Forest Expansion into Coastal Barrens in Nova Scotia, Canada

Scott T. Burley

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.

Supervisor:	**Dr. Jeremy Lundholm**
Supervisory Committee:	**Dr. Karen Harper**
	Dr. Philip Giles
External Examiner:	**Sean Basquill**

Your file Votre référence
ISBN: 978-0-494-50619-6
Our file Notre référence
ISBN: 978-0-494-50619-6

Forest Expansion into Coastal Barrens in Nova Scotia, Canada

By

Scott Burley

A Thesis Submitted to Saint Mary's University, Halifax, Nova Scotia,
in Partial Fulfillment for the Requirements for the
Degree of Science in Applied Science

January, 2009, Halifax, Nova Scotia

Examining Committee:

Approved:	Mr. Sean Basquill, External Examiner Ecologist, Atlantic Canada Conservation Centre
Approved:	Dr. Jeremy Lundholm, Senior Supervisor Department of Biology and Environmental Studies
Approved:	Dr. Karen Harper, Supervisory Committee Member Department of Biology
Approved:	Dr. Philip Giles, Committee Member Department of Geography
Approved:	Dr. Genlou Sun, Program Representative
Approved:	Dr. Kevin Vessey, Dean of Graduate Studies

Forest Expansion into Coastal Barrens in Nova Scotia, Canada

By

Scott Burley

Abstract

Coastal barrens are relatively open areas consisting of sparse tree cover and are dominated by shrubby vegetation, primarily from the *Ericaceae* family. These habitats are generally found within a forest matrix and may represent long lived, stable communities or early successional habitats, eventually giving way to forest expansion. I used aerial photos to quantify the amount of forest encroachment over the last ~70 years at five major coastal barrens sites and used a GIS to derive topographic and other spatial predictors to classify persistent coastal barrens, persistent forests, and barrens that developed into forests. I also used plot sampling along transects across the forest - barren ecotone in order to assess potential encroachment and changes in forest structure and soil properties within the transition zone between forests and open coastal barrens. Results from the five study sites, representing 3541 points, showed an average of 16% decrease in the area of coastal barrens habitat due to replacement by forest. The best predictors of persistent barrens were elevation and distance to coast, with barrens at relatively high elevations close to the coast. This suggests that climatic and edaphic conditions in areas close to the coast as well as more exposed areas inland may be conducive to the persistence of coastal barren habitat and resist forest encroachment. Results from transects surveyed in 18 forest patches show that forest expansion is occurring from forest patches located within the coastal barren study sites. Three distinct vegetation communities were detected including: forest communities, edge communities, and open coastal barren communities. Soil properties did not significantly differ across the ecotone. Forest patches located within coastal barrens may provide a seed and propagule source from which forest encroachment can occur.

Acknowledgements

I wish to thank my supervisor, Dr. Jeremy Lundholm for all of his guidance and positive support throughout this entire project. Thank you also to my supervisory committee Dr. Karen Harper, Dr. Philip Giles, and Sean Basquill for their comments and suggestions in all phases of this project. I would like to thank Erica Oberndorfer for her pioneering research on coastal barrens in Nova Scotia and for her advice and guidance throughout this project. Many thanks to the field assistants and fellow graduate students who aided in data collection and advice including: Kat Dillon, Crystal Hillier, Jen Lau, Melissa Ranalli, and Molly Simon. I also would like to thank Dr. Tyler Smith for his patience and advice with the statistical analyses conducted in this report. Thank you also to Greg Baker for his expertise and training with GIS software. Funding for this project was provided by Saint Mary's University and the National Science and Engineering Research Council of Canada. A special thanks to my wife Jen and to my family and friends for providing important support (and the occasional field assistants) that enabled me to stick with this and see it to the end.

Table of Contents

List of Tables

Chapter 2:

Chapter 3:

List of Figures

Chapter 1
Forest Expansion into Coastal Barrens in Nova Scotia, Canada: Background and Study Sites

Introduction

Human activities have altered or negatively impacted many if not all natural ecosystems on the planet (Chapin et al. 2000). As a result, many rare and sensitive habitats are becoming lost or threatened due to various environmental changes brought on by these activities (McCann 2000; Chapin et al. 2000; Tilman 2000). Conservation biologists are becoming increasingly aware of the importance of maintaining ecosystems and important ecosystem functions to support development of sound rare species conservation strategies (Anchorena and Cingolani 2000). Knowledge of the landscape processes that shape these habitats is vital in developing sustainable natural resource management strategies.

An example of a habitat in Nova Scotia, Canada that is increasingly threatened by coastal development, climate change, and recreational activities (Oberndorfer 2006) is coastal barren. Coastal barrens are found scattered along the Atlantic coast of Nova Scotia in areas with thin soil cover and numerous patches of exposed bedrock. These habitats are relatively open areas dominated by sparse tree cover and shrub vegetation primarily from the *Ericaceous* family (e.g. *Gaylussacia baccata* (Black Huckleberry) and *Vaccinium angustifolium* (Low-bush Blueberry)) (Dunwiddie et al. 1996). Coastal barrens hold a high cultural, aesthetic, and biological value and are important habitats for conservation since they contain many rare plant species (Canals and Sebastia 2002; Oberndorfer and Lundholm 2009) as well as uncommon species assemblages (Foster and Motzkin 2003).

Ecosystems such as coastal barrens are not static communities that remain unchanged for their entire duration (Parsons et al. 1999; Eagan and Howell 2005). These habitats are dynamic and change over time in response to fluctuating environmental variables and human influences. These changes fluctuate within a set of boundaries depending on the combination of external and internal influences acting at any given time and specific area (Landres et al. 1999). In order to develop sustainable conservation strategies, this historic range of variability along with the current ecosystem processes occurring within a specific area must be taken into consideration.

Characteristics of Coastal Barrens

Very little is known about interactions among landscape processes contributing to the development and maintenance of coastal barrens in Nova Scotia. Only one major study has been conducted on this vegetation. Oberndorfer and Lundholm (2009) described vegetation communities in six coastal barrens located along the eastern coast of Nova Scotia. This study determined that coastal barrens have a distinct vegetation community dominated by *Ericaceous* shrub and lichen species; however, species assemblages were relatively site-specific.

A number of studies have been conducted on similar habitats in other parts of the world including Newfoundland, northeastern United States and in many parts of Europe and the United Kingdom (Foster and Motzkin 2003; Kuiters and Slim 2001; Latham 2003; Mallik 2003; Meades 1983; Williams 2003). These studies more commonly refer to barrens as heathlands, sandplains, or shrublands. Barrens vegetation tends to occur where prevailing environmental conditions favour the persistence of low growing shrub and grass species and prevent tree species dominance. These conditions are found at high elevations, in areas subject to marine salt spray, or in areas that experience extreme fluctuations of the soil moisture gradient (Latham 2003).

Heathlands of the northeastern United States have been classified by Dunwiddie et al. (1996) into two major vegetation types based on dominance: grasslands dominated by graminoid species and shrublands dominated by low growing, woody vegetation including *Gaylussacia baccata* (Black Huckelberry), *Arctostaphylos uva-ursi* (Bearberry), *Corema conradii* (Broom Crowberry) and *Myrica pensylvanica* (Bayberry). These shrublands have similar environmental characteristics and species assemblages as Nova Scotia coastal barrens. Local barrens have shallow, acidic soils interspersed with patches of exposed bedrock, dominated by shrub species of the *Ericaceous* family (Nova Scotia Museum of Natural History 1997b and Oberndorfer and Lundholm 2009).

The Nova Scotia Museum of Natural History (1997b) also describes these areas as highly stressed environments, offering a limited number of niches resulting in a low plant species diversity. A niche refers to the total role a species plays within an ecosystem; it is believed that no two species can occupy the exact same niche without resulting in competitive exclusion or extirpation of one species (Brewer 1979). In providing evidence in support of the stochastic niche theory, Tilman (2004) found that established species showed the strongest inhibitory influences on invading species of the same functional group illustrating that species occupying similar niches are more likely to have a greater influence on each others distribution patterns through increased competition. Therefore an ecosystem with a low number of niches represented by low spatial-variance of environmental conditions provides limited opportunities for different species to cohabitate (Brewer 1979).

However, Oberndorfer and Lundholm (2009) found that these areas do not offer limited niches since environmental characteristics were found to be heterogeneously distributed throughout these habitats promoting a relatively high diversity of plant species. This finding has important implications concerning the conservation value of these ecosystems.

Although coastal barrens do receive severe environmental stresses in the form of high wind exposure, and extreme temperature and soil moisture fluctuations, and exposure to marine salt spray; a high number of plant species are able to thrive, including forest understory species such as *Maianthemum canadensis* (Wild-lily-of-the-valley), *Gaultheria procumbens* (Wintergreen), *Cornus canadensis* (Bunchberry), and *Trientalis borealis* (Star Flower) (Oberndorfer and Lundholm 2009). It is uncertain whether the forest understory species found on coastal barrens represent subspecies, genetically distinct populations from those that occur in the forest, or if they are the same species merely occupying a different habitat.

Origin and Maintenance of Coastal Barrens

Within a forested landscape, open vegetation typically represents an early successional stage that develops following a disturbance that removes the tree canopy and/or alters the vegetation composition of the area (Bazzaz 1979; Nova Scotia Museum of Natural History 1997a; Saldarriaga et al. 1988). Depending on the severity of the disturbance, the shrub and grass species that make up this habitat type emerge using various regeneration strategies such as seedling regeneration originating from a dormant seed bank or dispersal into the area from outside seed sources; advanced regeneration from residual species remaining in the disturbed area; or vegetative growth through clonal reproduction or originating from below ground root and stump sources (Frelich 2002; Leck and Schutz 2005; Roberts 2004). If environmental conditions are suitable and the disturbance interval is long enough, these species typically act as pioneers, creating conditions that promote the emergence of later successional species eventually resulting in the reestablishment of a forest habitat over time.

In certain areas, the environmental conditions created following a disturbance, or the dominant disturbance regime of the area may not be conducive to the establishment of forest species, thus allowing for the persistence of open shrublands habitat over relatively longer periods of time (Latham 2003; Nova Scotia Museum of Natural History 1997a). In this case these habitat types represent a stable climax successional stage or alternative stable state, maintained by a number of internal and external influences.

