladonia verruculosa	0.39	0.005	3	2	0.1	0	0
Cladonia chlorophaea	0.37	0.005	6	3	0.1	0	0
Cladina stellaris	0.33	0.043	10	2	2.2	2.55	2.55
Polytrichum piliferum	0.31	0.01	4	2	0.8	0.99	0.99
Lathyrus japonicus	0.30	0.019	4	2	0.55	0.64	0.64
Cladonia digitata	0.18	0.045	3	1	0.1	N/A	N/A

Ammophila breviligulata was present in four of five sample plots, represents the greatest indicator value, and was the most abundant species of the association; 38.8% cover (± SD=27.8% SEM= 16%). *Cladonia rangiferina* had the second largest indicator species value (0.862), was found in four of five plots and was the third most abundant species having a mean abundance of 9.1% cover (± SD=11.5%; SEM=6.6%). *Empetrum nigrum* was present in all plots with a mean abundance of 24.2% (± SD=14%; SEM=7%). *Cladonia mitis* was found in all five plots where mean abundance was 3.94% cover (± SD=4.34%; SEM =2.2%). *Cladonia terrae-novae* was found one plot less frequent; in four of five plots, also with slightly lower mean abundance of 2.7% (±SD= 2.46% ; SEM=1.42%).

Eleven indicator species represented low abundance but high exclusivity to the association. Included in those are all four occurrences of *Cladonia gracilis*, all three occurrences of *Cladonia cristatella*, all three occurrences of *Carex silicea*, three of four occurrences of *Ceratodon purpureus*, two of three occurrences of *Cladonia verruculosa*, four of six occurrences of *Cladonia crispata*, two of four occurrences of *Hieracium pilosella*, three of six *Cladonia chlorophaea*, two of four occurrences of *Lathyrus japonicus*, two of ten occurrences of *Cladonia stellaris*, four of nine occurrences of *Hieracium pilosella* and both occurrences of unidentified *Hieracium* species.

Two rare lichen species were found within this association: the only occurrence of *Cladonia brevis* known from Nova Scotia. A number of exotic species were also found within the association: *Leontodon autumnalis* is known from 11 plots within our study, 2 of which belong to this association. One of two occurrences of the exotic species

Leucanthemum vulgare, was found within this association and the indicator species *Hieracium pilosella* is also an exotic species.

Sphagnum flavicomans was identified only in the Saint Pauls Island plot, where it had an abundance of 60%. Our sample plot at Saint Pauls Island was within a bog containing a lichen covered rock. Floristic similarities between this plot and the sand dunes include general crypotgamic richness and abundance. However, species composition and environmental characteristics make this sample plot sufficiently unique that I consider it an outlier and remove this plot from subsequent analyses.

Environmental characteristics of *Ammophila breviligulata* dwarf heath

Ammophila breviligulata, Cladonia rangiferina, Cladonia mitis and *Cladonia terrae-novae* and the sample plots from Sand Hills Provincial Park, Point Michaud Provincial Park and Taylor's Head Provincial park dunes exhibited strongly positive scores on RDA axis 2. Associated environmental variables include deepest soils, also deepest rooting depth, greatest % cover of exposed mineral soil and soils of lowest (most basic) pH in comparison with other dwarf heaths. Wide separation is apparent between the vector of plots, environmental characteristics and species of this association in comparison with others.

Table 20 summarizes environmental characteristics of the association. Vegetation was on average 10.8cm tall (± SD=4.9cm SEM=2.8cm), shorter than the average across all study sites. Mean site area according to SRFRS data at two study sites was 65ha (± SD=9ha; SEM=9.5ha), less than the overall dwarf heath mean of 123ha (± SD=215ha; SEM= 29.3ha). Since study sites were sand dunes, we observed the area colonized by plants and particularly that of dwarf heaths, to be far smaller at each of four sites of this association.

Mean elevation was a variable 11.2m (±SD=19.5m SEM=9.5m), 1.2m greater than the average across all sites. When Saint Pauls Island is excluded from analyses, elevations were actually far lower, on average 2.5m (± SD=0.6m; SEM=0.3m). Each dune sample plot occurred on the level slope position; therefore slope length and aspect were also 0 at each plot. Microtopography was generally micromounded but one plot exhibited moderate mounding.

Fetch distance was shortest for this association, >22.7km (± SD >43Km, SEM >24.8Km) in the direction of most frequent wind and only >0.7Km (±SD > 1.4Km, SEM >0.8Km) in the mean direction of wind. Average wind speeds were at minimum 6.8m/s ± 0.5m/s SE=0.3m/s and maximum 7.3m/s ± 0.5m/s SEM=0.3m/s.

Mean distance of sample plots to the coastline was determined by GIS to be 69.6m (± SD=22.8m SEM=13.2m). Exposed sand was the only substrate of these four sample plots, where it comprised on average 19.8% cover (± SD=18.1%; SEM= 10.4 %.)

Table 20. Environmental characteristics of *Ammophila breviligulata* association. n represents the number of observations collected from 4 sample plots comprising this association. SD represents the standard deviation of each variable and SEM represents the standard error of the mean. N/A is reported when there was no variability due to no sample size or too little a sample size. One plot from Saint Paul's Island was removed from these summary statistics as an outlier because its environmental conditions and species composition differed so widely.

	n	mean	SD	SEM
Mean Vegetation height (cm)	4	10.8	4.9	2.8
Mean site area (ha)	1	58.3	N/A	N/A
Easting (UTM)	4	450306.0	190937.1	110237.6
Northing (UTM)	4	4914732.5	111582.4	64422.1
Aspect (North)	1	6.1	N/A	N/A
Aspect (East)	1	1.4	N/A	N/A
Elevation (m)	4	2.5	0.6	0.3
Median slope length (m)	1	0.0	N/A	N/A
Slope position (class)	4	2.3	2.9	1.7
Slope (%)	4	3.5	7.1	4.1
Microtopography (class)	3	1.7	1.2	0.8
Average average minimum wind speed (m/s)	4	6.8	0.5	0.3
Average average maximum wind speed (m/s)	4	7.3	0.5	0.3
Fetch: most frequent wind (Km)	4	22.7	43.0	24.8
Fetch: mean wind (Km)	4	0.7	1.4	0.8
Distance from coast (m)	4	69.6	22.8	13.2
Exposed bedrock (%)	0	N/A	N/A	N/A
Exposed rock (%)	0	N/A	N/A	N/A
Exposed mineral soil (%)	4	19.8	18.1	10.4
Exposed organic soil (%)	0	N/A	N/A	N/A

Sand dune soil

All plots (save for Saint Paul's island outlier) occurred on Aeolian coastal sand dunes. Dune soils were comprised exclusively of horizons of coarse grained sand, sometimes with organic staining in upper horizons or sparse litter cover. No established humus was encountered. Soil characteristics of this association are summarized in table 20.

Soil depth exceeded 100cm in depth at each of four soil pits, greater than the mean of all sample plots was 31cm (± SD=19.0cm ; SEM=3.26cm) . Mean rooting depth was 52.4cm (± SD=23.7%; SEM= 11.9%), more than twice the dwarf heath average of 24.5cm(± SD=17.8%; SEM=2.4%). On average, exposed sand comprised 15.81% (± SD=18%; SEM=9% cover).

pH of soils are acidic, though less acidic than those of other sample plots. Mean pH for soil plots of this association was 5.32 (±SD=0.33; SEM= 0.19), greater than the overall dwarf heath mean of 4.17(± SD=0.62; SEM=0.09).

Organic matter content was extremely low. Cation Exchange Capacity (CEC) was below average. The concentrations of all nutrients were far below overall dwarf heath average (Table 20). Salt content of soil was considerably less than the average across dwarf heaths; 0.025 ppm Na a vs 1.25 ppm Na overall.

Drainage conditions were exclusively rapid. Moisture class keyed to xeric at each sample plot.

Table 21. Soil characteristics of 4 sample plots where 4 soil pits were dug. Soil pits were not completed at Saint Paul's Island and this plot was excluded from analyses. n represents the number of samples collected for each parameter – all parameters were measured for each soil pit. Salt value is based on conductivity lab testing. SD represents the standard deviation and SEM the standard error of the mean for each variable.

Soil depth (cm)	**n**	**mean**	**SD**	**SEM**
Soil depth	4	>100	0.0	0.0
Rooting depth	4	50.5	26.9	15.6
Humus thickness	0	N/A	N/A	N/A
Soil chemistry	**n**	**mean**	**SD**	**SEM**
% Organic matter	4	1.4	1.7	1.0
CEC (Meq/100g)	4	84.3	0.5	0.3
K (ppm)	4	13.0	3.5	2.0
S (ppm)	4	4.5	1.7	1.0
Mg (ppm)	4	16.5	13.8	8.0
Fe (ppm)	4	78.8	40.6	23.4
N (%)	4	0.0	0.1	0.0
Ca (ppm)	4	25.0	13.0	7.5
pH	4	5.3	0.3	0.2
Na (ppm)	4	0.0	0.1	0.0
Salt (mS/cm)	4	0.0	0.0	0.0
Drainage condition	**n**	**mean**	**SD**	**SEM**
Moisture class	4	1	0	0
Drainage Class	4	1.0	0.0	0.0

Unique or dissimilar communities (n=14 plots, 11 sites, Si=0.44)

This group is comprised of sample plots that did not fit into the classification scheme, as indexed by a negative Si score: -0.08 (Figure 7). Four of 14 plots (Figure 7) have relatively high negative Si scores between -0.1 and -0.08 suggesting possibility of some commonality between those plots and other classification groupings. These plots include Gardens, Blue Rocks, Meat Cove and Lohnes Head. The ten other sample plots have Si scores between -0.1 and -0.2, suggesting high dissimilarity in species composition, abundance and frequency from all other dwarf heath sites.

Associated species: largest proportion of rare and exotic species

Table 22 Indicator species and associated values for Unique or dissimilar communities group. An IndVal closer to 1 represents a species with large mean abundance within an association (specificity), and presence within most sites of the association (fidelity). P represents the probability of finding a higher indicator in random permutations.Presence of either of these two species should not necessarily be considered a strong indication of this grouping because species composition is highly variable. *Coptis trifolia* is exclusive to one community type comprised of 8 sample plots described later as associated with high graminoid and forb cover, but was not found in any other sample plots. *Festuca rubra* is commonly occurring, but co-dominant within another community grouping of sample plots (described later).

	IndVal	**pvalue**
Festuca rubra	0.58	0.016
Coptis trifolia	0.21	0.03

Two indicator species are representative of this grouping of sample plots.The grass, *Festuca rubra* was found in a total of 36 sample plots throughout our study, 10 of which belong to this dissimilar group. Mean abundance of *Festuca rubra* was 9.7% cover (± SD=16.1%; SEM=5.4%). At Louisbourg and at Sober Island, abundance of *Festuca rubra* was 40% cover in each plot. All three occurrences of the indicator species *Coptis* *trifolia* were recorded from sample plots within this association where it occurred in low abundance: 0.1% in each sample plots where it was found.

The dissimilar group contained the highest number of exotic and rare species. This group contained 90% of the exotic species (18 of 20 species) recorded. At Meat Cove, we found 11 exotic species, more than at any other sample plot. The dissimilar group also contained 46% (six of 13) of rare species, more rare species than any other group. This included five of 18 study sites known to contain rare species. The six species included; *Dicranum condensatum, Salix glauca, Silene acaulis, Hudsonia ericoides, Shepherdia canadensis,* and *Poa glauca.* The dissimilar group included a large number of sample plots containing the range restricted species *Corema conradii*.

Mean species richness/plot was ten (10) species, less than half the overall dwarf heath average of 22 species.

Environment

Sites within this group include all of those that occur at the Northernmost extreme of Nova Scotia, specifically those plots from Meat Cove at the tip of the Cape Breton Highlands, and Saint Paul's Island. Plots were not limited in geographical range as several also occurred from Southwestern Nova Scotia.

As a group, environmental characteristics of the association are extremely variable. There are no obvious consistent trends. Site area was somewhat less than the overall average; 98.5 ha (± SD= 116.5ha; SEM=35.1ha) vs 123.5 ha between the average of all sample plots. Mean elevation was 15.2m (±SD=15m SEM=4.16m), 5.2m higher than the overall mean of 10m. Distance to the coast was slightly greater, 98.5m(±SD=77.3m; SEM=21.5m) vs the overall mean of 75.7m. Mean slope length was 74m(±SD=89.8m; SEM=29.9m), longer than the overall mean of 13.7m. Slope gradient was 16.5%(±SD=23.4%; SEM=6.5%), higher than the overall mean of 14 degrees. I was not able to identify all bedrock types, but slate, granite and some other metamorphosed bedrock types.

Soil

Soil surveys were not performed in ecologically sensitive areas, so humus classification is based from soil pits dug at half (7 of 14) of the sample plots. At one of these soil pits (Blue Rocks), one of four occurrences of charcoal was observed. Mean soil depth was 23.4m, shallower than the overall mean soil depth of 31m. Organic matter concentration was nearly equal to the mean across all sites as was CEC (91.3 Meq/100g ± 5.12 Meq/100g SE= 2.1 Meq/100g vs 90.4 Meq/100g). Nutrient concentrations did not differ strongly from the mean, save for Magnesium; 388.14ppm (±SD= 295.9ppm; SEM=120.8 ppm) vs 327.31ppm . Mean pH was 3.9, marginally more acidic than the overall mean of 4.18.

Table 23. Humus classification at 7 sample plots where soil was measured.

Humus type	Frequency
Hemimor	2
Humimor	3
Hydromor	1
Resimor	1

Trends in species composition and designation of three subgroups

In addition to high dissimilarity from other associations, sample plots greatly differ from each other in both species composition patterns and environmental characteristics. Several plots do not contain either indicator species and there are a high number of unique species. On closer inspection, some plots do share commonalities.

Alternative groupings reduce optimization according to plotting of silhouette heights and the plots remain misclassified (negative Si scores, unclear jumps in fusion levels) when the dendrogram is cut at different levels. Additional groupings provide sample sizes that are also too small to be definitive, *i.e.* less than 5 (Wildi 2011).

Despite these indications of poor statistical power, several trends in species composition were observed when the group was subdivided into three subgroups at a dendrogram branching height of approximately 1.5. I describe these groups for purposes of interpretation and exploration of community differences when trends were apparent and unique plots separately.

Corema conradii, Gaylussacia baccata community (n=3 sample plots, 3 sites)

Three sample plots at Blue rocks, The Gardens and Lohnes Head were connected in one branch of the dendrogram. These three plots also exhibited the highest within group negative Si values, suggesting the plots themselves are more similar to each other (within the context of a misclassified grouping), and to others in the study in that they are nearer to 0.

The three plots are floristically similar to each other in the consistent presence and high abundance of *Corema conradii* and *Gaylussacia baccata. Corema conradii* had

85%, 28% and 30% cover at Blue rocks, The Gardens and Lohnes Head, respectively. Outside of this grouping, the species was located at five other sample plots across the dwarf heaths, in lower abundance; at Peggys Cove with 25% abundance, and at no other plot of abundance greater than 9% cover. *Corema conradii* was not found within other sample plots belonging to the dissimilar communities group.

Gaylussacia baccata was found with abundances of 7%, 5% and 55% cover at Blue rocks, The Gardens and Lohnes Head, respectively. *Gaylussacia baccata* was found in 10 other sample plots within the dwarf heaths but was not found within other sample plots belonging to the dissimilar communities group. It was found in abundance greater than 10% at three other sites belonging to other classified groups; Western Head and Southwest Cove and Pennant Point where it was found with 8% and 7% cover.

Nine other species were faithful to these three plots in addition to the aforementioned species of highest abundance: *Vaccinium angustifolium*, *Photinia floribunda, Maianthemum canadense, Kalmia angustifolia*, *Juniperus communis*, *Gaylussacia baccata*, *Gaultheria procumbens, Corema conradii, and Cladonia boryi.*

These plots also have high abundance of *Cladonia* lichens. *Cladonia* spp. cover accounts for 5, 13 and 79% cover across the three sites. *Cladonia*s are absent in several other other plots in the dissimilar group, and where found, their abundance does not exceed 31% cover in any other given plot. The only bryophytes identified within this group were mosses of the genus *Dicranum* or *Polytrichum.*

Dissimilar community group indicator species were scarce within these plots. *Festuca rubra* L. was present only at the Gardens plot, where it was present with 0.2%

abundance. *Coptis trifolia,* an indicator species of the dissimilar group, was not present within these three plots.

Environment and soils characteristics of *Corema conradii* and *Gaylusaccia baccata* plots

Both *Corema conradii* and *Gaylusaccia baccata* associate closely with environmental variables of the *Juniperus communis* association within the RDA (Figure 5) Within the RDA, sites of the *Corema conradii*- *Gaylussacia baccata* community are projected at positive RDA 3 scores. Associated environmental variables include steeper slopes and higher elevations (Figure 5).

Mean vegetation height within these plot is 19.4cm(± SD=1.4cm; SEM=1cm), nearly twice the overall dwarf heath average of 13.3cm, and of the larger misclassified associations average of 10.8cm.

Three sites are located along Central Nova Scotia's coastline within Lunenburg and Southern Halifax counties. *Corema conradii* has a limited geographical range and was not reported from Southern and Northern extremes of the province. Site area was on average 220.8 ha (± SD=271.8ha; SEM=192.2 ha). This was highly variable and with low sample size difficult to be conclusive but on average these plots were located in sites about twice the hectarage of others. Elevation was on average 14m (±SD=14.9m SEM=10.6m).

These plots were located on steep upper to crest slopes: the plot at Blue rocks was located along an upper slope of 17.6 degrees and the plots at The Gardens and Lohnes Head were located on the crest of slopes. Slope length and grade were variable (Table X).

Fetch at the three sites was only around 300m in the mean direction of wind, but a variable >130.9 Km (± SD=226.5Km; SEM=160.2Km) in the most frequent wind direction. Average wind speed was lower than average ranging from 6.3m/s to 7.2m/s on average. Distance from the coast was on average 147.5m (± SD=100.4m; SEM= 71m) for these three plots, larger than the overall average of 75.7 across all sites.

Blue Rocks and Lohnes Head plots contained 6 and 7% exposed bedrock, and the Gardens contained 35% exposed rock. No other sites within the unique communities 14 plots contained exposed bedrock, though exposed rock was a factor in 6 of the other sites within the group of unique communities group.

Soil depth was on average 17cm (±SD=14.1cm; SEM=10cm), shallower than the overall average of 31cm. Humus depths were almost negligible at Blue Rocks and Lohnes head (7cm where soil existed) where bedrock was shallow to the surface. Soil depth was 27cm at the Gardens, but within the plot were large areas of exposed granite boulder.

Salt content was considerably lesser than overall average; 51ppm Na (± SD=8.7ppm; SEM= 6.16ppm), vs 270.9ppm. Magnesium concentration was considerably lower than overall average (161.3ppm vs 327.3ppm) all other nutrients were similar in concentration. Mean pH was acidic but lower for these three plots; 3.7 at each, while mean pH for the group was 4.1 for other groups. Humus types included two Hemimors and a Humimor. The soil pit at Blue rocks was one of four plots within this study where charcoal was identified.

Table 24. Environmental characteristics of *Corema conradii - Gaylussacia bacata* community. n represents the number of samples collected per variable SD represents standard deviation and SEM represents standard error of the mean.

	n	mean	SD	SEM
Mean Vegetation height (cm)	3	19.4	1.4	1.0
Mean site area (ha)	3	220.8	271.8	192.2
Easting (UTM)	3	401004.3	25570.1	18080.8
Northing (UTM)	3	4910814.0	26498.6	18737.3
Aspect (East)	3	2.2	0.5	0.3
Aspect (North)	3	5.9	0.2	0.1
Elevation (m)	3	14.0	14.9	10.6
Slope position (class)	3	1.3	0.6	0.4
Median slope length (m)	3	39.2	35.0	24.8
Slope (%)	3	10.6	9.3	6.6
Microtopography (class)	3	2.3	1.2	0.8
Average average minimum wind speed (m/s)	3	6.3	0.3	0.2
Average average maximum wind speed (m/s)	3	7.2	0.3	0.2
Fetch: mean wind (Km)	3	0.3	0.4	0.3
Fetch: most frequent wind (Km)	3	130.9	226.5	160.2
Distance from coast (m)	3	147.5	100.4	71.0
Exposed bedrock (%)	2	6.5	0.7	0.7
Exposed rock (%)	1	35.0	N/A	N/A
Exposed mineral soil (%)	0	N/A	N/A	N/A
Exposed organic soil (%)	0	N/A	N/A	N/A

Table 25. Soil characteristics of *Corema conradii* - *Gaylussacia bacata* community. n represents the number of samples collected per variable.SD represents standard deviation, SEM represents standard error of the mean.

Soil depth (cm)	**n**	**mean**	**SD**	**SEM**
Soil depth	3	17.0	14.1	10.0
Rooting depth	3	17.7	11.6	8.2
Humus thickness	3	11.2	7.8	5.5
Soil chemistry	**n**	**mean**	**SD**	**SEM**
% Organic matter	3	48.9	20.2	14.3
CEC (Meq/100g)	3	87.7	2.5	1.8
K (ppm)	3	139.0	42.5	30.0
S (ppm)	3	19.7	2.3	1.6
Mg (ppm)	3	161.3	64.5	45.6
Fe (ppm)	3	221.0	96.8	68.4
N (%)	3	0.9	0.4	0.3
Ca (ppm)	3	420.0	390.5	276.1
pH	3	3.7	0.0	0.0
Na (ppm)	3	51.0	8.7	6.2
Salt (mS/cm)	3	0.3	0.1	0.1
Drainage condition	**n**	**mean**	**SD**	**SEM**
Drainage Class	3	2.0	1.7	1.2
Moisture class	3	2.7	1.5	1.1
Presence of charcoal	1	N/A	N/A	N/A

Herbaceous - *Empetrum nigrum* communities (n=8, 7 sites)

This subgroup is characterized by high frequency, abundance and species diversity of graminoids and herbs. While the most common species to the dwarf heaths in general (frequency, abundance) remain the most common in this group, there is a high number of unique species per plot. The highest proportion of rare species and the highest proportion of exotic species were found within this group of plots. Environmental conditions appear to be more exposed than many other plots. Sample plots were located in more Northern locations of the province and oriented at more Northerly and Easterly aspects than any others in our study.

Average richness per plot was 22.9 species, near the overall dwarf heath average. In total 98 species were found in 8 sample plots; meaning a total richness of 12.25 different species/plot or that 12.25/22.9 = 53% of species per plot were unique within those plots, including many exotic or rare species. Only four species occurred in more than half of sample plots belonging to this sub association: *Empetrum nigrum, Fesuca rubra, Juniperus communis* and *Symphyotrichum novi-belgii. Empetrum nigrum* was found at mean abundance of 15.1% cover (±SD=15.1% SEM= 11.3%). *Festuca rubra* was found at mean abundance of 1.7% cover (±SD=1.9%, SEM=0.85%). *Juniperus communis* was found at 4.6% cover ± (SD=6.5%; SEM= 2.32%). *Symphyotrichum novi-belgii* was found at 2.5% cover (± SD= 4.8%; SEM=2.39%).

Save for *Empetrum nigrum*, the most abundant species were found in only one to three sample plots, *i.e*. there was high turnover. Exceptionally abundant species were: *Sphagnum flavicomans* at 60% cover in one plot, *Cornus candensis* with a mean cover from three plots of 41.7% (± SD=37.5%; SEM=26.5%), *Iris setosa* with 37% cover in one plot and *Cladonia boryii* with 25% cover in another plot.

Coptis trifolia was found exclusively within three sample plots; Saint Pauls Island 3163, Baccaro Lighthouse 3066, and Arnold 3070, where it had an abundance of 0.1% cover at each sample plot. *Cornus canadensis* was found in exceptionally high abundance within two sample plots; at Middle Head (3116) and Louisbourg (3124), it occurred in 40% and 80% cover respectively.

The distribution of life forms also differed throughout the eight plots in comparison with other dwarf heath plots. Herbs accounted for 42% of species identified (vs. overall dwarf heath total of 26%), and Graminoids made up 20% of species identified (vs 14% overall average), lichens comprised only (vs. 17% across all dwarf heaths) and shrubs maintained 17% proportion of species identified (vs 17% across all dwarf heaths).

Environment of herbaceous plots

Within the RDA, sites of the herbaceous and grassland community are projected along negative RDA 3 scores, associated along the same vector as increased distance from the coast and also long fetch distance in the direction of most frequent wind (Figure 5).

Table 26 presents summary statistics of environmental conditions within sample plots. Vegetation height was only measured at 3 sample plots within this group where it had a mean of 11.1cm, shorter than the overall mean of 13.2cm.

Site area was on average smaller than the overall dwarf heath mean (81.6 ha vs 123.5ha). Sites were not limited in geographical distribution but most sample plots were located in the extreme North of the province. Two plots are from Meat Cove, the Northernmost tip of Cape Breton, and two plots are located from Saint Pauls Island, the Northernmost island belonging to Nova Scotia (approximately 30KM north of Cape Breton), another plot is located at Louisbourg, at the Northeastern tip of Cape Breton. The remaining two plots were located at peninsular sites on the South Shore of Nova Scotia; Baccaro and Arnold. The aspect of plots differed in also being more Easterly and Northerly oriented than others.

Mean elevation was 20.25m (±SD=16.2m; SEM=6.1m), twice the overall average of 10m. Slope gradient was steeper on average 22.7% (±SD=29.4%;

SEM=11.1%), nearly twice (1.6x) the mean of all sample plots. Microtopography was only slightly mounded on average.

Fetch distance was extremely variable in the direction of mean wind: >5.6Km (±SD >20.2Km; SEM>90.3Km). Fetch in the direction of most frequent wind was at least twice as far as average; > 134.4Km (± SD > 201.9 Km; SE>90.3Km. Average windspeeds are higher at these sample plots than across other dwarf heaths. Mean average minimum wind speed was 8.8 m/s vs the overall average of 7.5 m/s, average maximum wind speed was 9 m/s vs the overall average of 8 m/s. This wind speed represents a fresh breeze on the Beaufort scale (next greatest windspeed from moderate breeze).

Of 8 sample plots, soil pits were dug at only 2 locations, and those two were at our southerly sites, therefore should not be considered representative of the group. Rooting depth was deeper than average; mean of 32.5cm vs the overall average of 24.4cm. Humus types included 1 Hydromor and 1 Resimor. Distance to the coast was also greater than average; 105.1m vs 75.7m across all plots. Salt content was lower than average (0.75 per na vs 1.24 per na). Concentrations of nutrients were lower than average for all but Magnesium. Mean drainage condition was (3) moderately well, poorer than average across dwarf heaths (2.27).