There is very little known about the origin and successional history of coastal barrens in Nova Scotia. Studies such as Latham (2003) conducted elsewhere suggest that high elevation occurrences of barrens are relics of the last ice age. The Wisconsin glaciation extended from approximately 110,000-10,000 years ago, scouring the land and leaving areas of exposed bedrock. Particularly at relatively higher elevations, extreme wind and precipitation levels associated with these coastal environments may prevent soil from accumulating and create stressful conditions that essentially prevent tree colonization (Latham 2003). This would indicate that these habitats are relatively stable and represent a climax successional stage.

Certain coastal barrens and heathlands have also been found to occupy areas at lower elevations that would have otherwise experienced environmental conditions suitable for the emergence of tree species at the time these habitats originated (Ehrenfeld et al. 1995; Latham 2003). Many authors feel that this represents an alternative successional pathway influenced by disturbance patterns and life history strategies, whereby different sets of dominant species can become established in an area resulting in different successional end points (Cattelino 1979; Laycock 1991; Suding et al. 2004).

Latham et al. (1996) studied the occurrence of persistent open barrens located in a forest matrix within the Pocono till barrens in Pennsylvania. This study found that there were no apparent differences between these open areas and the surrounding hardwood forests in terms of topography, depth to bedrock, soil moisture or soil pH to explain differences in above ground vegetation composition. Latham et al. (1996) concluded that the emergence of the dominant species within these forest openings represent an alternative steady successional state maintained by the vegetation itself influencing the local environmental conditions.

Others have also suggested that similar habitats have been maintained over time by the dominant shrub vegetation acting as "ecosystem engineers" that prevent the encroachment of tree species (Latham 2003; Mallik 2003). Shrub species found in coastal barrens create soil and substrate conditions that are favourable to other shrubs but unfavourable for the establishment of competing tree species. Leaf litter found under shrub canopies tends to be very thick and creates acidic soil conditions that result in a reduction in decomposition and mineralization, creating unsuitable conditions for tree seedlings to germinate (Mallik 1995; 2003; Wallstedt et al. 2002).

Shrub species can also create allelopathic soil conditions that restrict nitrogen and phosphorus acquisition by other plant species (Latham 2003; Mallik 1995; Wallstedt et al. 2002). Studies have shown that the allelopathy created in soils dominated by

Ericaceous species such as *Kalmia angustifolia* (Sheep Laurel) and *Vaccinium spp.* can restrict the establishment, growth, and survival of *Abies balsamea* (Balsam Fir), *Picea mariana* (Black Spruce) and *Pinus resinosa* (Red Pine) (Bradley et al. 1997; Jaderlund et al. 1997; Mallik 1995; Wallstedt et al. 2002). This can have a significant impact on the vegetation composition of an area and allow for the long term persistence of open habitats dominated by these shrub species.

Disturbance regime may also play a role in the emergence and long term maintenance of these habitats. Asselin et al. (2006) suggests the occurrence of unforested rock outcrops in the boreal forest of Quebec, Canada, are a result of the fire disturbance regime of the area where frequent fire events are required to maintain unforested rock outcrops within a forested matrix. These findings coincide with studies conducted by Mallik (1995 and 2003) which concluded that current fire suppression techniques that prevent intense fires required to create conditions suitable for tree seedling germination are allowing for the shift of a conifer dominated forest to an open shrubland community dominated by *Kalmia angustifolia* (Sheep Laurel).

Other studies concerning coastal heathlands or barrens suggest that disturbances associated with human land use methods contribute to the occurrence of these habitats (Faison et al. 2006; Foster and Motzkin 2003; Russell and Davis 2001). A number of these studies examined the hypothesis that large expanses of open heathlands persisted in the northeastern United States long before European settlement and developed as a consequence of Native American land use practices of sedentary agriculture and prescribed burning (Motzkin and Foster 2002; Parshall and Foster 2002; Russell 1980). Faison et al. (2006), however; found that there was very little paleoecological evidence indicating the occurrence of large areas of open shrub dominated habitat prior to European settlement and concluded that the emergence of these habitats would have been a result of the various land use practices conducted by early European settlers.

Prior to European settlement, Faison et al. (2006) suggests that open shrub dominated habitats would have occurred in small isolated patches. As Europeans spread across the northeastern United States these shrublands expanded in response to the abandonment of large agricultural fields as well as prescribed burning of forested landscapes (Foster and Motzkin 2003). The large scale removal of forest from coastal areas may have created environmental conditions such as increased wind exposure and loss of soil that prevented the reestablishment of trees and allowed for the spread and persistence of these open shrublands.

Based on this literature open habitats such as barrens and heathlands are influenced and maintained by a number of external and internal factors that vary depending on location and site-specific attributes. It is therefore important to gather as much information as possible concerning the landscape history and the various abiotic and biotic variables that play an influential role in the development and long term maintenance of specific habitats in order to develop sustainable conservation and land management strategies.

Conservation Importance of Coastal Barrens

Coastal barrens hold high biological and cultural value while contributing to regional and local biodiversity. The growing knowledge concerning the vegetation composition and community structure of these habitats has underscored the need to protect and conserve these unique habitats as threats from coastal development, climate change and recreational activities increases.

Coastal barrens and similar open habitats contain a number of rare and endangered species. Latham (1996) found that the Pocono till barrens located in the southern Pocono Plateau in Pennsylvania contain at least 30 regionally rare and 10 globally rare and endangered plant and animal species. Since this area is not well studied, these numbers are expected to increase as more studies are conducted within this barren complex (Latham 1996).

In Nova Scotia, Canada, Oberndorfer and Lundholm (2009) found eleven provincially designated rare species while studying six separate coastal barren areas. This study did not include the compilation of a comprehensive species list of the areas, therefore more rare and endangered species are expected to be discovered in these areas with additional scientific inquiry. Rare species occurring on coastal barrens in Nova Scotia as well as in similar habitats such as rock outcrop alvars in Ontario, Canada (Stark et al. 2003) tend to be found in open areas dominated by low growing shrub species and are typically absent from the forests and higher shrub communities located within these ecosystems.

Coastal barrens also hold a high aesthetic and cultural value. Peggy's Cove in Nova Scotia, Canada, is one of the most popular tourist destinations in the Maritime Provinces and is located on the largest coastal barren complex in Nova Scotia (Haaheim 1999). The uniqueness of these habitats creates a desire to explore and visit these areas and many are important tourism destinations such as the heathlands in Nantucket, US, (Dunwiddie et al. 1996) and subjects of a growing number of scientific studies.

Although there is growing knowledge concerning the vegetation composition and structure of coastal barrens, very little is known concerning the successional dynamics of this vegetation in Nova Scotia. An important aspect in developing sound conservation strategies for these habitats is to determine whether or not forest succession is occurring as well as what processes are acting to facilitate or inhibit forest succession onto these open habitats.

As illustrated in the literature, ecosystem processes allowing for the persistence of these areas over time or facilitating the spread of forest species onto these areas may have regional and/or local variations. Specific coastal barren systems may be more susceptible to forest encroachment than others and in turn may require more active management strategies. It is therefore important to examine the regional and local processes influencing the successional characteristics of coastal barrens in Nova Scotia to determine the level and type of management required to successfully protect these areas.

Study Sites

In Nova Scotia, the majority of coastal barren consists of isolated patches scattered along the Atlantic coast. Five (5) coastal barren study sites were chosen to address the objectives of this study. These areas represent the bulk of coastal barren habitat occurring in Nova Scotia and include four sites located on mainland Nova Scotia including Peggy's Cove, Chebucto Head, Taylor's Head Provincial Park, Canso Coastal Barren Wilderness Area, and one site, Baleine, located on Cape Breton Island.

Coastal areas are subject to a number of disturbances and stresses that are not experienced by inland ecosystems. They are climatically distinct from nearby inland locations. Many days when the sun is shining inland, coastal areas can experience fog and cloud and have summer temperatures up to ten degrees cooler (Environment Canada 2008). This may delay leafout in these areas, causing a reduction in the duration of the growing season.

The Atlantic coast in Nova Scotia experiences a high frequency of strong winds playing a significant role in influencing the vegetation patterns of these areas. This almost constant wind introduces high amounts of salt to the soil and air that can impede vegetation growth by increasing moisture stresses (Leone et al. 2007; Magio et al. 2005). Strong wind storms and hurricanes, which also are relatively frequent, can remove large amounts of biomass and soil from the landscape, exposing bedrock and creating extremely stressful conditions for vegetation re-establishment.

Peggy's Cove

Peggy's Cove, located at 44° 29' 35" N and 63° 55' 00" W (NRC 2006), is one of Nova Scotia's largest coastal barren ecosystems. This area consists of a vast expanse of low growing, shrub vegetation pockmarked with exposed bedrock and glacial erratics originating from Devono-Carboniferous granites (NSDME 1957b). The macrotopography of this site is heterogeneous with a general trend of low elevation close to the coast and a gradual increase with increased distance inland. Soil accumulation in depressions and in valleys consists primarily of glacial till and weathered bedrock (NSDME 1957a). Forest cover is very sparse in this area with copses of trees occurring in various sized patches scattered among open barren habitat. Tree cover consists primarily of: *Pinus banksiana*, *Picea mariana* and *Picea rubens,* with *Abies balsemea, Betula papyrifera,* and *Acer rubrum* as associates. The dominant vegetation of the area consists of low growing shrub species including *Juniperus communis*, *Gaylussacia baccata*, and *Empetrum nigrum*, as well as a number of *Cladina* lichen species.

Peggy's Cove was first settled by Europeans in 1811. A number of sources detailing the first settlement patterns of the area depict the landscape as being very similar to present day conditions (Degarthe 1956; Livesay 1944). Degarthe (1956) presents an example of a map depicting the area surrounding Peggy's Cove in 1811 which makes reference to the area around the settlement as "rock barrens". Post-European land use in this area including varying degrees of logging, fishing, farming and livestock rearing combined with past and present tourist activities such as hiking and ATV use, would all have an influence on the current vegetation patterns of the area.

Chebucto Head

Chebucto Head, located at 44° 30' 00" N and 63° 30' 57" W (NRC 2006), is a part of the Pennant Barrens complex which ranges from Halifax Harbour to St. Margaret's Bay (Oberndorfer 2006). Similar to Peggy's Cove, the underlying bedrock consists of Devono-Carboniferous granites overlain with glacial till (NSDME 1957b). The macrotopography of this site is heterogeneous with a number of valleys extending towards the coast. Within these depressions, small copses of trees can be found having dominant species consisting of *Picea mariana*, *Abies balsemea*, and *Picea glauca*. The barren habitat located at this site consists of low growing shrub species including *Vaccinium angustifolium*, *Juniperus communis*, and *Kalmia angustifolia* interspersed with patches of exposed bedrock that are inhabited by a number of crustose lichen species.