Table 26. Environmental characteristics for the herbaceous dwarf heath sample plots. Environmental characteristics were measured at all eight sample plots. n represents the number of samples collected, SD represents the standard error and SEM represents the standard error of the mean for each variable.

	n	**mean**	**SD**	**SEM**
Mean Vegetation height (cm)	3	11.1	1.2	0.9
Mean site area (ha)	7	81.6	66.2	27.0
Easting	3	456316.3	240005.7	169709.6
Northing	3	4913118.3	149314.5	105581.3
Aspect (East)	6	4.3	1.1	0.5
Aspect (North)	6	4.4	1.0	0.4
Elevation (m)	8	20.3	16.2	6.1
Median slope length (m)	4	76.3	47.5	27.4
Slope position (class)	7	2.4	1.8	0.7
Slope (%)	8	22.7	29.4	11.1
Microtopography (class)	7	2.0	1.2	0.5
Average average minimum wind speed (m/s)	8	8.8	1.0	0.4
Average average maximum wind speed (m/s)	8	9.0	0.7	0.3
Fetch: most frequent wind (Km)	6	134.4	201.9	90.3
Fetch: mean wind (Km)	6	5.8	201.9	90.3
Distance from coast (m)	8	105.1	72.3	27.3
Exposed bedrock (%)	0	N/A	N/A	N/A
Exposed rock (%)	5	6.2	5.5	2.8
Exposed mineral soil (%)	1	5	N/A	N/A
Exposed organic soil (%)	0	N/A	N/A	N/A

Table 27. (Limited)Soil characteristics for the grassland and herbaceous dwarf heath community type where soil pits were dug. Soils data was only collected from two sample plots because of sensitive habitat, legal permissions and time constraints and therefore soils data is not adequately representative. n represents number of samples collected.

Soil depth (cm) – South sites	**n**	**mean**	**SD**	**SEM**
Soil depth	1	36	N/A	N/A
Rooting depth	4	32.5	18.6	10.7
Humus thickness	2	31.5	6.4	6.4
Soil chemistry – South sites	**n**	**mean**	**SD**	**SEM**
% Organic matter	2	59.2	46.1	46.1
CEC (Meq/100g)	2	91.0	5.7	5.7
K (ppm)	2	71.5	40.3	40.3
S (ppm)	2	24.0	19.8	19.8
Mg (ppm)	2	473.0	466.7	466.7
Fe (ppm)	2	109.0	75.0	75.0
N (%)	2	0.9	0.5	0.5
Ca (ppm)	2	444.0	339.4	339.4
pH	2	4.0	0.7	0.7
Na (ppm)	2	153.5	118.1	118.1
Salt (mS/cm)	2	0.1	0.0	0.0
Drainage condition	**n**	**mean**	**SD**	**SEM**
Drainage Class	5	3	1.2	0.6
Moisture class	2	6	0	0

***Festuca rubra* and *Sibbaldiopsis tridentata* communities n=3, 3 sites)**

Summary

Within the RDA, plots belonging to *Festuca rubra – Sibbaldiopsis tridentata* community are located with wide spread on Axis 1, but negative scores on axes 2 and 3. There are only three sample plots and their wide spread on axis 1 does not provide much resolution but a few general trends. Sample plots are relatively near those of *Empetrum nigrum.* Associated environmental variables with those plots and with *Festuca rubra* are exposed rock and bedrock, higher salt concentration and higher CEC (Figure 5).

This community type is dominated by grasses, largely *Festuca rubra*. Only three shrubs were identified: *Juniper communis* in two plots and *Empetrum nigrum* in one plot. *Vaccinium vitis-idaea* was indentified in all three sample plots. The majority of species were graminoids, forbs lichens or mosses; 32% of species were herbs, 20% were lichens, 17% graminoids and 18% mosses.

The three sample plots where it was found exhibited no geographical restriction; occurring across the Eastern shore of Nova Scotia through Cape Breton. Each plot was very near to the coast oriented at an aspect facing the coast along slopes of generally shallow gradient. Sample plots were low in elevation. Soil testing showed these sample plots were high in salinity. Nutrient status of the soils was also relatively high especially for Magnesium and Calcium. Cation Exchange Capacity was also relatively high.

Plant community within *Sibbaldiopsis tridentata* and *Festuca rubra* sample plots

Average richness was 19.3 species per plot. Total community richness is represented by 40 species, and of this 49, most were not shared between plots.

Approximately 69% (13.3) of species were not shared between plots. However, five species were present in all three sample plots and these five also had the highest mean abundance, save for *Empetrum nigrum* and *Carex panicea* which had high abundances found in one plot each only; 35% cover at Sober Island 3080 and 9% cover at Louisbourg 3090, respectively. The most frequent and abundant species were: *Festuca rubra, Sibbaldiopsis tridentata, Vaccinium vitis-idaea, Danthonia spicata,* and *Symphyotrichum novi-belgii* (table 28).

Table 28. Most frequent and abundant species of *Fesuca rubra* community. n represents the number of occurrences of a given species.

Species	n	mean	SD	SE
Festuca rubra	3.0	5.0	1.7	1.2
Danthonia spicata	3.0	2.2	1.7	1.2
Sibbaldiopsis tridentata	3.0	1.6	1.2	0.9
Symphyotrichum novi-belgii	3.0	1.5	1.3	0.9
Vaccinium vitis-idaea	3.0	0.8	1.1	0.8

Environmental and soil characteristics of *Festuca rubra and Sibbaldiopsis tridentata* sample plots

Vegetation height was slightly shorter than average; 10.6cm (± SD=1.3cm; SEM=0.9cm). Sites were about half the size of average, but highly variable: 56.2ha (±SD= 77.4ha; SEM=54.7ha). There was no geographical restriction between the three sample plots of this community. Mean elevation was 3m(±SD=1m; SEM=0.7m), considerably lower than the average of 10m. Slope position was variable; middle and upper. Slope length of these three sample plots was highly variable; 0m, 17.5m and 300m. Slope gradients were generally shallower (0, 3.5 and 14 degrees vs 14 degrees). All three sample plots aspects faced the coast. Two plots were micromounded and one plot was moderately mounded.

Fetch distance was on average smaller in comparison with other sample plots, at least 134.4Km (±SD=0.2Km; SEM=0.09 Km) in the direction of most frequent wind and 59Km (± SD=102.1Km; SE=72.2Km) in the direction of mean wind. Wind speeds were slower than average ranging between 6.8m/s and 7.5m/s on average.

Distance to the coast was on average 32.2m (± SD=11.8m; SEM=8.3m), shorter than the mean across all sites of 75.7m. Exposed rock was present in all three plots with mean cover of 2.3 %(± SD=4%; SEM= 8.3%).

At two of three locations, a soil pit was dug. In each, humus type was classified as a Humimor. Soil depth was 16 cm and 31 cm resulting in a mean of 23cm, less than the overall average across dwarf heaths. Drainage class varied; rapid in one plot and imperfect in another. Salt content is notably higher than average. In one plot, salinity was 1113 ppm, in another 416ppm, while the average across all sites is 270.9 ppm. Cation Exchange Capacity and the concentration of all nutrients in soil was higher, especially in the case of Magnesium and Calcium, where concentrations were nearly double the overall average. pH was slightly higher than average.

Table 29. Environmental characteristics of *Festuca rubra* and *Sibbaldiopsis tridentata* sample plots where n represents the number of samples collected, SD represents the standard deviation and SEM represents the standard error of the mean.

	n	mean	SD	SEM
Mean Vegetation height (cm)	3	10.6	1.3	0.9
Mean site area (ha)	3	56.2	77.4	54.7
Easting (UTM)	3	621638.7	98041.6	69325.9
Northing (UTM)	3	5012006.0	64162.3	45369.6
Aspect (East)	2	3.8	1.5	1.5
Aspect (North)	2	4.8	1.2	1.2
Elevation (m)	3	3.0	1.0	0.7
Median slope length (m)	3	105.8	168.4	119.1
Slope position (class)	3	1.7	1.5	1.1
Slope (%)	3	5.9	7.3	5.2
Microtopography (class)	3	1.7	1.2	0.8
Average average minimum wind speed (m/s)	3	6.8	0.6	0.4
Average average maximum wind speed (m/s)	3	7.5	0.5	0.4
Fetch: most frequent wind (Km)	3	134.4	.2	.09
Fetch: mean wind (Km)	3	59	102.1	72.2
Distance from coast (m)	3	4	4.1	2.9
Exposed bedrock (%)	0	N/A	N/A	N/A
Exposed rock (%)	3	2.3	4.0	2.9
Exposed mineral soil (%)	0	N/A	N/A	N/A
Exposed organic soil (%)	0	N/A	N/A	N/A

Table 30. Soil characteristics of *Festuca rubra* community where n represents the number of samples collected, SD represents standard deviation and SEM represents standard error of the mean.

Soil depth (cm)	**n**	**mean**	**SD**	**SEM**
Soil depth	2	23.5	10.6	10.6
Rooting depth	2	21	7.1	7.1
Humus thickness	2	15.5	0.7	0.7
Soil chemistry	**n**	**mean**	**SD**	**SEM**
% Organic matter	2	46.2	64.6	64.6
CEC (Meq/100g)	2	97.0	2.8	2.8
K (ppm)	2	181.0	38.2	38.2
S (ppm)	2	21.5	12.0	12.0
Mg (ppm)	2	643.5	6.4	6.4
Fe (ppm)	2	252.0	158.4	158.4
N (%)	2	0.8	1.09	1.09
Ca (ppm)	2	858.0	141.4	141.4
pH	2	4.3	0.2	0.2
Na (ppm)	2	764.5	492.9	492.9
Salt (mS/cm)	2	0.6	0.1	0.1
Drainage condition	**n**	**mean**	**SD**	**SEM**
Drainage Class	2	2.5	2.1	2.1
Moisture class	2	3.5	0.7	0.7

DISCUSSION

The goal of this thesis was to classify and describe dwarf heath community types on the coastal barrens of Nova Scotia and to identify and quantify environmental factors that explain variation in their community composition, diversity and distribution. This study is the first numerical classification of barrens communities in Nova Scotia. In surveying the entire distribution of coastal barrens in Nova Scotia, this study represents the largest geographical representation of barrens in Nova Scotia to date, allowing for better geographical comparison and evaluation of the conservation status of plant communities in Nova Scotia.

Through cluster analyses, I identified three distinctive dwarf heath plant communities and several variants. The plant communities I describe may be used to inform landscape decision making in the future, especially in the context of conservation work. This study greatly expands our floristic knowledge of coastal barrens. This study identifies the largest vascular species richness yet described, and also includes the first inventory of liverwort species on coastal barrens in Nova Scotia; an important contribution to overall biodiversity that was previously overlooked. Within the overall inventory are also several rare species and new provincial occurrence records. A list of rare species is provided in Appendix 2, but it is important to note that these records were only those from within our sample plots and we encountered other rare species during this study.

This study serves to greatly expand our understanding of the soils on the coastal barrens. Being unsuitable for agriculture, provincially mapped ‘Rockland soils’ are the least described. Rockland soils are vaguely known for their stoniness and unsuitability for agriculture. Burley (2009) and also Oberndorfer (2009) described basic chemistry, moisture and soil depth information for a limited number of plots on a limited number of sites. This study presents a complete inventory of humus classes, salinity ranges, and soil chemistry profiles of coastal dwarf heaths. We identified nationally rare and vulnerable follisols (Fox and Tarnocai 2011)

Dwarf heath flora

Species richness largely from five vascular plant and lichen families

Total species richness of dwarf heath plant communities largely belongs to five plant and lichen families (in order: Cladoniaceae, Asteraceae, Ericaceae, Poaceae, Rosaceae), the remainder of species were sparsely distributed through 61 other families.

The lichen family Cladoniaceae includes 29 species (12% of total richness), making it the most speciose family within this study. Species of the *Cladonia* genus grow on a number of substrates (e.g, soil, peat, woody debris, rock). As poor competitors with vascular plants, they thrive in microhabitats that are too harsh for vascular plants to survive (Brodo *et al*. 2001). The second most species rich lichen family was Parmeliaceae, containing nine other lichens, though frequency and abundance of this family was exceptionally low.

The vascular plant family Asteraceae is next speciose, comprised of 24 species (9.7%), a group known largely from open habitats across a spectrum of soil conditions (Roland and Zinck 1998). In our inventory, the largest genera of Asteraceae is *Solidago*, species from which are generally known to generally inhabit dry, open habitats save for two frequently encountered microhabitat specific species: Bog goldenrod (*Solidago uliginosa*) and Seaside goldenrod (*Solidago semprevirens*). (Roland and Zinck 1998). Asters were also frequent, especially *Symphyotrichum novi-belgii*; the third most frequent species identified and ubiquitous throughout Nova Scotia. In the dwarf heaths, it appears in a stunted growth form. Bog Aster *(Aster nemoralis)* is specific to bog habitats and was also frequently encountered on our study sites. The *Hieracium*s, though less frequent, comprise a large proportion of species belonging to Asteraceae. These species are associated with well drained to dry sites and are also often exotic pasture species (Roland and Zinck 1998).