This area comprises a portion of the Duncan's Cove Nature Reserve and is a popular destination for hikers who use the ATV and hiking trails established throughout the barrens. Historically, this area was used for military fortifications, protecting Halifax Harbour, evidence of which is still visible today. Influences to the area associated with this activity include tree felling for firewood and building materials, as well as potential livestock rearing and farming from nearby communities.

Taylor Head Provincial Park

Taylor's Head Provincial Park, 44° 49' 06" N and 62° 33' 46" W, consists of a peninsula of land stretching out from the eastern coast of Nova Scotia approximately six and a half kilometres into the Atlantic Ocean (NRC 2006). The underlying geology of the area consists of Cambrian quartzite and slate, overlain with glacial till (CDMGS 1911). At this site, there are distinct striations carved into the bedrock caused by ice scouring during the last ice age. This peninsula contains many different vegetation communities including coastal forests, old fields, bogs and fens, as well as shrub dominated coastal barrens (NSDNR 2004). The dominant tree species surrounding and found scattered within the coastal barren habitat include *Picea glauca*, *Picea mariana* and *Abies balsemea*, while the dominant shrub vegetation consists of *Empetrum nigrum*, *Juniperus communis*, and *Kalmia angustifolia*.

The coastal barren habitat found at Taylor's Head is primarily located in two distinct areas. The first representation of this habitat type is an area located on the headland of the southernmost tip of the peninsula which extends inland approximately 600 meters. The second area is located on the western coast, originating at the coast and spreading inland to cover the center of the peninsula. In both these areas there seems to be less exposed bedrock than in other coastal barren sites where ground cover at Taylor's Head consists mostly of mats of *Empetrum nigrum* and *Gaylusaccia baccata.*

Taylor's Head was first settled in the early 19th century, being primarily used as a seasonal fishing camp (NSDNR 2004). This community relied heavily on farming, fishing, and logging, evidence of which is still present today in the form of old fields and cart paths located within the park (NSDNR 2004). Many of these activities could have occurred within the coastal barren study site potentially having a major influence on the current day conditions of this site. If the coastal barren was present prior to the establishment of this settlement, settlers could have used the barrens as a grazing area for livestock, or harvested peat from the bogs located within these areas. Sheet Harbour and other communities surrounding Taylor's Head were also known for shipbuilding and logging and as a result, portions of this area could have been logged for building materials and lumber at one time or another throughout history (Rutledge 1954).

Canso Coastal Barren Wilderness Area

Canso Coastal Barren Wilderness Area is located at the northeastern tip of mainland Nova Scotia, 45° 17' 12" N and 61° 05' 21" W (NRC 2006). This area consists of 8,026 hectares of well drained, undulating terrain supporting a barren to semi-barren habitat type (NSDEL 2002). The underlying bedrock consists primarily of Devonian/Carboniferous granites, overlain by glacial scoured bedrock and stony till (NSDEL 2002). Currently the dominant vegetation consists of a patchwork of open areas dominated by shrub and fern species such as *Osmunda cinnamomea*, *Kalmia angustifolia*, and *Gaylussacia baccata* intermixed with closed canopy tree islands, dominated by *Picea rubens*, *Abies balsamea*, and *Picea mariana.*

The Nova Scotia Theme Regions Guide (1997b) makes reference to reports from 1912 describing the Canso Coastal Barren wilderness area as having exposed rock and erratics with very thin soils. The word "Canso" is derived from the Mi'kmaq word "Kamsok," meaning "opposite the lofty cliffs," indicating that this vegetation community may have been a long-term feature of the landscape prior to European settlement (Nova Scotia Museum 1997b).

In 1998, 3000 hectares of this area was granted protected status under the Nova Scotia Wilderness Areas Protection Act (Williams 2006). Under this Act, many activities such as logging, recreation, and development are regulated and restricted in an attempt to minimize the human impact to this ecosystem (Nova Scotia, Province of 1998). Although activities such as logging and urban development have ceased, this area is still influenced by recreational activities such as off-highway vehicle use despite these regulations.

Baleine

Located at 45° 57' 30" N and 59° 50' 04" W, Baleine represents the most northerly site of the five coastal barren habitats studied (NRC 2006). The underlying geology of this area originated from the Fourchu Group and consists of tuff, basalt, slate, quartzite, sandstone, and rhyolite. Macrotopography at Baleine is relatively homogeneous, consisting of low elevations near the coast with a very gradual increase in elevation with increased distance inland. There is very little area of exposed bedrock where the microtopography consists of undulating hummocks and troughs covered with low growing shrubs including *Empetrum nigrum*, *Rhodedendron groenlandicum*, and *Andromeda polifolia*. Small copses of trees primarily consisting of *Abies balsemea* and

Picea rubens can be found scattered among the site. Due to the harsh weather experienced at Baleine these tree islands tend to develop krumholtz growth forms.

Baleine is located approximately ten kilometres northeast of the town of Louisbourg. Small fishing settlements have been established surrounding Baleine and it may have been an area of past logging operations although the Louisbourg Institute of Cape Breton University (2006) make reference to a report from 1672 that states the area is "worth very little" and another report from the 1750's that describes the area as deserted and treeless and too wet to cross on foot or horse due to the soft, peaty ground. These reports indicated that this is another area in which this habitat type may have been relatively stable prior to European settlement and has changed very little since.

Purpose of Study

The purpose of this research is to gather and provide information concerning the current successional state of coastal barrens in Nova Scotia in order to develop sustainable conservation strategies. The major questions this project will attempt to answer include:

1. What is the extent of forest encroachment into coastal barrens in Nova Scotia in the past 70 years?
2. Are there environmental variables that play a significant role in facilitating or preventing forest encroachment into coastal barrens in Nova Scotia?
3. How do vegetation composition and structure as well as soil properties change across the forest-barren ecotone?

It is expected that depending on the combination of environmental variables interacting in different areas, certain areas of coastal barrens are experiencing forest encroachment whereas other areas may be relatively stable. The reason for this may be due to specific spatial attributes such as distance to coast, elevation, slope, aspect, or relative topography; or it could also be due to differences in soil characteristics such as soil depth, substrate characteristics or soil moisture (depth to water table).

References

Anchorena, J. and Cingolani, A. 2002. Identifying habitat types in a disturbed area of the forest-steepe ecotone of Patagonia. *Plant Ecology* 158: 97-112.

Asselin, H.; Belleau, A.; and Bergeron, Y. 2006. Factors responsible for the co-occurrence of forested and unforested rock outcrops in the boreal forest. *Landscape Ecology* 21: 271-280.

Bazzaz, F.A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics*. 10: 351-371.

Bradley, R.L.; Titus, B.D.; and Fyles, J.W. 1997. Nitrogen acquisition and competitive ability of Kalmia angustifolia L., Paper Birch (Betula papyrifera Marsh.) and Black Spruce (Picea mariana (Mill.) B.S.P.) seedlings grown on different humus forms. *Plant and Soil* 195: 209-220.

Brewer, R. 1979. Principles of Ecology. W.B. Saunders Company. Philadelphia, PA.

Canada Department of Mines. 1911. Southeast Nova Scotia Structural Geology. Geological Survey of Canada.

Canals, R.M. and Sebastia, M.T., 2002. Heathland dynamics in biotically disturbed areas: on the role of some features enhancing heath success. *Acta Oecologica* 23: 303-312.

Cattelino, P.J.; Noble, I.R.; Slatyer, R.O.; and Kessell, S.R. 1979. Predicting the multiple pathways of plant succession. *Environmental Management* 3 (1): 41-50.

Chapin III, F.S; Zavaleta,E.S.; Eviner, V.T.; Naylor, R.L.; Vitousek, P.M.; Reynolds, H.L.; Hooper, D.U.; Lavorel, S.; Sala, O.E.; Hobbie, S.E.; Mack, M.C.; and Díaz, S. 2000. Consequences of changing biodiversity. *Nature* 405 (11): 234-242.

Degarthe, W.E. 1956. This is Peggy's Cove Nova Scotia, Canada. Nova Scotia Archives, Halifax, NS.

Dunwiddie, P.W.; Zaremba, R.E.; and Harper, K. 1996. A classification of Coastal Heathlands and Sandplain Grasslands in Massachusetts. *Rhodora* 98 (94): 117-145.

Egan, D. and Howell, E.A. 2005. The Historical Ecology Handbook. Island Press. Washington, US.

Ehrenfeld, J.G.; Zhu, W.; and Parsons, W.F.J. 1995. Above- and below-ground characteristics of persistent forest openings in the New Jersey Pinelands. *Bulletin of the Torrey Botanical Club* 122 (4): 298-305.

Environment Canada. 2008. Weather Office. Viewed July 19, 2007. Available [online] http://www.weatheroffice.gc.ca/city/pages/ns-19_metric_e.html.

Faison, E.K.; Foster, D.R.; Oswald, W.W.; Hansen, B.S.C.; and Doughty E. 2006. Early Holocene openlands in southern New England. *Ecology* 87 (10): 2537-2547.

Foster, D.R. and Motzkin, G. 2003. Interpreting and conserving the openland habitats of coastal New England: insights from landscape history. *Forest Ecology and Management* 185: 127-150.

Frelich, L.E. 2002. Forest Dynamics and Disturbance Regimes. Cambridge University Press. Cambridge.

Haaheim, D. 1999. Nova Scotia's Beautiful Peggy's Cove. Viewed February 7, 2007. available [online] http://www.tourcanada.com/pegcove.htm.

Jaderlund, A.; Zackrisson, O.; Dahlberg, A.; and Nilsson, M. 1997. Interference of *Vaccinium myrtillus* on establishment, nutrition, and growth of *Picea abies* seedlings in a northern boreal site. *Canadian Journal of Forest Research* 27: 2017-2025.

Kuiters, A.T. and Slim, P.A. 2002. Regeneration of mixed deciduous forest in a Dutch forest-heathland, following a reduction in ungulate densities. *Biological Conservation* 105: 65-74.

Livesay, J.F.B. 1944. Peggy's Cove. The Ryerson Press. Toronto, Canada.

Landres, P.B.; Morgan, P.; and Swanson, F.J. 1999. Overview of the Use of Natural Variability Concepts in Managing Ecological Systems. *Ecological Applications* 9 (4): 1179-1188.

Latham, E.R. 2003. Shrubland longevity and rare plant species in the Northeastern United States. *Forest Ecology and Management* 185: 21-39.

Latham, E.R.; Thompson, J.E.; Riley, S.A.; and Wibiralske A.W. 1996. Pocono till barrens: shrub savannah persisting on soils favoring forests. *Bulletin of the Torrey Botanical Club* 123 (4): 330-349.

Laycock, W.A., 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. *Journal of Range Management* 44 (5): 427–433.

Leck, M. A., Schutz, W. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. *Perspectives in Plant Ecology, Evolution and Systematics* 7: 95-133.

Leone, A.P.; Menenti, M.; Buondonno, A; Letizia, A.; Maffei, C.; and Sorrentino, G. 2007. A field experiment on spectrometry of crop response to soil salinity. *Agricultural Water Management* 89: 39-48.

Louisbourg Institute of Cape Breton University. 2006. Viewed June 2 , 2008. The official research site for the Fortress of Louisbourg National Historic Site of Canada. available [online] http://fortress.uccb.ns.ca/search/List_gen.html.

Maggio, M.; De Pascale, S.; Ruggiero, C.; and Barbieri, G. 2005. Physiological response of field-grown cabbage to salinity and drought stress. *European Journal of Argonomy* 23: 57-67.

Mallik, A.U. 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. *Critical Reviews in Plant Science* 22 (3&4): 341-366.

Mallik, A.U. 1995. Conversion of temperate forests into heaths: Role of ecosystem disturbance and Ericaceous plants. *Environmental Management* 19 (5): 675-684.

McCann, K.S. 2000. The diversity-stability debate. *Nature* 405 (11): 228-233.

Meades, W.J. 1983. The origin and successional status of anthropogenic dwarf shrub heath in Newfoundland. *Advances In Space Research* **2**: 97-101.

Motzkin G. and Foster, D.R. 2002. Grasslands, shrublands, and heathlands in coastal New England: historical interpretations and approaches to conservation. *Journal of Biogeography* 29: 1569-1590.

Natural Resources Canada (NRC). 2006. Geographical Names of Canada. http://geonames.nrcan.gc.ca/index_e.php. Viewed 1 December, 2006.

Nova Scotia Department of Environment and Labour (NSDEL). 2002. Natural Landscapes of Nova Scotia: Summary Descriptions. Protected Areas Division. Nova Scotia, Canada.

Nova Scotia Department of Mines and Energy (NSDME). 1957a. Geological Map of Halifax and Sambro.

Nova Scotia Department of Mines and Energy (NSDME). 1957b. Glacial Geology of Halifax and Sambro. Map 87-2.

Nova Scotia Department of Natural Resources. 2004. Taylor Head Provincial Park. Parks and Recreation Division. Colchester County, NS.

Nova Scotia Museum of Natural History. 1997a. *Natural History of Nova Scotia VolumeI: Topics and Habitats.* Nova Scotia Museum of Natural History, Nova Scotia.

Nova Scotia Museum of Natural History. 1997b. *Natural History of Nova Scotia VolumeII: Theme Regions*. Nova Scotia Museum of Natural History, Nova Scotia.

Nova Scotia, Province of. 1998. Wilderness Areas Protection Act.c. 27, s. 1.

Oberndorfer, E. 2006. Vegetation Structure and Species Richness in Coastal Barrens of Nova Scotia. Masters Thesis, Biology Department, Saint Mary's University. Halifax, NS.

Oberndorfer, E. and Lundholm, J.T. 2009. Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. In press, Biodiversity and Conservation.

Parshall, T. and Foster, D.R. 2002. Fire on the New England Landscape: regional and temporal variation, cultural and environmental controls. *Journal of Biogeography* 29: 1305-1317.

Parsons, D.J.; Swetnam, T.W.; and Christensen, N.L. 1999. Uses and Limitations of Historical Variability Concepts in Managing Ecosystems. *Ecological Applications* 9 (4): 1177-1178.

Roberts, M.R. 2004. Response of the herbaceous layer to natural disturbance in North American forests. *Can. J. Bot.* 82: 1273–1283.

Russell, E.W.B. and Davis, R.B. 2001. Five centuries of changing forest vegetation in the Northeastern United States. *Plant Ecology* 155: 1-13.

Russell, H.S. 1980. Indian New England before the Mayflower. University Press of New England, Hanover, NH.

Rutledge, J.E. 1954. Sheet Harbour: A Local History. William Macnab and Son, Halifax, NS.

Saldarriaga, J.G.; West, D.C.; Tharp, M.L.; and Uhl, C. 1988. Long-term chronosequence of forest succession in the Upper Rio Negro of Columbia and Venezuela. *The Journal of Ecology* 76 (4): 938-958.

Stark, K. E., J. T. Lundholm, and D. W. Larson. 2003. Relationships between seed banks and spatial heterogeneity of North American alvar vegetation. *Journal of Vegetation Science* 14:205-212.

Suding, K.N.; Gross, K.L.; and Houseman, G.R. 2004. Alternative states and positive feedback in restoration ecology. Trends in Ecology and Evolution 19 (1): 46-53.

Tilman, D. 2004. Inaugural Article: Niche tradeoffs, neutrality, and community structure: A stochastic theory of resource competition, invasion, and community assembly. Proceedings of the National Academy of Sciences of the United States of America.

Tilman, D. 2000. Causes, consequences, and ethics of biodiversity. *Nature* 405 (11): 208-211.

Wallstedt, A.; Coughlan A.; Munson, A.D.; Nilsson, M.C.; and Margolis, H.A. Mechanisms of interaction between *Kalmia angustifolia* cover and *Picea mariana* seedlings. *Canadian Journal of Forest Research* 32: 2022-2031.

Williams, B. 2003. A comparison of heathland management practices, approaches and mechanisms in the UK and the Netherlands. National Trust Arkell Fellowship, UK.

Williams, B. 2006. Personal communication. Nova Scotia Department of Natural Resources. November 16, 2007.

Wells, B.W. and Shunk, I.V. 1938. Salt spray: an important factor in coastal ecology. *Bulletin of the Torrey Botanical Club* 65 (7): 485-492.

Chapter 2:
Forest expansion in coastal barrens: effects of elevation, distance to coast and disturbance

Abstract

Open barrens within forested biomes often contain rare species assemblages which may be endangered by forest encroachment. Very little is known concerning the origin and long-term maintenance of coastal barrens in Nova Scotia. These habitats resemble tundra or heathland and are dominated by Ericaceous vegetation. We used aerial photos to quantify the amount of forest encroachment over the last ~70 years at five major coastal barrens sites and we used a GIS to derive topographic and other spatial predictors to classify persistent coastal barrens compared with persistent forests or barrens that succeed to forests. Soil depth and the presence of charcoal were sampled in a subset of locations. Results from 3541 data points within the five study sites showed an average of a 16% decrease in the area of coastal barrens habitat that has become forested over the 70 year period. The best predictors of persistent barrens were elevation and distance to coast, with barrens found at relatively high elevations close to the coast. This suggests that climatic and edaphic conditions in areas proximate to the coast and in more exposed areas may be conducive to the persistence of coastal barren habitat. Evidence of fire was not found at all barrens sites, thus at least some of the open barrens are maintained by shallow soils, salt spray, and exposure to high winds. The results suggest two separate syndromes of coastal barrens maintenance, a "persistent refugium" typically near the coast and at high elevations, where barrens are maintained by coastal effects and harsh edaphic conditions, and a dynamic, successional process whereby large areas, typically inland, are colonized with coastal barrens vegetation after a disturbance but eventually become reforested. The "persistent refugium" model may be a global phenomenon, and appears to occur in disparate barrens and heathland systems across the northern hemisphere. Managers can use these results to determine conservation priorities and areas which may require disturbance to maintain larger areas of barrens vegetation.

Keywords: forest succession, rock barrens, heathland, conservation biology, landscape dynamics, remote sensing, disturbance

Introduction

Coastal barrens are open plant communities embedded within a forested landscape. They can persist for long periods of time or represent an early successional community eventually developing into a forest. In Nova Scotia, this habitat type is scattered along the Atlantic coast in areas with shallow soil and patches of exposed bedrock. This vegetation is relatively open and dominated by sparse tree cover and shrub vegetation primarily from the Ericaceae (e.g. *Gaylussacia baccata* (Black Huckleberry) and *Vaccinium angustifolium* (Low-bush Blueberry)) (Oberndorfer and Lundholm 2009). Coastal barrens in northeastern North America hold high cultural, aesthetic, and biological values and are important habitats for conservation since they contain many rare plant species (Oberndorfer and Lundholm 2009) as well as uncommon species assemblages such as those dominated by *Empetrum* sp., *Corema conradii* and *Prenanthes nana* (Dunwiddie et al. 1996, Foster and Motzkin, 2003). Rare plant species are often associated with open barrens dominated by creeping shrubs and their abundances are negatively correlated with vegetation height (Oberndorfer and Lundholm 2009). Patches of trees within the barrens are not associated with regionally uncommon vegetation, thus forest encroachment represents the potential for loss of rare species and community types (Oberndorfer and Lundholm 2009).

Rock barrens are known to function globally as refugia for rare species and habitat types (Anderson et al. 1999, Larson et al. 2000). In forested biomes, open vegetation types such as rock outcrops, heathlands, and grasslands often occur as isolated landscape elements in the forest matrix, with the long-term persistence of these distinct habitats attributable to stressful edaphic conditions (e.g. McVaugh 1943; Burbanck and Platt 1964; Arabas 2000) or disturbance (e.g. Oosting and Anderson 1939; Bakker et al. 1996; Asselin et al. 2006). Determining the successional status of such habitats and the mechanisms that maintain them is crucial to the task of preserving their biodiversity in the face of changing climates and disturbance regimes. This study examines the successional status of potentially rare and under-investigated coastal barrens habitat in Nova Scotia, Canada.