Eighteen species (7.3%) belong to the heath family, Ericaceae. This family is most commonly associated with barren habitats and heathlands in general are named after the heath species. Ericaceous plants are associated with bogs, acid soils and woodlands throughout Atlantic Canada (Hinds 1998). They have adapted mycorrhizal associations to cope with those nutrient deficient conditions (Gurevitch *et al* 2002).

Grasses (Poaceae) were represented by 18 species. Grasses have very broad ecological characteristics as a family, however *Festuca rubra*, *Danthonia spicata*, and *Agrostis scabra* were three of the top ten most frequent species identified in the dwarf heaths. *Festuca rubra* is known from pastures, highly exposed habitats, beaches and upper zones of salt marshes. *Danthonia spicata* is known from poor soils and dry cliff ledges (Hinds 1998). On barrens, these habitats overlap at the edge of the contiguous barrens with the rock-crack salt spray zone, where these species were most often observed. *Agrostis scabra* inhabits a broad moisture gradient (Mittlehauser *et al*. 2010).

The next most speciose families were Rosaceae, Dicranaceae and Sphagnaceae. The rose family (Rosaceae) was made up of 18 species (7.3% of total richness). Nine species belong to moss families Dicranaceae, and Sphagnaceae, representing 3.6% of total species richness each.

The most common species on dwarf heaths align with previous findings

The most frequent species I identified on the dwarf heaths largely with previous findings with similar studies sites within the province. This study supports Oberndorfer and Lundholm (2009)'s findings that showed *Empetrum nigrum* and *Juniperus communis* to be the most frequent and abundant across all plant community types on Nova Scotia coastal barrens. The three most dominant species on coastal barrens according to the Nova Scotia Museum of Natural History (Davis and Browne 1996) include *Cladonia* spp, *Corema conradii* and *Empetrum nigrum*. In this study, *Corema conradii* was only found in a small subset of plots, though casually observed within several study sites to be of greater frequency and abundance.

In contrast with Oberndorfer and Lundhom (2009), the shrubs, *Gaylussacia baccata, Corema conradii*, *Ledum groenlandicum,* and the fern *Osmunda cinnamomea* were absent from our 15 most frequent and abundant list. These four species were observed at our field sites and within dwarf heaths in lesser frequency and abundance. The most frequent graminoid and herbaceous species were: *Symphyotrichum novi-belgii*, *Sibbaldiopsis tridentata*, *Festuca rubra, Danthonia spicata*, and *Agrostis scabra* and the shrub *Morella pensylvanica* was of abundance on the dwarf heaths.

Rare species are concentrated in Northern sites and on sand dunes

Our inventory of rare species (Appendix 2) is not comprehensive. This is because our releve style plot sampling design does not have large within-site coverage and because the diversity of microhabitats throughout a coastal barren site was not explicitly targeted within each site. Some rare species we encountered outside of sample plots had highly specialized habitats in areas we did not sample. For example, *Cochlearia tridactylites* (Scurvy grass) ranked S1 by ACCDC, is only known in Nova Scotia from rock cracks within the salt spray zone (Benjamin and Newell 1985). Additional rare species including *Cochlearia tridactylites* were recorded from field sites we surveyed, but not captured within our sample plots.

In Nova Scotia, bryophytes are underreported and understudied. This has historically made it difficult to assess the conservation status of these species on coastal barrens (Oberndorfer and Lundholm 2009). The conservation statuses of bryophytes have since been resolved making this less of an issue. Our study contributes additional records of more common species and those which have recently been delisted (*e.g. Racomitrium lanuginosum.* I discovered three occurrences of the S1 ranked *Dicranum condensatum,* a rarespecies in both Nova Scotia and New Brunswick (personal communication, Sean Basquill; Bruce Bagnell). One moss rare (S1) to NS & NB was identified at three sites.

We identified two new species of *Cladonia* lichen to Nova Scotia. *Cladonia brevis*, found at Point Michaud, is mentioned but not described in the Flora of North America (Brodo *et al* 2001) and previously known within North America only from Pennsylvania, USA (Naturserve, 2012). The only previously reported occurrence of *Cladonia oricola* in North America includes one finding from coastal heathlands in

Newfoundland, Canada. This finding shows lichen richness to be greater than expected and expands on known geographical distribution of species. It provides evidence that lichen surveys in the province may be incomplete and provides conservation incentive to protect lichen rich communities.

Rare vascular plants can largely be considered arctic-alpine or boreal species

A number of arctic and boreal species are known from Nova Scotia in distributions largely concentrated within but not confined to Cape Breton and the Cobequid Hills. These species are found in habitats including exposed rocky outcroppings, barrens and bogs at higher elevation, river gorges, waterfalls and cliffs, and exposed coastal headlands (Hounsell and Smith 1966; 1968). Some habitat types described by Hounsell and Smith reportedly received shade from surrounding forest as well as open areas. Only few sites were these species were found could be classified as coastal habitats.

Within our sample plots, several rare species we identified belong to those that can be classified as arctic, boreal, and/or alpine, including: *Salix glauca*, which is not rare in other parts of its North American range, *Silene acaulis* which is rare throughout much of its North American range, presumed extirpated from Maine, USA, though common in Quebec and the Yukon Territory, Can. (NatureServe, 2012), *Vaccinium uliginosum*, common in some Canadian provinces but Imperiled (S2) to Critically Imperiled (S1) in the Maritime Provinces. *Poa glauca* has a similar distribution, though it is also critically imperiled within the Northeastern United States and possibly extirpated from New Hampshire, USA.

Sagina nodosa is distributed throughout much of Canada, known from five states in Northern America, and is found throughout Canada. While common in centeral parts of the country, the species is ranked Vulnerable to Critically Imperiled in Atlantic Canada. *Shepherdia canadensis* is a common species through Central to Western Canada, but rare in the Canadian Maritime provinces and in Maine and Vermont in the Northeastern United States. *Hudsonia ericoides* is a species constrained in its North American distribution to the Eastern Atlantic coastline where it is rare in all Canadian provinces and American states with the exception of New York and New Jersey states, USA. *Agalinis neoscotica* was considered a Nova Scotia endemic, but has since been found in New Brunswick and Maine. It is ranked vulnerable in Nova Scotia, imperiled in New Brunswick and critically imperiled in Maine. Its populations are largest in Nova Scotia and have recently been spreading in the province, where it is associated with some types of disturbances (NatureServe 2012). This species has also been observed by naturalists to be locally abundant in some parts of the province (Personal communication, Nova Scotia Wild Flora Society meeting).

Environmental factors of dwarf heath plant communities

The most important environmental variables in differentiating plant communities were: soil depth, moisture condition and distance from the coast. Dwarf heaths are shown to differ in community composition and also species on sand dunes versus. coastal barrens. While all habitats are subject to coastal influences in Nova Scotia, I show variability in species composition and plant community differentiation occurs on a scale under 1Km from the coastline. Future work should continue to define coastal barrens as sites that are within 500m from the coast.

This study also shows geographical limitation of one dwarf heath plant community on the coastal barrens in Nova Scotia. The *Juniperus communis – Arctostaphylos uva ursi* plant community is almost exclusively distributed in central to southern parts of the province. Supporting species that co-characterize this group such as *Corema conradii* are also range limited.

The most frequent soil type underlying barrens in Nova Scotia are also the least described; *Rockland soils* (MacDougall *et al* 1963). This study classified humus forms of these soils at our study sites in order to better understand which conditions regulate plant community structure. The majority of humus types we surveyed are part of the great group Organic Order Folisol. The Folisols that support dwarf heath plant communities are themselves relatively rare within Canada and also especially sensitive to environmental disturbance (Fox and Tarnocai 2011). These soil forms are also indicative of the harsh conditions coastal barrens plants are subject to.

Humus forms were most frequently identified from rapidly to imperfectly drained mor and moder groups. These forms generally indicate conditions of slow nutrient release, acidic pH and extended periods of cold (Fox and Tarnocai 2011; Green *et al* 1992, 1993; Klinka *et al* 1981, 1997). Shallow humus also subjects plants to extended periods of dryness. At the opposite end of the moisture spectrum, Sphagnum-peat wetland mors and a Histic folisol were also identified at some survey sites. These humus forms are either saturated for extended periods of time, or permanently saturated. Anoxic waterlogged conditions, slow nutrient release from poor decomposition rate, acidity and cold temperatures are indicated by their presence (Jabiol *et al* 2013; Green *et al* 1993; Klinka *et al* 1981, 1997).

Charcoal was found in only 4 soil pits within this study. In addition, the most common humus form, Humimor, does not develop under conditions where there are frequent fires (Klinka *et al* 1981). The lack of evidence of fire re-enforces Burley 2009's findings that many coastal barrens in Nova Scotia persist without fire disturbance.

Bedrock geology is of importance to species composition and distribution on barrens in other regions (Akpulat and Celik 2005; Eberhardt and Latham 2000; Friedlander 1970; Meades 1983). This is due largely to soil parent material and soil chemistry. Since the parent material of most soils, and soil depth of rooting on our barrens is organic, this is not likely to be of great influence in Nova Scotia. Dwarf heaths were found on a wide range of bedrock types and there was no relationship between plant community structure and bedrock type within our study sites. This provides evidence that the existing coastal barrens classification scheme in Nova Scotia that differentiates sites into for example "granitic barrens" categories (Davis and Browne 1996), has no ecological basis.

Role of disturbance in maintaining or regulating barrens plant communities

Vast transition in plant communities over time has been casually observed during field studies on coastal barrens in Nova Scotia (Nick Hill, personal communication). Burley (2009) showed that forest encroachment occurs on some coastal barrens and that in these areas, open heathland is replaced by tree cover and forest communities over time. From unpublished data collected by the Nova Scotia Nature

Trust, transition from barren to forested habitat is apparent on some islands along Nova Scotia's eastern shore (Hill et al. 2012). In other regions, heathlands are maintained by management practices such as prescribed burning (Gimingham 1972, Foster and Motzkin 2003), partially to prevent forest succession. Lack of historical fire evidence on many coastal barrens suggests this approach is not appropriate for many sites in Nova Scotia. To date, succession on the coastal barrens of Nova Scotia has not been explicitly studied and this thesis did not investigate successional processes. Future research may seek to examine the role succession has in the structure and composition of plant communities on the coastal barrens of Nova Scotia, with implications for management and conservation.

Some barren sites in Nova Scotia are also known to be persistent (i.e. were not undergoing succession into forest) (Burley 2009; Neily et al. 2008). Burley (2009) observed coastal barrens that were persistent over the timeframe for which aerial photography in these areas was collected (approximately 70 years).

Persistent coastal barrens are thought to be regulated by climatic and edaphic conditions in exposed inland sites and near-coast exposed sites (Burley 2009). Salt spray is one driving mechanism behind the maintenance of coastal heathland plant communities by inhibiting the growth of tree species but not common heathland shrubs and herbs (Griffiths and Orians 2003, 2004, Griffiths 2006). Wind is thought to present a significant constraint to the establishment and growth of plants on barrens (Griffiths and Orians 2004) and in Nova Scotia (Neily et al. 2008). The persistent coastal barrens occur in areas with greatest exposure to wind (Burley and Lundholm 2009). Shallow, acidic and nutrient poor soils may also prevent the establishment of trees. Shallow soils are particularly stressful to plants (Lugo & McCormick 1981). Nova Scotia's coastal barrens are underlain by shallow, acidic and nutrient poor soils, and these are generally recognized as a defining characteristic of barrens ecosystems (Macdonald et al. 2011; Oberndorfer and Lundholm 2009).

Implications for conservation

Identification of candidate sites and regional priorities for conservation on coastal barrens

Currently a number of coastal barrens sites in Nova Scotia benefit from some level of protection, since they occur within a Provincial Wilderness Area, National Park, Nature Reserve, Provincial Parks or Conservation Easments on privately owned land. Some of the largest protected sites include Cape Breton Highlands National Park, Scatarie Island Wilderness Area, Gabarus Wilderness Area, Canso Coastal Barrens Wilderness Area, Andrew Island Provincial Park, Taylor's Head Provincial Park, Crystal Crescent Beach Provincial Park, Duncans Cove and Chebucto Head Nature Reserve, Terrence Bay Wilderness Area, West Dover Provincial Park, some land parcels within Prospect, Peggys Cove Preservation area, Gaff Point and Kejimkujik Seaside Adjunct. A number of relatively smaller areas are also protected provincially or by non-governmental conservation groups such at the Nature Conservancy of Canada, Nova Scotia Nature Trust or Kingsburg Coastal Conservancy. Barrens newly proposed for provincial protection include my field sites at Gooseberry Cove, New Harbour Head, West Baccaro, Port Bickerton Provincial Park, Cape Saint Mary's, Capelin Cove, Baliene, Gooseberry Cove and Stuarts Island (NSE 2013). The majority of protected areas for coastal barrens are located in the central to northern parts of the province. The largest areas of coastal barrens are located within these regions and also the largest proportion of rare species are concentrated in these regions. Between existing and proposed conservation sites, representative habitats of each broad community type described from this thesis and from each geographical region benefits from some level of protection.