Within a forested landscape, open habitats can represent an early successional stage that emerges following a disturbance that removes the canopy and/or alters the vegetation composition of the area (Saldarriaga et al. 1988; Bazzaz 1979; Nova Scotia Museum of Natural History 1997a). These openings can persist for many years and even decades before forest expansion occurs (Bradley et al. 1997; Ehrenfeld et al. 1995; Faison et al. 2006; Jaderlund et al. 1997; Latham et al. 1996; Laycock 1991; Mallik 1995; 2003; Suding et al. 2004). Other rocky habitats that persist as islands in a forested landscape have been shown to last for hundreds of years without significant development of soil and succession into forest (Stark et al. 2003; 2004). Fire is one of the main disturbances that can maintain open habitats in temperate or boreal forest biomes (Oosting and Anderson 1939; Asselin et al. 2006), but the role of fire in coastal barrens is unknown.

Topographic heterogeneity of certain coastal barrens in Nova Scotia may render some areas more likely to experience forest encroachment than others. These habitats generally have undulating topography which can create depressions of protected patches allowing for soil and seed accumulation, possibly leading to forest establishment (Nova Scotia Museum of Natural History 1997a). Conversely, exposed areas at ridge tops or areas lacking protection by topographic variation may experience conditions not suitable for tree seedling establishment, thus allowing for the persistence of low growing barren habitat.

Despite the number of external and internal influences that contribute to the long-term persistence of open habitat types such as barrens and heathlands, many studies have shown a reduction of these habitats in response to forest encroachment (Kuiters and Slim 2001; Maurice 2004; Curt et al. 2003). In many of these cases there is a shift in driving variables such as the dominant disturbance regime or climatic conditions that enable the encroachment of tree species and subsequent forest succession to occur.

Forests surrounding coastal barrens in Nova Scotia are generally dominated by coniferous tree species including *Picea glauca* (White Spruce), *Picea rubra* (Red Spruce), *Larix laricina* (Tamarack), and *Abies balsamea* (Balsam Fir) (Neily et al. 2004; Nova Scotia Museum of Natural History 1997a; Oberndorfer and Lundholm 2009). The common regeneration strategy for these species is sexual reproduction through seed dispersal and pollination; however, these species can also reproduce asexually through layering, which consists of regeneration by means of vegetative propagation (Greene et al. 1998). Trees may be able to encroach onto the barrens and outcompete dominant shrub species (Krause 2005; Greene et al. 1998).

The goals of this study were to assess the successional status of coastal barrens in Nova Scotia in order to develop sustainable conservation strategies. In particular, the study determines the extent of forest spread into coastal barrens in Nova Scotia in the past 70 years and quantifies key environmental variables that differentiate between areas that have experienced forest encroachment and areas that have remained unchanged.

Methods

Study Sites

In Nova Scotia, the majority of coastal barren consists of isolated patches scattered along the Atlantic coast. Five coastal barren study sites were chosen to address the objectives of this study (Figure 1). These areas represent the bulk of coastal barren habitat occurring in Nova Scotia and include four sites located on mainland Nova Scotia including Peggy's Cove, Chebucto Head, Taylor's Head Provincial Park, Canso Coastal Barren Wilderness Area, and one site, Baleine, located on Cape Breton Island.

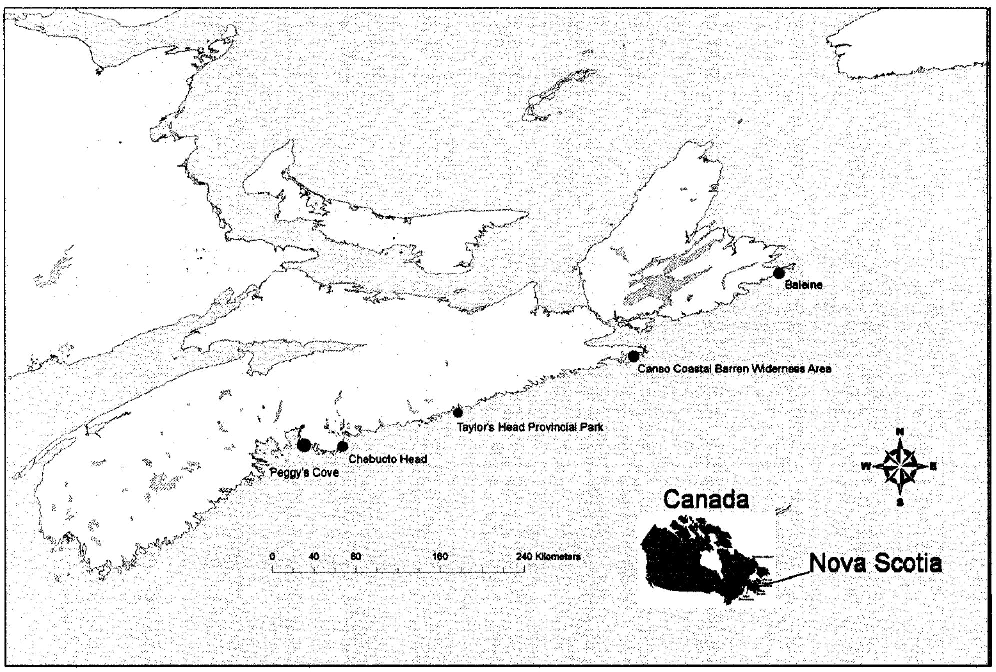


Figure 1. Locations of Five Coastal Barren Study Sites along the Atlantic coast of Nova Scotia including: Peggy's Cove, Chebucto Head, Taylor's Head, Canso, and Baleine.

Coastal habitats are subject to a number of disturbances and stresses not experienced inland. Coastal areas experience a unique climate that can be very different from nearby inland locations. Many days where the sun is shining farther inland, coastal areas can experience fog and clouds with summer temperatures up to ten degrees cooler (Environment Canada 2006). This may delay leaf out in these areas, causing a reduction in the duration of the growing season. Different locations along the coast within Nova Scotia also experience various climatic conditions. Climate normals (Environment Canada 2006) suggest that each study site may experience significantly different climatic conditions over the growing season (Table 1). Deming and Ecum Secum may not be significantly different from each other in the number of days per month with precipitation; however, they are both significantly different than Louisbourgh. St. Margaret's Bay is also significantly different than Louisbourgh and Ecem Secum in days per month with precipitation.

Table 1. Monthly average (± 1 SE) climate data collected from April to October 1971-2000

Weather Station Location	Closest Study Site	Daily Average Temperature per Month (°C)	Average Monthly Precipitation (mm)	# Days per month with Precipitation >= 0.2 mm
Louisbourgh	Baleine	10.9 ± 0.4	124.4 ± 0.7*	15.1 ± 0.2*
Deming	Canso	10.8 ± 0.4	115.5 ± 0.7*	12.4 ± 0.2
Ecum Secum	Taylor's Head	10.9 ± 0.4	120.2 ± 0.5*	13.0 ± 0.2
St. Margaret's Bay	Peggy's Cove/ Chebucto Head	12.1 ± 0.4	102.8 ± 0.5*	11.3 ± 0.2

*Note: *indicates value is significantly different than all other sites (95% Confidence Intervals; α= 0.05).*

Field evidence (Scott Burley pers. obs.) and historic fire records (CCC 1912) indicate that Peggy's Cove, Canso, and to a much lesser extent Chebucto Head, have all experienced various degrees of fire disturbance over the past 100 years. Based on this evidence, Taylor's Head and Baleine have remained relatively fire free. This indicates that perhaps fire, which was thought by some to be necessary for the occurrence of coastal barrens, may not be the sole means by which these ecosystems can persist.

Assessing Forest Encroachment

In order to determine if, and to what extent, forests are encroaching into coastal barren habitat, three sets of aerial photographs taken at different times were compared. For these parts Nova Scotia, the earliest aerial photographs available were taken in the early 1930s. These photographs were compared with photos recorded between 1950 and 1965 and also with the most recent photos available, recorded between 1998 and 2003. This method provided a time span of approximately 70 years from which forest encroachment was tracked.

All aerial photographs were scanned and georeferenced into ArcGIS 9.2 computer software using a base map taken from the Nova Scotia 1:10,000 topographic database. A 100 m^2 point grid was projected over the photos encompassing the entire area covered by the aerial photos. The extent of study areas for which aerial photos were examined were based on the limits of coastal barren habitat. Boundaries for each study area were established beginning at the high water mark at the coastline, extending inland until reaching either 50 meters from residential communities, or from where the occurrence of coastal barren habitat ceased and continuous forest dominated. This assessment of continuous forest is based on the most recent photograph available and does not imply that areas farther inland from the study area did not represent barren habitat in the past. Each point was examined and assigned to one of four successional scenarios, which were: 1) coastal barrens remaining relatively unchanged; 2) forested areas that were previously coastal barren; 3) forested areas that have remained forested; and 4) coastal barrens that were previously forested. It should be noted that this was a comparison between the oldest photo available and the most recent photo. The intermediate photo was used to validate the interpretation of the oldest photo as well as to detect possible "encroachment – die back" scenarios.

A random sample of points was chosen in order to verify the aerial photo interpretation, detect presence of charcoal, as well as to gather soil data from the field. A sub-sample of 165 points representing the three major successional scenarios found during the analysis was visited at three of the study sites (Peggy's Cove, Taylor's Head, and Canso) (Table 2). The fourth category (coastal barrens that were previously forested) had a limited occurrence and points experiencing this successional scenario will be addressed separately.

Table 2. Distribution of points representing the three main successional categories visited in three study sites.

Site	CBU	CBC	FOU
Canso	19	20	20
Peggy's Cove	20	20	20
Taylor's Head	20	6	20

Note: CBC = forested areas that were previously coastal barren or bog; CBU = coastal barrens or bogs; that remained coastal barrens or bogs; FOU = forested areas that remained forests

Environmental Variables

In order to determine whether there were soil differences between barrens areas experiencing forest encroachment compared with barrens areas that have remained relatively unchanged, soil characteristics were assessed at each of the 165 sub-sampled points using a soil auger that was driven into the ground until it reached bedrock (or resistance prevented it from going any further down). The core was than extracted and visually examined for the presence of charcoal as an indication of past fire events.