Future assessment of conservation status of coastal barrens or of dwarf heaths need to incorportate quantitative assessment of habitat representivity. Instead of using arbitrary or ambiguous measures such as “pennant” (Davis and Browne 1996) to evaluate whether a candidate site provides representative habitat, conservation practitioners should use quanitative data and rigorously defined classification units. Firstly, to approximate the threshold between dwarf heath and tall shrub communities, dwarf heaths in Nova Scotia are on average 13.2 cm in height. To classify dwarf heath community types on the coastal barrens, practitioners can use a combination of community type descriptions, indicator species lists, and the list of most frequent and abundant species. In order to capture representative habitat, practitioners should continue to evaluate the presence of key environmental gradients (Oberndofer and Lundholm 2009). In addition to Oberndorfer and Lundholm (2009)’s findings, I would add that a wide moisture gradient, long fetch in the direction of most frequent wind, distance from the coast ranging 0 to at least 500m, and a variety of soil depths are important to persistence of dwarf heaths and differentiation of dwarf heath plant communities. I recommend decisions maker consider these variables when making conservation plans for coastal barrens..

Despite coverage of representative habitat, of the 15 study sites where rare species were recorded, only two of those sites have any level of conservation protection. Rare species should continue to remain a conservation priority. Rare species concentrations were greatest in the northern sites and on dune communities but ACCDC records should be considered since rare species were found in all community types and there was variability between sites. Within central to southern regions, habitats for the species *Corema conradii, Hudsonia ericoides,* and *Ilex glabra*, should also be conservation priorities since these are range limited and important species at a scale larger than the province of Nova Scotia.

Sand dunes provide habitat to a relatively high proportion of rare dwarf heath species and unique species to the dwarf heaths. Combined with sensitivity to disturbance, these communities are of high conservation priority. Robinson 2012 cites coastal sand dunes and beaches as one of the "most heavily impacted ecosystems in Nova Scotia". All of the Dwarf Heath sand dunes within this study are under some level of provincial protection; Taylor's Head, Sand Hills, and Point Michaud Provincial Parks.

When considering habitat conservation priorities, I found coastal barrens sites ranged widely in size. There was no correspondence between the number of rare species we identified and the size of sites. I did casually observe that some of the largest sites contained the largest concentration of rare species. However, some of the smallest sites, particularly sand dunes or islands, also had large concentrations of rare species as well. Whether larger sites contain more community types has not been properly assessed. At this time, a minimum patch size is not suggested for conservation efforts.

For unprotected private and public land, coastal residential development remains a concern. According to CBCL (2009), 86% of Nova Scotia's coastline (this included Bras d'Or Lakes) is privately owned. According to the Ecology Action Center's Coastal and Water Issues Committee (2013), over 95% of Nova Scotia's coastline is privately owned. Either statistic indicates a large proportion of Nova Scotian coastaline is privately owned. Coastal areas are highly desirable places to live and population decline within Nova Scotia (Moreira 2009) is actually buffered in coastal areas, occurring at a slower rate and receiving some immigration according to census data (CBCL 2009). Subdivision of coastal properties is not limited to urban centers and has been widespread throughout the province (CBCL 2009). Unfortnately, current coastal management policy and regulation in Nova Scotia are both inadequate and confusing for landowners to understand (EAC 2013).

There have been no efforts to quantify loss of barrens on private land in Nova Scotia. Between Oberndorfer 2006, Oberndorfer and Lundholm 2009 and this study in 2010 and 2011, one of six of Oberndorfers study sites (on private land) was developed for coastal housing. This development involved bisection of the entire site with a new road development, and in 2011, a housing foundation was constructed. I observed throughout the province many other sites bisected by a road for the development of new expensive summer housing.

Management considerations for existing conservation areas

ATV disturbance is considered the predominant threat to coastal barrens in Nova Scotia (Simon 2012; Oberndorfer 2006; Burley 2009; O'Toole 2006; Lau 2009). Conservation efforts have legally protected large tracts of land and DNR enforces strict regulations such as requirement of a permit to operate an off highway vehicle on coastal or highland barrens, beaches or sand dunes (Weseloh-McKeane *et al*. 2008). Despite these legal measures and the concerted personal effort of many individuals, habitat destruction from irresponsible ATV use persists. For example, conservation status has not prevented destruction of some bogs and barrens at Peggys Cove Preservation Area, and tracks of destroyed humus and vegetation are notable within Canso Coastal barrens (Simon 2012).

Within the coastal barrens complexes in Nova Scotia, Simon 2012 notes that low shrub plant communities, bogs, and rock outcrops (all considered dwarf heath) are the most sensitive and also the most vulnerable to ATV disturbance. These disturbances include but are not limited to nearly irreversable compaction and rutting of soils, physical crushing of plants, changes in regenerating species composition, and probable hydrological changes at any given site. As open habitats, it is difficult to prevent access to these sites by ATVs unlike conservation management practices applied in forested areas. Efforts to maintain the integrity of existing protected areas should focus on monitoring, public education, and community outreach and participation. Conservation efforts may be more successful with the help of volunteer land stewards and community-led initiatives.

Sand dunes are also sensitive to human activity by way of trampling. We found *Cladonia brevis* on the sand dune heaths at Point Michaud, and it was the only known occurrence of the species in Nova Scotia. This lichen is small and extremely fragile. Like other *Cladonia species* it is brittle when dry and walking across the population would crush it. The species is difficult to identify from other more common *Cladonia* it was growing amongst, meaning its value as a unique specimen would be difficult to recognize for most people walking by the dune area. Trampling can affect coastal dune vegetation at both the species and the community level (Santoro *et al* 2012). The *Cladonia* mats are also easily disturbed by trampling and therefore should be considered ecologically sensitive (Brodo 2001).

Another potential threat is colonization of the invasive *Rosa rugosa* (Hill *et al* 2010). Hill *et al* 2010 describe the take-over of one fragile coastal dune system in Cape Breton by the species, and Garbary 2011 sites this as a concern for coastal habitats on Briar Island.

Invasive species and trampling by some beach-goers are significant threats to dune vegetation and ecosystem function in parts of Europe, even though recently instated regulations protect dunes from development or other destructive anthropogenic activities there (Santoro *et al* 2012). Santoro *et al* (2012) show that fencing off sections of coastal dunes from human access prevents trampling, assisting recovery of plant communities, and increasing plant species diversity in fenced-off areas, even after a short time.

Coastal squeeze, *i.e.* shoreline habitat loss by erosional processes, may be one of the most important threats the coastal barrens in Nova Scotia face. At our Gaff Point field site, Hill *et al.* (2012) document 85% loss of barrens habitat over the last 35 years, where the headlands are eroding. The authors note that erosion has been most significant within the past 10 years. Unpublished survey data collected by the Nova Scotia Nature Trust that suggest similar losses may be occurring on coastal barrens within other parts of the Atlantic Coastline (Hill *et al.* 2012). Coastal squeeze should be considered by landscape managers and future research should assess the current and projected extent of habitat loss on coastal barrens within various coastal environments (*e.g*. high energy *vs*. sheltered shorelines) and where barrens occur over differing bedrock types.

Future research

Proportion of dwarf heath communities and classification of other community types

This thesis focuses exclusively on the dwarf heaths because of the (supported) assumption they comprise the dominant structural community on the coastal barrens in Nova Scotia. Future work is needed to clarify this assumption and to classify and describe other plant communities on the coastal barrens.

At this time, it is not known precisely what proportion of barrens plant communities are dwarf heaths. No classification efforts have included the tall shrub communities, bog communities, rock crack communities identified by a number of previous researchers (Oberndorfer and Lundholm 2009; Simon 2012) in Nova Scotia.

Prior to this study, the only major 'quantitiave' classification of the coastal barrens in Nova Scotia, at the level plant community scale, is from a single field site (Western Head Bog) by Damman and Dowhan (1980). That study describes a number of plant communities on coastal barrens that were not included in my classification of dwarf heaths. Among these community types were: dwarf shrub heath, *Trichophorum cespitosum* lawn, *Rhynchospora alba- Trichophorum cespitosum* lawn, *Gaylusaccia baccata* heath and hummock (each a separate community), mud bottoms and shallow bog pools, a bog forest community, and several types of fen.

Another specific example of an undescribed community is observations of the fern *Osmunda cinnamomea* growing in large patches as a dominant species. Oberndorfer 2006 and Garbary and Taylor 2006 note similar dominance of the species in patches on coastal barrens. From casual observation, the species grows in depressions. I dug an exploratory soil pit in one of these areas and found deeper mineral soil than usual, with mottles and seepage apparent in the face of the pit. This is an example of another potentially distinct plant community on the barrens – in environmental condition and in floristic assemblage. Future studies need to explore those community types of tall heath, bog, forest, fen, and grassland across multiple sites in order to adequately describe and classify the coastal barrens.

I also observed patches of either *Cornus canadensis* or *Cornus suecica*, occurring in patches that interrupted mats of *Empetrum nigrum* on the dwarf heath. *Cornus suecica* is rare and limited in distribution to only a few sites in Nova Scotia. It is found in “Sphagnous depressions in barrens, gravelly shores, and dry exposed headlands” (Roland and Zinck 1998). That description is congruent with the *Empetrum nigrum* association, and *Cornus canadensis* is one herbaceous community variant identified by this study. Further study is needed to examine prevalence of herbaceous communities in particular.

I collected a second data set in 2011/2012 using a systematic random sampling design on 21 coastal barrens sites in Nova Scotia. In order to better understand plant communities on the coastal barrens, we need to quantify what proportion of which communities comprise them. Because of time constraints, these data are not included in my thesis, but future analyses will shed more light on the proportion of other community types on the barrens and quantitatively test the (supported) assumption that dwarf heaths do dominate the coastal barrens habitats in Nova Scotia.

Is there an ecological basis for differentiation of highland, inland and coastal barren?

The existing classification scheme designates these three types of barren are based on general observations rather than data, and the threshold in influence of environmental conditions in partitioning plant communities is still unresolved. Research should address what threshold exists (if any) between environmental variables responsible for highland, inland and coastal barrens in Nova Scotia, and how plant communities differ if this is the case.

Incomplete lichen species inventory on the coastal barrens

Recent new provincial and continental records of macrolichens found in our study combined with other recent findings within the past two years, suggest that a full inventory of lichen species on coastal barrens in the province is still lacking. The crustose lichens were not surveyed as a part of this project but deserve further study since the only published inventory on coastal barren crustose lichens was limited to a single field site in Halifax County, and uncovered many new species to the province (Macdonald *et al.* 2011). Frances Anderson and Sean Basquill have additionally identified an inventory of crustose lichens from Saint Pauls Island.

CONCLUSIONS

Prior to this study, the best tools conservation and land management practitioners had to define and describe coastal barren vegetation diversity and distribution were limited. Tools included: 1) DNR's SFRS layer for mapping the area and distribution of most barrens in the province, 2) Oberndorfer 2006, Oberndorfer and Lundholm 2009's description of plant species composition variability and environmental gradients and 3) NSMNH's description of barrens in their Topics and Habitats and the Theme Regions documents (Davis and Browne 1996). We have now classified dwarf heath plant communities on the coastal barrens based on sampling across a range of sites in Nova Scotia.

Oberndorfer and Lundholm 2009 conclude high turnover or low congruence in species composition on the coastal barrens between sites. My findings show that while turnover is high, there are re-occuring plant communities characterized by consistently recurrent species in high abundance (consistent set of dominant species), and an associated suite of environmental conditions.

Floristic groupings derived from cluster analyses are supported with environmental consistencies shown in RDA ordinations, and also on closer inspection of the range of means of each variable supported by each community type. Because I only sampled dwarf heaths for this study, it will be important in the future to explore and describe other plant community types to obtain a full inventory of community types on the coastal barrens.

LITERATURE CITED

Ahti, T. and Stenroos, S. 2008. *Cladonia oricola*, a new coastal species of reindeer lichen in eastern North America. Abhandlungen aus dem Westfalischen Museum fur Naturkunde. 70 (3/4) 401-406.

Akpulat, H.A. and N, Celik 2005. Flora of gypsum areas in Sivas in the eastern part of Cappadocia in Central Anatolia, Turkey. Journal of Arid Environments. 61 (1) 27-46

Anderson, L., Crum, H. and Buck, W.. 1990. List of the mosses of North America north of Mexico. The Bryologist 93:4.448-499.

Atlantic Canada Conservation Data Center (ACCDC). Species Conservation Ranks. Accessed 2013. Online: http://www.accdc.com/Products/ranking.htm

Atlantic Geoscience Society (AGS). 2001. The Last Billion Years: A Geological History of the Maritime Provinces of Canada. Nimbus Publishing. Halifax, NS.

Balmford, A., Green, R. and Jenkins, M. 2003. Measuring the changing state of nature. Trends in Ecology and Evolution. Vol.18 No.7 326-330.

Benjamin, L. and Newell, R. 1985. Scurvygrass, *Cochlearia tridactylites*, a new plant record for Nova Scotia. Canad. Field-Nat, 99(3), 373-375.

Blaikie, P. and Jeanrenaud, S. 1996. Biodiversity and Human Welfare. Report for the United Nations Research Institute for Social Development. ISSN 1012-6511

Blanchet, F., Legendre, P. and Borcard, D. 2008. Forward selection of explanatory variables. Ecology. 89. 2623-2632.

Bonan, G. 2002. Ecological Climatology. Cambridge University Press. 690 Pages. ISBN: 0521800323

Borcard, D., Gillet, F. and Legendre, P. 2011.Numerical Ecology with R. Springer. New York.

British Bryological Society (BBS). 2012 British Mosses and liverworts: a field guide. *Frullania tamarisci*. Accessed online: http://www.bbsfieldguide.org.uk/content/frullania-tamarisci

Brodo, I., Sharnoff, S. and Sharnoff, S. 2001.Lichens of North America. Yale University Press.

Burley, S. 2009. Forest Expansion into Coastal Barrens in Nova Scotia, Canada. Thesis. Master of Science. Saint Mary's University, Halifax, Nova Scotia.

Canadian National Vegetation Classification (CNVC)[online] 2013. Sault Ste. Marie, ON, Canada. Accessed 2013. Available online from: http://cnvc-cnvc.ca.

Canadian Department of Agriculture 1971. System of Soil Classification for Canada. The Expert Committee on Soil Survey (CanSIS) 1982.

Canada Soil Information System (CanSIS): Manual for Describing Soils in the Field, 1982 Revised. Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa. LRRI Contribution no 82-52. 166 pp.

Carbyn S., Catling, P., Vander Kloet, S.P., and S. Basquill. 2006. An analysis of the Vascular Flora of Annapolis Heathlands, Nova Scotia. The Canadian Field Naturalist 120: 351-362.

Catling, P. and Carbyn, S. 2005. Invasive Scots Pine, Pinus sylvestris, replacing Corema, Corema conradii, Heathland in the Annapolis Valley, Nova Scotia. The Canadian Field Naturalist 119: 237-244.

CBCL. 2009. The 2009 State of Nova Scotia's Coast Technical Report. Report prepared for Government of Nova Scotia ISBN: 978-1-55457-327-1; Crown copyright, Province of Nova Scotia, 2009

Clarke, W. S. 1946. The effect of low temperatures on the Barrens of Pennsylvania. Ecology 27: 188-189.

Clarkson, B., Smale,M., Williams, P., Wiser,S. and Buxton, R. 2010. Drainage, soil fertility and fire frequency determine composition and structure of gumland heaths in northern New Zealand. New Zealand Journal of Ecology. 35(1) 96-113.

Clements, F.1916. Plant succession: An analysis of the development of vegetation. Washington, DC: Carnegie Institute of Washington Publication.

Crandall-Stotler, B., Stotler, R. and Geissler, P. 1987. A Biosystematic Study of the Subspecies of *Frullania tamarisci* (L.). The Bryologist. 90 (4) 287-308. Stable URL: http://www.jstor.org/stable/3243091 .Accessed: 14/11/2011 12:28

Crawley, M. 1997. Plant Ecology 2 ed. Blackwell Publishing, Malden, MA.

Damman, A. 1957. The south-Swedish Calluna-heath and its relation to the Calluneto-Genistetum. Botaniska Notiser 110: 363–398.

Damman, A. and Dowhan, J. 1980. Vegetation and habitat conditions in Western Head Bog, a southern Nova Scotian plateau bog. Canadian Journal of Botany 59, 1343-1358.

Davis, D. S. and Browne, S. 1996. In The Natural History of Nova Scotia. Topics and Habitats Nova Scotia Museum of Natural History, Halifax. pp. 464-466. Nimbus.

Dobson, A., Lodge, D., Alder, J., Cumming, G., Keymer, J., McGlade, J., Mooney, H., Rusak, J., Sala, O., Wolters, V., Wall, D., Winfree, R., and Xenopoulos, M. 2006. Habitat Loss, Trophic Collapse, and The Decline Of Ecosystem Services. Ecology 87:1915–1924.

Dunwiddie, W. P. 1989. Forest and heath: the shaping of the vegetation on Nantucket Island. Journal of Forest History 33, 126-133.

Dufrêne, M. and Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological monographs, 67:3. 345-366.

Dray, S., Legendre, P. and Blanchet, F. 2007. Packfor: R package for forward selection with permutation. Version 0.07

Eberhardt, R. W. and Latham, R. E. 2000. Relationships among vegetation, surficial geology and soil water content at the Pocono mesic till barrens. Journal of the Torrey Botanical Society 127, 115-124.

Ecology Action Center. Coastal and Waster Issues Committee. Responding to Coastal Development Issues. Online. Accessed 2013: http://www.ecologyaction.ca/content/responding-coastal-development-issues

Ellenberg, H. and D. Mueller-Dombois. 1966. A Key to Raunkier plant life forms with revised subdivisions. Berichte des Geobotanischen Institutes der Eidgenoessischen Technischen Hochschule Stiftung Riibel 37: 56-73

Environment Canada (EC). 2012. National Climate Data and Information Archive. Climate Normals Data. Online: http://climate.weatheroffice.gc.ca/climate_normals/

Esslinger, T. 2012. A cumulative checklist for the lichen-forming, lichenicolous and allied fungi of the continental United States and Canada. North Dakota State University: http://www.ndsu.edu/pubweb/~esslinge/chcklst/chcklst7.htm (First Posted 1 December 1997, Most Recent Version (#18) 13 December 2012), Fargo, North Dakota.

Ezekiel, M. 1930. Methods of correlation analysis. Wiley. New York and London.

Federal Geographic Data Committee (FGDC), U.S. Geological Survey, Vegetation Subcommittee. 2008 National Vegetation Classification Standard, Version 2. FGDC-STD-005-2008 (Version 2).

Flora of North America Editorial Committ (Ed.). (2010). Bryophyte Flora of North America. Volumes 27,28,29. Oxford University Press.

Fosberg, F. 1967. Classification of Vegetation. In; Guide to the check sheet for I.B.P areas. I.B.P Handbook, No. 4 (ed. Peterken, G.F.). Oxford and Edinburgh.

Fox, C. and Tarnocai, C. 2011. Organic soils of Canada: Part 2. Upland organic soils. Canadian Journal of Soil Science, 91(5), 823-842.

Friedlander, C.P. 1970. Heathland Ecology. Heineman Educational Books Ltd. Toronto.

Garbary, D. 2011. Invasion of Rosa rugosa into coastal plant communities of Briar Island, Nova Scotia. Talk at Plant Canada Conference, Saint Mary's University, Halifax. July 20, 2011

Garbary, D. and Taylor, B. 2006. Technical Note No. 06/01 Floristic Survey of Canso Coastal Barrens Wilderness Area. Antigonish, Department of Biology, Saint Frances Xavier University, for Nova Scotia Environment and Labour Environmental and Natural Areas Management Division, Protected Areas Branch.

Gimingham, C. 1972. Ecology of Heathlands. Chapman and Hall. London, UK

Gimingham, C. 1981. Conservation: European heathlands. In: Specht RL ed. Heathlands and related shrublands: analytical studies. Ecosystems of the World 9B. Amsterdam, Elsevier. Pp. 249–259.

Glaser, H. and Mooers, P. 1989. Active patterned ground at sea level, Fourchu , Nova Scotia. Arctic and Alpine Research 2:4. 425-432.

Gleason, H. 1926. The Individualistic Concept of the Plant Association. Bulletin of the Torrey Botanical Club 53: 7-26

Green, R.N., Trowbridge, R. and Klinka, K. 1993. Towards a taxonomic classification of humus forms. Forest Science Monograph. 29: 1-48.

Gurevitch, J., Scheiner, S. and Fox, G. 2002. The Ecology of Plants. Sinauer Associates, Inc., Publishers. Sunderland, Mass, USA.

Hales, W. 1992. Sand Dunes of Nova Scotia. Hamilton, ON, McMaster University.

Hall, I. and Aalders, L. 1968. The Botanical Composition of Two Barrens in Nova Scotia. Naturaliste Canadien 95, 393-396.

Hill, N., Beveridge, L., Flynn, A. and Garbary, D. 2010 Rosa rugosa as an invader of coastal sand dunes of Cape Breton Island and mainland of Nova Scotia. Canadian Field-Naturalist 124: 2. 151-158 Apr-June

Hill, N., Vander Kloet, S. and Garbary, D. 2012. The regeneration of *Empetrum nigrum*, the black crowberry, on coastal heathland in Nova Scotia. Botany. 90: 379-392

Hill, M. and Gauch Jr, H. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio, 42(1-3), 47-58.

Hinds, H. 2000. The Flora of New Brunswick. Fredericton, NB, University of New Brunswick.

Hoekstra,J., Boucher, T., Ricketts,T. and Roberts,C. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters 8(1): 23-29.

Hounsell, R. and Smith, E. 1966. Contributions to the flora of Nova Scotia VIII Distribution of Arctic-Alpine and Boreal Disjuncts. Rhodora. 68:776. 409-419

Hounsell, R. and Smith, E. 1968. Contributions to the flora of Nova Scotia IX Habitat Studies of Arctic-Alpine and Boreal disjunct species. Rhodora. 70. 176-192.

Jabiol, B., Zanella, A., Ponge, J., Sartori,G., Englisch,M.,van Delft, B., de Wall, R. and Le Bayon, R. 2013. A proposal for including humus forms in the World Reference Base for Soil Resources (WRB-FAO). Geoderma. 192. 286-294.

Kartesz, J.T.; Meacham, C.A. 1999. Synthesis of the North American Flora, Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC, USA. ISBN 1-889065-05-6.

Keppie, J.D. 2000. Map ME 2000-1, Geological Map of the Province of Nova Scotia, Digital Version Version 2, 2006. scale 1:500 000, compiled (Formerly DP ME D00-01) Nova Scotia Department of Natural Resources.

Keys, K. 2007. Forest Soil Types of Nova Scotia. Nova Scotia Department of Natural Resources. Manual FOR 2007-2

Keys, K., Neily, P. and Quigley, E. 2010. Forest Ecosystem Classification for Nova Scotia. Part II: Soil Types. Department of Natural Resources. Renewable Resources Branch. Report for 2011-3.

Klinka, R., Green, R.N., Trowbridge, R.L and L.E. Lowe. 1981 Taxonomic Classification of Humus Forms in Ecosystems of British Columbia. Province of British Columbia Ministry of Forests.

Klinka, K., Krestov, P., Fons, J. and Chourmouzis, C. 1997. Towards a taxonomic classification of humus forms: third approximation.Forest Sciences Department, University of British Columbia. Science Silvica extension series, 1209-952X, no 9. Online: https://circle.ubc.ca/handle/2429/683

Ladislav, M. 1997. Classification of vegetation: past, present and future. Journal of vegetation Science 8: 751-760.

Latham, R. E. 2003. Shrubland longevity and rare plant species in the northeastern United Stites. Forest Ecology and Management 185, 21-39.

Lau, J. 2009. Phenotypic and genotypic differentiation between coastal barren and forest plant populations in Nova Scotia, Saint Mary's University.

Legendre, P. and Gallagher, E. 2001. Ecologically meaningful transformations for ordination of species data. Oceologia. 129: 271-280.

Legendre, P. and Legendre, L. 1998. Numerical Ecology: Second English Edition, Developments in Environmental Modelling, 20. Elsevier, New York.

Legendre, P., Oksanen, J. and ter Braak, C. 2011. Testing the significance of canonical axes in redundancy analysis. Methods in Ecology and Evolution. 2: 269-277.

Luttmerding, H. A., Demarchi, D.A. and Lea, E.C. 1990. Describing Ecosystems in the Field. Province of British Columbia Ministry of Environment in cooperation with Ministry of Forests, Victoria.

MacDonald, A. Lundholm, J. and Clayden, S. 2011. Saxicolous Lichens on a Nova Scotian Coastal Barren. Northeastern Naturalist. 18 (4) 475-488.

MacDougall, J., Cann, D. and Hilchey, J. 1963. Soil Survey of Halifax County, Nova Scotia. Canada department of Agriculture. Report for Nova Scotia Soil Survey (Canada), no. 13.

McCune, B. and Grace, J. 2002. Analysis of Ecological Communities. MjM Software Design, Glenden Beach, Oregon.

Meades, W. J. 1983. Heathlands. In: Biogeography and Ecology of Newfoundland South, G. R., pp. 267-318. The Hague.

Miyanishi, K. and Johnson, E. 2007. Coastal Dune Succession and the Reality of Dune Processes. In: Plant Disturbance Ecology; The Process and the Response. Elsevier, New York.

Moiera, P. 2009. Backwater: Nova Scotia's economic decline. Nimbus Publishing, Halifax.

Mueller-Dombois, D. and Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. Wiley, New York.

NatureServe Explorer. 2012. Online. Accessed 2013. http://www.natureserve.org/explorer/

Nilsen, L., Johansen, L., and Velle, L. 2005. Early stages of Calluna vulgaris regeneration after burning of coastal heath in central Norway. Applied Vegetation Science 8: 57-64

Nova Scotia Department of Environment (NSDoE). Parks and Protected Areas Strategy. Accessed 2010 and 2013. URL: http://www.gov.ns.ca/nse/12percent/

Nova Scotia Department of Energy (NSE). 2012. K.C. Irving Chair in Sustainable Development at the Universite de Moncton and the Applied Geomatics Research Group at the Nova Scotia Community College. The Nova Scotia Wind Atlas Project. Online: http://www.nswindatlas.ca/

Nova Scotia Department of Natural Resources (NSDNR). 2007. Recovery Plan for Moose (*Alces alces americana*) in Mainland Nova Scotia. Report Accessed 2010. http://www.gov.ns.ca/natr/wildlife/large-mammals/pdf/MainlandMooseRecoveryPlan.pdf

Nova Scotia Department of Natural Resources(NSDNR). 2011. Spatially Related Forest Resources (SRFR) information system. GIS data.

Oberndorfer, E. 2006. Plant, macrolichen and moss community structure and species richnes in the coastal barrens of Nova Scotia. Thesis. Master of Science. Saint Mary's University, Halifax, Nova Scotia.