Spatial variables, including slope, aspect, elevation, landscape position, proximity to coast, level of exposure, and exposure to coast, were calculated for each point using ArcView 9.2 computer software to determine if there were any detectable differences among the three main successional categories. A digital elevation model (DEM) with a horizontal grid spacing of 10 m and vertical step size of 1m was created and added to the working file containing the digitized aerial photographs from which elevation, slope and aspect were calculated for each point. In order to convert aspect into a value that can be compared between points, the aspect value was divided by 360. To get a value for northerly and easterly directions, the cosine and sin, respectively, were then taken of the converted radian value and multiplied by 2 Π. Proximity to the coastline was calculated from the base map used to georeference the aerial photographs. The "near" command found in the spatial analyst tool box (ESRI 2006) was used to calculate the distance of each point to the coastline feature depicted in the base map.

Landscape position represents the relative position of a point to its immediate surroundings: valley bottom, ridge top, or at an intermediate location. This method used the neighbourhood command in the spatial analyst tool box. Using the previously created DEM, the mean elevation of the four cells located to the north, south, east and west sides of each point was calculated and subtracted from the elevation of the cell within which the point in question was located. The results of this calculation gives an indication of the relative landscape position of each point in that a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge.

The focal flow command was used to calculate the level of potential wind exposure for each point. This analysis examines eight cells surrounding the processing cell (the cell within which the point is located) to determine which cells are higher and which cells are lower than the processing cell. The processing cell is assigned a number which corresponds to the surrounding cells that are higher. This is similar to landscape position in which it provides an indication of whether it is on a ridge or in a valley. However, this function also determines in which direction the point is either exposed or protected. Using this function in conjunction with the relative angle of the coast to each point, the relative exposure to the coast was also calculated.

Statistical Analysis

Linear discriminant analyses (LDA) were conducted in an attempt to explain differences in abiotic variables between areas representing unchanged coastal barrens versus forested areas (including points representing unchanged forests as well areas experiencing forest encroachment). An LDA is a multivariate technique designed to classify samples in a dataset that has been divided into predefined groups. This technique chooses linear combinations of environmental variables that best explain the differences between the pre-classified groups (Legendre and Legendre 1998). A jackknife train/test procedure was used to test the result of the analysis. In this procedure the data was randomly separated into a training set (70 %) for creating the discriminate scores and a test set (30 %) for evaluating the result. A multivariate analysis of variance (MANOVA) using a Wilks' Lambda test was then conducted using the LDA scores to test the significance of the model. These analyses were conducted using the MASS package in R version 2.5.1 (2007).

In order to examine regional patterns in abiotic variables between unchanged coastal barrens and forested areas, points collected from all 5 barrens sites were combined and analysed together. Where it was hypothesised that these variables may interact on a more site specific level, the LDAs were also conducted using points from each barrens site separately. In an attempt to improve the ability of the model to discriminate between the two groups, an additional LDA was conducted using the soil depth and charcoal data collected from a sub-sample of points from three sites.

Used in conjunction with a MANOVA, the LDA provided a parametric means to test the significance of differences detected between the two groups; however, this method was restricted to detecting linear relationships which limited this method's ability to capture the entire story. Classification trees (CTs) hold two main advantages over LDAs, the first being the ability to process categorical and binary data which increase the potential number of abiotic variables examined. The second advantage is that CTs are able to explain more ecological complexity by further dissecting each variable, detecting nonlinear patterns and interactions that would otherwise be missed.

Classification tree analyses were used to further explain the differences in abiotic variables between forest and coastal barren habitats. This method uses binary recursive partitioning to separate the data into a hierarchical set of rules that attempt to classify the data based on predetermined groups. CTs examine each variable one at a time in order to determine which variable creates the best split or node resulting in the two most homogeneous groups. Additional splits are made until there is no more improvement to the fit of the model relative to the number of nodes used (Gotelli and Ellison 2004). The resulting classification tree is essentially a binary key comprised of various ranges of the selected abiotic variables that best separate the predefined classes. A jackknife train/test procedure was again used to test the model where the data was randomly separated into a 75 % training set and a 25 % test set. The analyses were conducted using a Microsoft Excel based program developed using the C4.5 algorithm designed by Ross Quinlan (Saha, A. 2008).

Results

A total of 3541 points were visually examined on the aerial photographs in order to assess the successional status represented by each point. Many of the points representing areas that experienced forest encroachment were typically found away from the coast whereas the majority of unchanged coastal barrens were generally found closer to the coast or in areas where exposed rock outcrops were present (Figure A1 to A5, Appendix A).

The proportion of points that fell into each of the four successional categories were: 51% unchanged forests; 41% unchanged coastal barrens; 7.9% former coastal barrens that experienced forest encroachment; and 0.1% former forests that are now open bog or coastal barren. The last category was not included in further analyses due to the small proportion of points within this group. These points were all located around streams or lakes and were thought to represent localized changes in hydrography resulting in the expansion of open bog or fen habitats.

Across all five study sites, a total of 16% of coastal barren habitat was found to experience forest encroachment over an average time frame of 66 years (Table 3). This rate of change was not uniform across all sites as the percentage of forest encroachment into coastal barren habitat ranged from approximately 4% to 25%.

Table 3. Amount and rate of coastal barren (CB) habitat loss as a result of forest encroachment.

Site	Time (years)	Total # of Points	Original # CB Points	Current # CB Points	CB % Change
Canso	55	1169	635	500	-21.3
Taylor's Head	72	264	57	43	-24.6
Chebucto Head	72	555	200	175	-12.5
Peggy's Cove	71	908	505	414	-18.0
Baleine	62	638	331	317	-4.2
Total/Average	**66**	**3534**	**1728**	**1449**	**-16.0**

Note: CB (coastal barrens) represents all non-forested habitat including low shrub barren, bog and rock outcrop habitats. +/- signs indicate a percent increase or decrease of habitat respectively. Time refers to the time between the oldest and the most recent aerial photos for each site.

The results of the initial linear discriminant analysis (LDA) conducted using the entire data set consisting of 3534 data points classified into one of two successional groups (Unchanged Coastal Barren and Forested Areas; including coastal barrens experiencing forest encroachment and unchanged forests) resulted in a success rate of 61% of the test data into the appropriate groups (Table 4). This analysis showed that elevation and distance to coast were the two most important variables in differentiating between the two groups. Slope and landscape position were the next two important variables respectively (Table 4). Based on group means, areas close to the coast and at higher elevations tended to be coastal barrens that remained unchanged, whereas forests or barrens that changed into forests tended to be found away from the coast, at lower elevations. Forests (both original and former barrens) were also generally found lower in valleys and in areas with steeper slopes with barrens found on top of ridges and in areas with more level slopes. The multivariate analysis of variance (MANOVA) conducted using the LDA scores indicated a significant difference between the two habitat types ($F_{(8, 3525)}$ 36.643, $P < 0.001$).

Table 4. Linear discriminant analysis (LDA) for all points classified into 2 successional groups (CBU and FOU) with actual means ± 1 SE and ranges for the measured environmental variables.

Environmental Variable	LD1	Coastal Barren Unchanged				Forest Unchanged			
		Standardized Mean	Mean ± SE	max	min	Standardized Mean	Mean ± SE	max	min
Northerly aspect	**0.0616**	0.0196	- 0.10 ± 0.02	1	-1	0.0077	- 0.11 ± 0.01	1	-1
Easterly aspect	**-0.052**	0.0364	0.13 ± 0.02	1	-1	-0.026	0.09 ± 0.02	1	-1
Total exposure	**-0.1035**	0.1017	4.07 ± 0.02	8	0	-0.0356	3.99 ± 0.015	8	0
Exposure to coast	**0.1152**	0.0486	2.00 ± 0.03	3	0	-0.0462	1.91 ± 0.02	3	0
Landscape position	**0.2512**	-0.1268	- 0.01 ± 0.00	0.48	-0.53	0.0886	0.00 ± 0.00	0.79	-0.48
Elevation	**-0.9193**	0.0195	19.19 ± 0.35	62.16	-0.3	-0.0072	18.06 ± 0.22	56.17	0.85
Distance to coast	**1.3517**	-0.2308	456.68 ± 9.29	1992.37	1.58	0.1607	649.45 ± 10.42	1948.08	0.39
Slope	**0.3925**	-0.0321	3.09 ± 0.07	17.92	0	0.0234	3.25 ± 0.06	19.83	0.04

See environmental variable descriptions in methods section. LD1 *represents the discriminant function used to classify the points into one of the two successional statuses. The* ***group means*** *represent the standardized means for each variable.*

LDAs with data from individual barrens sites separately (with points classified into two groups (CBU and FOU)) showed correct classifications ranging from 52% to 90% (Appendix B, tables B-1 to B-10). The most important variables at all sites were elevation, distance to coast, and slope but some sites showed important deviations from this pattern.

Both Peggy's Cove and Baleine had coastal barren habitat at lower elevations than forests, in contrast to the general model across all sites (Table 5). Canso showed the opposite pattern in distance to coast: forests were closer on average than coastal barrens. Landscape position at Taylor's Head differed from the general model: forests had higher landscape positions than coastal barrens (Table 5). Although forests were found on average to be at higher elevations than coastal barrens, the mean landscape position for forests was still a relatively low position within valleys.

Table 5. Summary of the linear discriminant analyses conducted using the data from each site separately. Included in the table: top two important environmental variables; LDA scores; mean scores; MANOVA results.

Site	LDA Summary					MANOVA Summary			
	Env Variable		LDA Score	CBU Mean	FOU Mean	p-value	F-statistic	D.F. Num	D.F. Denom
Baleine	1st	Elevation	0.6613	-0.5312	0.5549	<0.001	46.612	8	629
	2nd	Distance to coast	0.5478	-0.4854	0.4972				
Canso	1st	Elevation	-1.7543	0.3902	-0.2664	<0.001	37.825	8	1160
	2nd	Distance to coast	1.0341	0.1613	-0.1052				
Chebucto	1st	Distance to coast	1.1131	-0.5750	0.2706	<0.001	18.7806	8	556
	2nd	Elevation	-0.3983	0.0950	-0.0174				
Peggy's Cove	1st	Distance to coast	1.4367	0.1613	-0.1052	<0.001	34.218	8	899
	2nd	Elevation	-0.6223	0.3902	-0.2664				
Taylor's Head	1st	Elevation	-1.0826	0.2486	0.0200	<0.001	3.3888	8	255
	2nd	Landscape Position	-0.9254	0.1959	0.0279				

The LDA conducted for classifying the subset of 165 points with soil data using the two successional groups indicated that elevation, proximity to the coast and soil depth had the greatest ability to discriminate between the two groups. Coastal barrens at lower elevations with shallow soils and a close proximity to the coast tended to resist forest encroachment, where as forests tended to be found away from the coast, at lower elevations, and in areas with deeper soils (groups differed significantly: MANOVA: $F_{9,133}$=3.8238, P<0.001). Using this data set, the discriminant function was only slightly improved from 61% to successfully classifying 66% of the test data into the appropriate groups.