Oberndorfer, E. and Lundholm, J. 2009. Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. Biodiversity Conservation 18, 1523-1553.

O'Toole, E. 2006. Regeneration Characteristics of Coastal Barren Plant Species. Honours Thesis. Environmental Studies 4599,, Bachelor of Science, Environmental Studies Program. Saint Mary's University, Halifax, Nova Scotia.

Pärtel, M, Kalamees, R., Zobel, M. and Rosén, E. 1999. Alvar Grasslands in Estonia: Variation in Species Composition and Community Structure. Journal of Vegetation Science 10, 561-570.

Pearsall, W.H., 1965. Mountains and Moorlands. Collins, London. 312 pp.

Piessens, K. and Hermy, M. 2006. Does the heathland flora in north-western Belgium show an extinction debt? Biological Conservation 132: 382-394

Pimm, S. and Raven, P. 2000. Biodiversity; Extinction by numbers. Nature 403, 843-845
Price, E. 2003. Lowland Grassland and Heathland Habitats. Routledge. New York, New York.

Quine, C. and Gardiner, B. 2007. Understanding how the interaction of wind and trees results in wind-throw, stem breakage and canopy gap formation. In: Johnson, K. and Miyanishi , E. Plant Disturbance Ecology: The Process and the Response. Elsevier, New York.

Rao, C. 1995. A review of canonical coordinates and an alternative to correspondence analysis using Hellinger distance. Qüestiió 19:23-63

Rhoades, C. Miller, S. and Skinner,D. 2005. Forest Vegetation and Soil Patterns Across Glade-forest Ecotones in the Knobs Region of Northeastern Kentucky, USA. The American Midland Naturalist 154, 1-10.

Robinson, S. 2012. A biodiversity and vegetation community inventory or coastal dune ecosystems in Nova Scotia. Atlantic Canada Conservation Data Centre.

Roem, W. J., Klees, H., and Berendse, F. 2002. Effects of Nutrient Addition and Acidification on Plant Species Diversity and Seed Germination in Heathland. Journal of Applied Ecology 39, 937-948.

Rousseeuw, P. 1987. Silhouettes: a Graphical Aid to the Interpretation and Validation of Cluster Analysis. Computational and Applied Mathematics 20: 53–65.

Rodwell, J., Pigott, C., Ratcliffe, D., Malloch, A., Birks, H., Proctor,M., Shimwell, D., Huntley, J., Radford, E., Wigginton, M. and Wilkins, P. 2000. British Plant Communities, Volume 5. Maritime communities and vegetation in open habitats. Cambridge University Press, Cambridge, UK.

Rodwell, J. 1998. British Plant Communities: Mires and Heaths. Volume 2. Cambridge University Press. New York.

Roland, A.E. and Smith, E.C. 1969. The Flora of Nova Scotia. Proceedings of the Nova Scotian Institute of Science. Halifax, Nova Scotia.

Roland, A. and Zinck, M. 1998. Roland's Flora of Nova Scotia 3 ed. Nimbus Publishing and Nova Scotia Museum, Halifax.

Santoro, R., Jucker, T., Prisco, I., Carboni, M., Battisti, C. and Acosta, A. 2012. Effects of Trampling Limitation on Coastal Dune Plant Communities. Environmental Management. 49: 534-542.

Schmidt, I. K., Tietema, A., Williams, D., Gundersen, P., Beier, C., Emmett, B.A. and Estiarte, M. 2004. Soil solution chemistry and element fluxes in three European heathlands and their responses to warming and drought. Ecosystems 7: 638–649.

Simon, Molly. 2012. Seedling germination and survival on Nova Scotia's disturbed coastal barrens. Honours thesis. Saint Mary's University. Halifax, NS

Stenroos, S., Ahti, T., and Hyvönen, J. 1997. Phylogenetic analysis of the genera Cladonia and Cladina (Cladoniaceae, lichenized Ascomycota). Plant systematics and evolution, 207:1-2. 43-58.

Strang, R. M. 1971. Ecology and Land Use of the Barrens of Western Nova Scotia. Canadian Journal of Forest Research 2, 276 - 290.

Tedrow, J.2003. In: Interpreting and conserving the openland habitats of coastal New England: insights from landscape history. Forest Ecology and Management 185, 127-150.

Thurman, H. and Trujilo, A. 1999. Essentials of Oceanography. 5th ed. Library of Congress Cataloging in Publication Data. Pretince Hall, Inc. Upper Saddle River, New Jersey

Vagts, I. and Kinder, M. 1999.The Response of Different Cladonia Species after Treatment with Fertilizer or Lime in Heathland. The Lichenologist. The Lichenologist. 31 : pp 75-83 Published online: 28 March 2007

Van der Maarel, E. and Franklin, J. 2013. Vegetation Ecology. Second Edition. Wiley-Blackwell.

Webb, N.R. 1986. Heathlands, Collins. London.

Weseloh McKeane, S. and Gregory, A. edited by Baccardax, A. 2008. Navigating the Maze, A Citizen's Guide to Coastal Management in Nova Scotia. A publication of the Ecology Action Center's Coastal Issues Committee, Halifax, Nova Scotia.

Wildi, O. 2010. Data Analysis in Vegetation Ecology. Oxford, UK, Wiley- Blackwell.

APPENDIX 1. INVENTORY OF DWARF HEATH SPECIES

Inventory of species found within sample plots at 50 field sites (67 Sample plots) including *lifeform*, *frequency:* within sample plots and *abundance*: mean percent cover where found. Nomenclature follows Atlantic Canada Conservation Data Centre Database, which is based on Kartesz (1999) for vascular plants. For bryophytes, naming is based from the Flora of North America, Bryophyte Flora of North America, and Anderson et al (1990). Lichens are named according to Esslinger (2012), except for Cladonias, for which I use Stenroos et al 1997.

Rarity is represented by* Provincial record for Nova Scotia; S1, extremely rare: five or fewer occurrences; S2, rare: six to twenty occurrences; S3, uncommon or with restricted range even if locally abundant at some locations: 21-100 occurrences; S4, usually widespread, fairly common and apparently secure but of longer term concern (e.g., watch list): 100+ occurrences; S5; Widespread, abundant and secure under present conditions; SNA, Not Applicable: exotic, hybrid not considered of conservation concern, specimen was not identified to species, SNR, Unranked: Nova Scotia Provincial conservation status not yet assessed , exotic: exotic species established in the province; may be native in nearby regions (Atlantic Canada Conservation Data Centre), N2N3, vulnerable to imperiled: nationally within Canada (NatureServe Explorer). The status of bryophytes and lichens is derived from the General Status of Species in Canada Working Group (2011).

Table 31. Complete list of species identified in dwarf heath sample plots, organized by family.

Species	Life form	Rarity
Aceraceae		
Acer rubrum L.	tree	S5
Amblystegiaceae		
Calliergon stramineum (Brid.) Kindb.	liverwort	S4S5
Sanionia uncinata (Hedw.) Loeske	liverwort	S5
Aneuraceae		
Riccardia latifrons (Lindb.) Lindb.	liverwort	SNA
Apiaceae		
Angelica sylvestris L.	herb	exotic
Carum carvi L.	herb	exotic
Ligusticum scoticum L.	herb	S5
Asteraceae		
Achillea millefolium L.	herb	S5
Anaphalis margaritacea (L.) Benth.	herb	S5
Aster sp. L.	herb	SNA
Doellingeria umbellata (P. Mill.) Nees	herb	S5
Hieracium caespitosum Dumort.	herb	exotic
Hieracium pilosella L.	herb	exotic
Hieracium piloselloides Vill.	herb	exotic
Hieracium scabrum Michx.	herb	S5
Hieracium sp. L.	herb	SNA
Leontodon autumnalis L.	herb	exotic
Leucanthemum vulgare Lam.	herb	exotic
Oclemena nemoralis Ait.	herb	S5
Prenanthes trifoliolata (Cass.) Fern.	herb	S5
Senecio jacobaea L.	herb	exotic
Senecio viscosus L.	herb	exotic
Solidago bicolor L.	herb	S5
Solidago canadensis L.	herb	S5
Solidago puberula Nutt.	herb	S5
Solidago rugosa P. Mill.	herb	S5
Solidago sempervirens L.	herb	S5
Solidago sp. L.	herb	
Solidago uliginosa Nutt.	herb	S5
Sonchus arvensis L.	herb	exotic
Symphyotrichum novi-belgii L.	herb	S5
Aulacomniaceae		
Aulacomnium palustre (Hedw.) Schwaegr.	moss	S5

Betulaceae		
Alnus incana (L.) Moench	shrub	S5
	shrub	S5
Brachytheciaceae		
Brachythecium salebrosum (Web. & Mohr) B.S.G.	moss	S5
Brachythecium sp. Schimp.	moss	SNA
Bryaceae		
Pohlia nutans (Hedw.) Lindb.	liverwort	S5
Calypogeiaceae		
Calypogeia muelleriana (Schiffn.) K. Muell.	liverwort	SNA
Calypogeia sp.	liverwort	SNA
Campanulaceae		
Campanula rotundifolia L.	herb	S5
Caprifoliaceae		
Linnaea borealis L.	herb	S5
Viburnum nudum L.	shrub	S5
Caryophyllaceae		
Cerastium arvense L.	herb	SNR
Cerastium fontanum Baumg.	herb	exotic
Moehringia lateriflora (L.) Fenzl	herb	S5
Sagina nodosa (L.) Fenzl	herb	S2S3
Silene acaulis (L.) Jacq.	herb	S1
Cephaloziaceae		
Cephalozia sp.	liverwort	SNA
Cistaceae		
Hudsonia ericoides L.	shrub	S2 (N2N3)
Lechea intermedia L.	herb	S4
Cladoniaceae		
Cladina mitis (Sandst.) Hustich	lichen	S4S5
Cladina rangiferina (L.) Nyl.	lichen	S4S5
Cladina stellaris (Opiz) Brodo	lichen	S4S5
Cladina subtenuis (Abbayes) Halle & Culb.	lichen	
Cladina terrae-novae (Ahti) Halle & Culb.	lichen	S4S5
Cladonia arbuscula (Wallr.) Hale & Culb.	lichen	S4S5
Cladonia boryi Tuck.	lichen	S4S5
Cladonia brevis (Sandst.) Sandst.	lichen	record
Cladonia cenotea (Ach.) Schaerer	lichen	S4S5
Cladonia chlorophaea (Flörke ex Sommerf.) Sprengel	lichen	S4S5
Cladonia crispata (Ach.) Flotow	lichen	S4S5
Cladonia cristatella Tuck.	lichen	S4S5

Cladonia digitata (L.) Hoffm.	lichen	SNR
Cladonia farinacea (Vainio) A. Evans	lichen	S4S5
Cladonia floerkeana (Fr.) Flörke	lichen	SNR
Cladonia gracilis (L.) Willd.	lichen	S4S5
Cladonia gracilis ssp. turbinata (L.) Willd. (Ach.) Ahti	lichen	S4S5
Cladonia maxima (Asah.) Ahti	lichen	S4S5
Cladonia ochrochlora Flörke	lichen	S4S5
Cladonia phyllophora Hoffm.	lichen	SNR
Cladonia pleurota (Flörke) Schaerer	lichen	S4S5
Cladonia pyxidata (L.) Hoffm. Cladonia oricola Flörke	lichen	S4S5
Cladonia scabriuscula (Delise) Nyl.	lichen	S4S5
Cladonia sp. 1 P. Browne	lichen	SNA
Cladonia sp. 2 P. Browne	lichen	SNA
Cladonia squamosa Hoffm.	lichen	S4S5
Cladonia uncialis (L.) F.H. Wigg.	lichen	S4S5
Cladonia verticillata (Hoffm.) Schaerer	lichen	SNA
Cornaceae		
Cornus canadensis L.	herb	S5
Cupressaceae		
Juniperus communis L.	shrub	S5
Juniperus horizontalis Moench.	shrub	S4
Cyperaceae		
Carex conoidea Schk.	graminoid	S4?
Carex hormathodes Mack.	graminoid	S4S5
Carex magellanica Michx.	graminoid	S5
Carex nigra (L.) Reichard	graminoid	S5
Carex panicea L.	graminoid	exotic
Carex silicea Olney	graminoid	S4S5
Carex sp. 2 L.	graminoid	SNA
Carex sp. L.	graminoid	SNA
Carex stricta Lam.	graminoid	S5
Eleocharis parvula Roemer & J.A. Schultes (Link ex Bluff, Nees & Schauer)	graminoid	S4
Eriophorum virginicum L.	graminoid	S5
Schoenoplectus tabernaemontani	graminoid	S5
Trichophorum caespitosum (L.) Hartman	graminoid	S5
Dennstaedtiaceae		
Pteridium aquilinum (L.) Kuhn	fern	S5
Dicranaceae		
Dicranum condensatum Hedw.	moss	record

Dicranum flagellare Hedw.	moss	S5
Dicranum leioneuron Kindb.	moss	S4S5
Dicranum montanum Hedw.	moss	S5
Dicranum polysetum Sw.	moss	S5
Dicranum scoparium Hedw.	moss	S5
Dicranum sp.	moss	SNA
Dicranum spurium Hedw.	moss	S4?
Dicranum undulatum Brid.	moss	S5
Ditrichaceae		
Ceratodon purpureus (Hedw.) Brid.	moss	S5
Droseraceae		
Drosera rotundifolia L.	herb	S5
Elaeagnaceae		
Shepherdia canadensis (L.) Nutt.	shrub	S2
Equisetaceae		
Equisetum arvense L.	fern allies	S5
Ericaceae		
Andromeda polifolia Link	shrub	S5
Arctostaphylos uva-ursi (L.) Springl.	shrub	S4
Chamaedaphne calyculata (L.) Moench	shrub	S5
	shrub	S4
Empetrum eamesii Fern. & Wieg.	shrub	S3
Empetrum nigrum L.	shrub	S5
Epigaea repens L.	shrub	S5
Gaultheria procumbens L.	shrub	S5
Gaylussacia baccata (Wang.) K.Koch	shrub	S5
Gaylussacia bigeloviana (Andr.) Torr. & Gray	shrub	S5
Kalmia angustifolia L.	shrub	S5
Kalmia polifolia Wang.	shrub	S5
Ledum groenlandicum Oeder	shrub	S5
Vaccinium angustifolium Ait.	shrub	S5
Vaccinium macrocarpon Ait.	shrub	S5
Vaccinium oxycoccos L.	shrub	S5
Vaccinium uliginosum L.	shrub	S2
Vaccinium vitis-idaea L.	shrub	S5
Fabaceae		
Lathyrus japonicus Willd.	herb	S5
Trifolium pratense L.	herb	exotic
Trifolium repens L.	herb	exotic
Grimmiaceae		
Racomitrium lanuginosum (Hedw.) Brid.	moss	S4?

Grossulariaceae		
Ribes hirtellum Michx.	shrub	S5
Hylocomiaceae		
Pleurozium schreberi (Brid.) Mitt.	moss	S5
Rhytidiadelphus loreus (Hedw.) Warnst.	moss	S4?
Hypnaceae		
Hypnum cupressiforme Hedw.	moss	S4S5
Hypnum imponens Hedw.	moss	S5
Hypnum sp. Hedw.	moss	SNA
Ptilium crista-castrensis (Hedw.)	moss	S5
Iridaceae		
Iris setosa Penny	herb	S4
Iris versicolor L.	herb	S5
Sisyrinchium montanum Greene	herb	S5
Jubulaceae		
Frullania tamarisci (L.) Dum. subsp. asagrayana (Mont.) Hatt.	liverwort	SNA
Juncaceae		
Juncus balticus Willd.	graminoid	S5
Juncus canadensis J.Gay	graminoid	S5
Luzula acuminata Raf.	graminoid	S5
Luzula multiflora (Ehrh.) Lej.	graminoid	S5
Jungermanniaceae		
Mylia anomala (Hook.) S. Gray	liverwort	SNA
Tritomaria exsecta (Schrad.) Loeske	liverwort	SNA
Jungermanniales		
Cephalozia lunulifolia (Dum.) Dum.	liverwort	SNA
Lepidoziaceae		
Bazzania trilobata (L.) S. Gray	liverwort	SNA
Kurzia sylvatica	liverwort	SNA
Lepidozia reptans (L.) Dumort	liverwort	SNA
Leucobryaceae		
Leucobryum glaucum (Hedw.) Ångstr. ex Fr.	moss	S5
Liliaceae		
Maianthemum canadense Desf.	herb	S5
Maianthemum stellatum (L.) Desf.	herb	S4
Lophocoleaceae		
Lophocolea heterophylla (Schrad.) Dum.	liverwort	SNA
Lycopodium clavatum L.	fern allies	S5
Lycopodium hickeyi L.	fern allies	S4?
Mniaceae		
Mnium hornum Hedw.	moss	S4S5

Myricaceae		
Comptonia peregrina (L.) Coult.	shrub	S5
Morella pensylvanica Loisel.	shrub	S5
Myrica gale L.	shrub	S5
Onagraceae		
Oenothera biennis L.	herb	S5
Orchidaceae		
Cypripedium acaule Ait.	herb	S5
Spiranthes sp.	herb	
Osmundaceae		
Osmunda cinnamomea L.	fern	S5
Parmeliaceae		
Cetraria muricata (Ach.) Eckfeldt	lichen	SNR
Cetraria sp. Ach.	lichen	SNR
Hypogymnia physodes (L.) Nyl.	lichen	S4S5
Hypogymnia sp. (L.) Nyl.	lichen	S4S5
Parmelia squarrosa Hale	lichen	S4S5
Parmelia sulcata Taylor	lichen	S4S5
Usnea flavocardia Räsänen (Clerc)	lichen	S2S3
Usnea hirta (L.) F.H. Wigg	lichen	SNR
Xanthoria sp. (Fr.) Th. Fr.	lichen	SNA
Peltigeraceae		
Peltigera sp. Willd.	lichen	SNA
Pinaceae		
Abies balsamea (L.) Mill	tree	S5
Picea glauca (Moench.) Voss.	tree	S5
Picea mariana (Mill.) B.S.P.	tree	S5
Pinus banksiana Lamb	tree	S4
Plantaginaceae		
Plantago maritima L.	herb	S5
Poaceae		
Festuca rubra L.	graminoid	S5
Agrostis capillaris L.	graminoid	exotic
Agrostis scabra Willd.	graminoid	S5
Agrostis sp. L.	graminoid	SNA
Agrostis stolonifera L.	graminoid	S5
Ammophila breviligulata Fern.	graminoid	S5
Anthoxanthum odoratum L.	graminoid	exotic
Calamagrostis canadensis (Michx.) Beauv.	graminoid	S5
Calamagrostis pickeringii Gray	graminoid	S5
Danthonia spicata (L.) Beauv.	graminoid	S5
Deschampsia caespitosa (L.) Beauv.	graminoid	S4

Deschampsia flexuosa (L.) Trin.	graminoid	S5
Dichanthelium acuminatum Ell.	graminoid	S5
Elymus repens (L.) Desv. ex B.D. Jackson	graminoid	exotic
Phleum pratense L.	graminoid	exotic
Poa glauca Vahl	graminoid	S2S3
Poa pratensis L.	graminoid	S5
Trisetum melicoides	graminoid	S1
Polygonaceae		
Rumex acetosa L.	herb	exotic
Polytrichaceae		
Polytrichum commune Hedw.	moss	S5
Polytrichum juniperinum Hedw.	moss	S5
Polytrichum piliferum Hedw.	moss	S5
Pottiaceae		
Weissia controversa Hedwig, Sp. Musc. Frond	moss	S4?
Primulaceae		
Trientalis borealis Raf.	herb	S5
Ptilidiaceae		
Ptilidium ciliare (L.) Hampe	liverwort	?
Ptilidium pulcherrimum (G.Web.) Hampe	liverwort	
Ramalinaceae		
Ramalina roesleri (Hochst ex Schaerer) Hue	lichen	S4S5
Ranunculaceae		
Coptis trifolia (L.) Salisb.	herb	S5
Rosaceae		
Dasiphora fruticosa (Pursh) Kartesz	shrub	S4
Fragaria virginiana Duchesne	herb	S5
Photinia floribunda L.	shrub	S5
Photinia melanocarpa (Michx.) Ell.	shrub	S5
Photinia pyrifolia (L.) Pers.	shrub	S4?
Potentilla simplex Michx.	herb	S5
Rosa carolina L.	shrub	S4S5
Rosa nitida Willd.	shrub	S4
Rosa virginiana Mill.	shrub	S5
Rubus allegheniensis Porter	shrub	S5
Rubus canadensis L.	shrub	S5
Rubus chamaemorus L.	shrub	S4
Rubus hispidus L.	shrub	S5
Rubus idaeus L.	shrub	S5
Rubus pubescens Raf.	shrub	S5
Sanguisorba canadensis L.	herb	S4
Sibbaldiopsis tridentata Ait.	herb	S5

Spiraea alba Wieg.	shrub	S5
Salicaceae		
Salix glauca L.	tree	S1
Sarraceniaceae		
Sarracenia purpurea L.	herb	S5
Scrophulariaceae		
Agalinis neoscotica (Greene) Fern.	herb	S3
Euphrasia randii Robins.	herb	S4
Euphrasia stricta Wolff.	herb	exotic
Melampyrum lineare Desr.	herb	S5
Rhinanthus minor L.	herb	S5
Veronica officinalis L.	herb	S5
Veronica serpyllifolia L.	herb	S5
Sphagnaceae		
Sphagnum fallax (Klinggr.) Klinggr.	moss	G5
Sphagnum flavicomans (Card.) Warnst.	moss	S4S5
Sphagnum fuscum (Schimp.) Klinggr.	moss	S5
Sphagnum magellanicum Brid.	moss	S5
Sphagnum papillosum Lindb.	moss	S5
Sphagnum rubellum Wils.	moss	S5
Sphagnum sp. L.	moss	SNA
Sphagnum squarrosum Crome	moss	S5
Sphagnum tenellum (Brid.) Pers. ex Brid.	moss	S4S5
Stereocaulaceae		
Stereocaulon sp. (Schreb.) Hoffm.	lichen	SNA
Violaceae		
Viola sp.	herb	SNA

APPENDIX 2. RARE SPECIES

Table 32. Rare species located within sample plots, including family, life form, rarity, site where located. * Provincial record for Nova Scotia; S1, extremely rare: five or fewer occurrences; S2, rare: six to twenty occurrences; S3, uncommon

Species	**Family**	**Life form**	**Rarity**	**Sites**
Cladonia brevis	Cladoniaceae	Lichen	S1*	Point Michaud
Dicranum condensatum	Dicranaceae	Moss	S1*	Gardens, Flour Cove, Digby Neck, Blue Rocks
Cladonia oricola	Cladoniaceae	Lichen	S1*	Saint Paul’s Island, Duncans Cove
Salix glauca.	Salicaceae	Herb	S1	Saint Paul’s Island
Silene acaulis	Caryophyllaceae	Herb	S1	Saint Paul’s Island
Hudsonia ericoides	Cistaceae	Dwarf shrub	S2 (N2N3)	Arnold
Shepherdia canadensis	Elaeagnaceae	Shrub	S2	Meat Cove, Black Point, Green Cove
Vaccinium uliginosum	Ericaceae	Shrub	S2	White Point
Poa glauca	Poaceae	Graminoid	S2S3	Meat Cove
Sagina nodosa	Caryophyllaceae	Herb	S2S3	Green Cove, Cape Forchu
Usnea flavocardia	Parmeliaceae	Lichen	S2S3	Baccaro
Agalinis neoscotica	Scrophulariaceae	Herb	S3	Cape Forchu

APPENDIX 3. EXOTIC SPECIES

Table 33. Exotic species and study sites where found.

Species	Family	Life form	Sites
Angelica sylvestris	Apiaceae	Herb	Meat Cove
Carum carvi	Apiaceae	Herb	Meat Cove, Middle Head
Hieracium caespitosum	Asteraceae	Herb	Meat Cove
Hieracium piloselloides	Asteraceae	Herb	Flour Cove, Middle Head
Hieracium pilosella	Asteraceae	Herb	Freeport, Flour Cove, Point Michaud, Louisbourg, Donkin, Martinique, Taylors, Sandhills
Leontodon autumnalis	Asteraceae	Herb	Cape Forchu, Sandhills, Donkin, Louisbourg, Big Cove, Meat Cove, White Point, Green Cove
Leucanthemum vulgare	Asteraceae	Herb	Meat Cove, Sandhills
Senecio jacobaea	Asteraceae	Herb	Saint Pauls Island
Senecio viscosus	Asteraceae	Herb	Saint Pauls Island
Sonchus arvensis	Asteraceae	Herb	Cape Forchu
Cerastium fontanum	Caryophyllaceae	Herb	Big Cove, Meat Cove, Black Point(Cape Breton)
Carex panicea	Cyperaceae	Graminoid	Louisbourg
Trifolium pratense	Fabaceae	Herb	Meat Cove, Black Point (Cape Breton), Big Cove
Trifolium repens	Fabaceae	Herb	Louisbourg, Meat Cove
Agrostis capillaris	Poaceae	Graminoid	Flour Cove, Meat Cove
Anthoxanthum odoratum	Poaceae	Graminoid	Flour Cove, Middlehead, Big Cove, Dartmouth Pt
Elymus repens	Poaceae	Graminoid	Green Cove, Meat Cove
Phleum pratense	Poaceae	Graminoid	Big Cove, Meat Cove
Rumex acetosa	Polygonaceae	Herb	Big Cove, Freeport, Flour Cove
Euphrasia stricta	Scrophulariaceae	Herb	Louisbourg

APPENDIX 4. REPRESENTATIVE SAMPLE PLOT PHOTOS

Figure 8. *Juniperus communis* association at Long Island.

Figure 9. *Juniperus communis* association with *Arctostaphylos uva-ursi* at Goose Island.

Figure 10. *Corema conradii, Arctostaphylos uva-ursi* and *Cladonia* lichens on a rock in Shelburne county.

Figure 11. *Juniperus communis, Arctostaphylos uva-ursi, Corema conradii,* and *Gaylusaccia baccata* with *Cladonia* lichens at Blue Rocks.

Figure 12. ***Empetrum nigrum*** **association at Sober Island**

Figure 13. *Ammophila breviligulata* dwarf heath association at Sand Hills Provincial Park

Figure 14. *Empetrum nigrum* assocation at Gooseberry Cove.

Figure 15. Dwarfed jack pines in dwarf heath at Andrews Island were approximately 80 years old.