Classification Tree

The classification tree (CT) analysis for all five study sites combined resulted in correctly classifying 66 % and 65 % of the training and test data respectively (Figure 2). Elevation and distance to coast were found to be the most important variables in classifying this data set, contributing to eleven out of fifteen rules. The results of this concur with the results of the LDAs in suggesting that, in general, coastal barrens tend to occur within approximately 500 meters of the coast, at relatively higher elevations and in areas with gentle slopes. Forests are located at lower elevations, generally away from the coast, and in areas with steeper slopes.

This analysis goes a step further than the LDAs by explaining some of the interactions between variables in differentiating between the two groups. According to this analysis when coastal barrens occur at distances greater than 995m from the coast they generally occupy elevations greater than 45m on less than 4° slopes. Comparatively, forests found farther than 995m from the coast and at elevations greater than 45m typically occur on slopes with an angle greater than 4°. At distances closer than 995m coastal barrens generally occupy elevations greater than 45m or elevations lower than 1m where as forests generally occupy intermediate elevations closer than 995m from the coast.

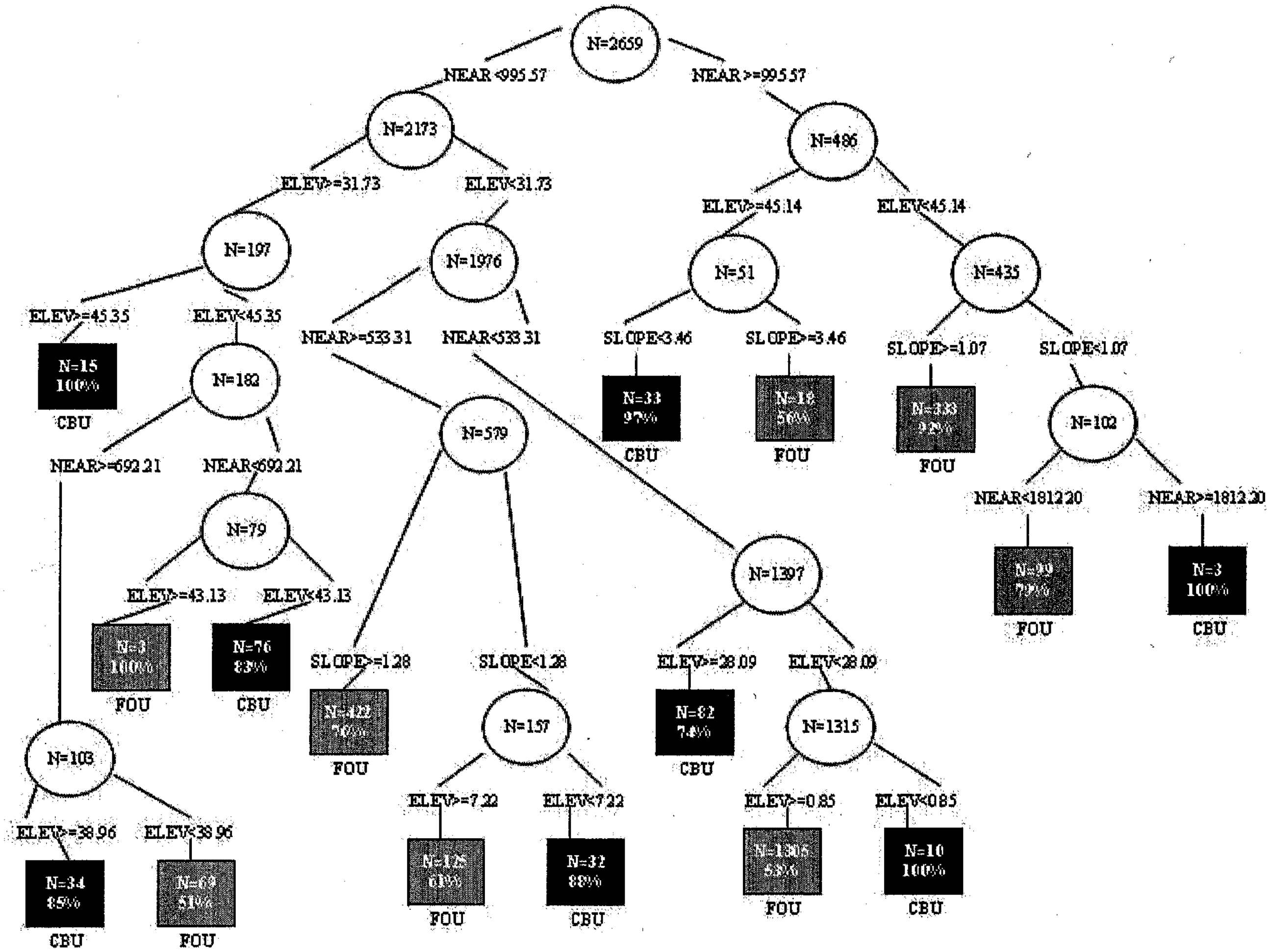


Figure 2. Classification tree diagram explaining differences in abiotic variables between points representing coastal barren habitat (**CBU**) and points representing forest habitat (**FOU**). Terminal leaves are represented by squares, where black indicates coastal barren habitat and grey indicates forests. The number of points the rule refers to as well as the accuracy of the rule are provided in the squares. **ELEV** refers to elevation, measured in meters; **SLOPE** refers to the slope of the ground, measured in degrees; **NEAR** refers to the proximity to the coast line, measured in meters.

Classification Tree Site Specific Results

Chebucto Head and Taylor's Head showed similar patterns to the global model (Table 6 and Table 7 respectively) with distance to coast and elevation as the most important variables in differentiating forest from coastal barren habitat, with coastal barrens occurring at higher elevations and relatively close to the coast. Canso was also found to be similar to the overall model in terms of elevation where coastal barrens are typically found higher than forest habitat (Table 8). However in terms of proximity to the coast, the CT analysis showed that forests are not only found at greater distances from the coast (approximately >500 meters), but are also found to occur within 100 meters of the coast whereas coastal barrens are generally found at intermediate distances at this site.

Table 6. Summary of rules generated from classification tree analysis for points located at Chebucto Head. The CT analysis conducted for points located at Chebucto Head correctly classified 84 % of the training data and 73 % of the test data.

Rule #	Rule Description	Class	Capture
1	If ELEV >= 29.99;and NEAR < 559; then status = CBU	CBU	10.1%
2	If ELEV < 31.73;and NEAR >= 559; then status = FOU	FOU	55.0%
3	If lpos4 < -0.018;and NEAR < 559; then status = CBU	CBU	24.8%
4	If Northss < 0.03; then status = CBU	CBU	60.8%
5	If SLOPE >= 10.67; then status = CBU	CBU	5.4%
6	If SLOPE >= 7.22; then status = CBU	CBU	12.4%
7	If EXPOS < 4; then status = FOU	FOU	12.4%
8	If NEAR >= 1139.19; then status = FOU	FOU	37.5%
9	If Northss >= 0.99; then status = CBU	CBU	8.5%
10	If NEAR < 134.23; then status = CBU	CBU	17.1%
11	If NEAR >= 134.23; then status = FOU	FOU	96.9%
12	If NEAR < 559;and Northss >= 0.03; then status = CBU	CBU	45.7%
13	If SLOPE < 7.22;and SLOPE >= 5.56; then status = FOU	FOU	9.6%
14	If ELEV >= 15.92; then status = FOU	FOU	79.4%
15	If ELEV >= 31.73;and SLOPE >= 3.06; then status = FOU	FOU	12.7%
16	If ELEV >= 45.01; then status = CBU	CBU	3.9%

ELEV *= elevation relative to mean sea level;* ***SLOPE*** *= slope angle of ground;* ***NEAR*** *= distance to coast line;* ***LPOS4*** *= determines whether point is in a valley or on a ridge top where a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge.* ***EXPOS*** *= records how many of the eight compass directions are exposed or protected, 8 being completely exposed and 0 being completely protected.* ***Northss*** *= determines what direction the slope is facing relative to North where 1 is due North and -1 is due South.* ***Class*** *includes the two successional groups used in the analysis including* ***CBU*** *= unchanged coastal barrens;* ***FOU*** *= unchanged forests as well as forests that were previously coastal barren.* ***Capture*** *refers to the percentage of the class, the rule applies to, that obey the rule.*

Table 7. Summary of rules generated from classification tree analysis for points located at Taylor's Head. The CT analysis conducted for points located at Taylor's Head correctly classified 93 % of the training data and 82% of the test data

Rule #	Rule Description	Class	Capture
1	If ELEV >= 18.21; then status = CBU	CBU	22.6%
2	If Northss >= -0.23; then status = FOU	FOU	61.1%
3	If NEAR >= 189.23; then status = FOU	FOU	38.9%
4	If ELEV < 7.94; then status = FOU	FOU	38.9%
5	If SLOPE < 2.29; then status = FOU	FOU	54.9%
6	If SLOPE >= 1.82; then status = FOU	FOU	58.6%
7	If NEAR < 130.71; then status = FOU	FOU	43.2%
8	If Eastss < 0.47; then status = FOU	FOU	64.2%
9	If Northss < -0.92; then status = FOU	FOU	9.9%
10	If lpos4 < -0.0054; then status = FOU	FOU	37.0%

ELEV *= elevation relative to mean sea level;* ***SLOPE*** *= slope angle of ground;* ***NEAR*** *= distance to coast line;* ***LPOS4*** *= determines whether point is in a valley or on a ridge top where a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge.* ***Northss*** *= determines what direction the slope is facing relative to North where 1 is due North and -1 is due South.* ***Eastsst*** *= determines what direction the slope is facing relative to East where 1 is due East and -1 is due West.* ***Class*** *includes the two successional groups used in the analysis including* ***CBU*** *= unchanged coastal barrens;* ***FOU*** *= unchanged forests as well as forests that were previously coastal barren.* ***Capture*** *refers to the percentage of the class, the rule applies to, that obey the rule.*

Table 8. Summary of rules generated from classification tree analysis for points located at Canso. The results of the CT conducted for points located at Canso correctly classified 75 % of the training data and 70 % of the test data.

Rule #	Rule Description	Class	Capture
1	If ELEV<5.32; then status = CBU	CBU	21.1%
2	If ELEV<29.07;and SLOPE>5.16; then status = FOU	FOU	19.3%
3	If ELEV>48.61; then status = CBU	CBU	11.1%
4	If NEAR>1250.71; then status = FOU	FOU	6.5%
5	If ELEV>50.05; then status = CBU	CBU	8.1%
6	If NEAR<76.15; then status = FOU	FOU	19.7%
7	ELEV<29.07;NEAR>488.13	FOU	30.3%
8	ELEV>29.07	CBU	40.1%
9	ELEV<12.3;ELEV>5.32	FOU	17.9%
10	ELEV>12.3;NEAR<488.13	CBU	36.3%
11	LPOS4<-0.0033	CBU	51.2%
12	ELEV<48.61;NEAR>993.53	FOU	12.8%

Note: ELEV *= elevation relative to mean sea level;* ***SLOPE*** *= slope angle of ground;* ***NEAR*** *= distance to coast line;* ***LPOS4*** *= determines whether point is in a valley or on a ridge top where a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge.* ***Class*** *includes the two successional groups used in the analysis including* ***CBU*** *= unchanged coastal barrens;* ***FOU*** *= unchanged forests as well as forests that were previously coastal barren.* ***Capture*** *refers to the percentage of the class, the rule applies to, that obey the rule.*

Coastal barren habitat at Baleine and Peggy's Cove showed similar results to the overall model in terms of proximity to the coast in that this habitat generally occurs within 250 and 700 meters of the coast respectively (Table 9 and Table 10 respectively). Elevation at these two sites deviated from the overall model in that coastal barrens are found at lower elevations (approximately < 10m) than forests. This analysis showed that coastal barren habitat at Peggy's Cove actually occurs at both ends of the elevation gradient whereas forests are generally found at intermediate elevations.

Table 9. Summary of rules generated from classification tree analysis for points located at Baleine. The CT analysis conducted for the points located at Baleine resulted in correctly classifying 86 % of the training data and 74 % of the test data.

Rule #	Rule Description	Class	Capture
1	If NEAR < 232.72; then status = CBU	CBU	39.4%
2	If ELEV < 7.43; then status = CBU	CBU	69.5%
3	If NEAR >= 1008.03; then status = FOU	FOU	30.6%
4	If ELEV >= 7.43; and SLOPE >= 1.62; then status = FOU	FOU	51.9%
5	If SLOPE >= 2.08; then status = FOU	FOU	41.3%
6	If SLOPE >= 1.3; then status = FOU	FOU	68.9%
7	If ELEV >= 7.43; and NEAR < 775.02; and NEAR >= 505.65; then status = FOU	FOU	20.4%
8	If SLOPE < 1.62; then status = CBU	CBU	74.0%
9	If NEAR >= 775.02; then status = FOU	FOU	52.3%
10	If NEAR < 234.95; the status = CBU	CBU	39.8%
11	If Eastss < 0.06; then status = CBU	CBU	47.2%

***Note: ELEV** = elevation relative to mean sea level; **SLOPE** = slope angle of ground; **NEAR** = distance to coast line; **Eastsst** = determines what direction the slope is facing relative to East where 1 is due East and -1 is due West. **Class** includes the two successional groups used in the analysis including **CBU** = unchanged coastal barrens; **FOU** = unchanged forests as well as forests that were previously coastal barren. **Capture** refers to the percentage of the class, the rule applies to, that obey the rule.*

Table 10. Summary of rules generated from classification tree analysis for points located at Peggy's Cove. The CT analysis conducted using points located at Peggy's Cove correctly classified 78 % and 68 % of the training and test data respectively.

Rule #	Rule Description	Class	Capture
1	If NEAR < 180.51; then status = CBU	CBU	34.6%
2	If ELEV < 9.77; then status = CBU	CBU	29.4%
3	If NEAR >= 745.76; then status = FOU	FOU	51.3%
4	If Eastss >= 0.49; and NEAR >= 745.76; then status = FOU	FOU	19.9%
5	If ELEV >= 25.18; and NEAR < 745.76; then status = CBU	CBU	19.4%
6	If ELEV >= 42.23; then status = FOU	FOU	0.5%
7	If Eastss >= 0.18; then status = FOU	FOU	47.4%
8	If lpos4 >= 0.048; then status = FOU	FOU	16.8%
9	If NEAR < 469.55; and Northss >= 0.4; then status = CBU	CBU	24.9%
10	If ELEV < 25.18; and NEAR >= 469.55; then status = FOU	FOU	42.3%
11	If NEAR < 745.76; then status = CBU	CBU	87.4%

***Note: ELEV** = elevation relative to mean sea level; **SLOPE** = slope angle of ground; **NEAR** = distance to coast line; **LPOS4** = determines whether point is in a valley or on a ridge top where a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge. **Northss** = determines what direction the slope is facing relative to North where 1 is due North and -1 is due South. **Eastsst** = determines what direction the slope is facing relative to East where 1 is due East and -1 is due West. **Class** includes the two successional groups used in the analysis including **CBU** = unchanged coastal barrens; **FOU** = unchanged forests as well as forests that were previously coastal barren. **Capture** refers to the percentage of the class, the rule applies to, that obey the rule.*

Subset Data

The CT analysis conducted using the subset of 165 points located at Peggy's Cove, Taylor's Head and Canso correctly classified 75 % and 66 % of the training and test data respectively. Table 9 presents the rules for this analysis for which soil depth was found to be the most important variable in classifying this data set. Distance to coast, aspect, and total exposure were also found to be important in differentiating between the two classes. Based on this analysis, coastal barrens occur in areas with shallow soil, and are along north and south facing slopes. Forests are found in areas that are more exposed. Charcoal data was added as a variable in this analysis but this did not improve the model in differentiating between habitat types. This further indicates that fire may not be the sole means by which coastal barrens can persist.

Table 11. Summary of rules generated from classification tree analysis for points located at Taylor's Head.

Rule #	Rule Description	Class	Capture
1	If DEPTH < 7; then status = CBU	CBU	14.6%
2	If NEAR < 31.21751; then status = CBU	CBU	4.9%
3	If Northss < -0.9975336; then status = CBU	CBU	7.3%
4	If Northss >= 0.9949845; then status = CBU	CBU	2.4%
5	If EXPOS < 3; then status = CBU	CBU	2.4%
6	If EXPOS >= 3; then status = FOU	FOU	100.0%

***NEAR** = distance to coast line; **Northss** = determines what direction the slope is facing relative to North where 1 is due North and -1 is due South; **EXPOS** = records how many of the eight compass directions are exposed or protected, 8 being completely exposed and 0 being completely protected; **DEPTH** = soil depth (cm). **Class** includes the two successional groups used in the analysis including **CBU** = unchanged coastal barrens; **FOU** = unchanged forests as well as forests that were previously coastal barren. **Capture** refers to the percentage of the class, the rule applies to, that obey the rule.*

Charcoal

The presence of charcoal in soil was examined at three of the five study sites including Peggy's Cove, Taylor's Head, and Canso. No evidence of fire was found at Taylor's Head whereas charcoal was detected at 21 and 13 points at Peggy's Cove and Canso respectively (Table 12).

Table 12. Percentage of points where charcoal was detected at three study sites including Peggy's Cove, Taylor's Head, and Canso.

Habitat Type	Peggy's Cove	Taylor's Head	Canso
FOU	55 %	0 %	25 %
CBC	25 %	0 %	20 %
CBU	25 %	0 %	21 %
Total	35 %	0 %	22%

***Habitat Type: FOU** = all points classified as unchanged forests; **CBU** = all points classified as unchanged coastal barrens; **CBC** = all points classified as forests that were previously coastal barren.*

Discussion

This study showed that coastal barrens tend to occur closer to the coast than forests, at relatively higher elevations and along ridge tops. In general, areas close to the coast tend to experience coastal effects such as salt spray and wind exposure that may impede forest establishment (Griffiths and Orians 2004). These stresses remove moisture from vegetation through mechanical means created by the wind as well as through chemical and physical reactions caused by the increased levels of salt in the air and soil (Leone et al. 2007; Magio et al. 2005; Wells and Shunk 1938). Elevated sodium levels can be detrimental to non-tolerant vegetation causing defoliation, necrosis, reduction in moisture uptake, and increased mortality.

At relatively high elevations and along ridge tops, land may be more exposed to harsh climatic conditions, exposed bedrock, and substantially less soil development. These conditions may support the persistence of the microshrub habitats associated with coastal barren ecosystems consisting of a thin layer of vegetation spreading clonally on top of exposed bedrock (Oberndorfer and Lundholm 2009). These persistent barrens may be maintained by at least two factors: severely shallow and exposed soils, and coastal effects of wind and/or salt spray. The distribution of such conditions on the landscape is limited by topography and the presence of bedrock close to the surface; thus the area available for long-term persistence of low shrub barrens communities is small. Our assessment of the long-term persistence of these barrens is only based on the last 70 years. It is also possible that the lower classification success for some of the analyses is because forest succession may still be occurring in some of the current-day unchanged barrens that may still develop into forests.

Results of the aerial photograph analysis show that forests are encroaching onto coastal barren habitat in Nova Scotia. Rare plant species that occur in low shrub communities are typically absent from areas with taller vegetation (Oberndorfer and Lundholm 2009). As forest succession occurs, and competition for light increases, these rare species become replaced by taller growing shrubs and eventually tree species (Mitchell et al.1997). This is a widespread issue in barrens and heathlands of many kinds across the northern hemisphere (Harper 1995; Andrés and Ojeda 2002; Mitchell et al. 2000; Maurice et al. 2004; Rhoades et al. 2005). As a result, important environmental conditions required by these rare species offered by unproductive, open habitats may diminish over time as forests encroach further onto coastal barren habitat.

Our results suggest that soil depth may be a significant factor in explaining abiotic differences between coastal barren and forest habitat. Coastal barrens typically have shallower soil than forests. However, soil depth may not be independent of the above ground vegetation used to classify the points in this study, as forest succession can increase soil depth through litter deposition and decomposition. Therefore, soil depth may not be a causal factor in forest encroachment.

Sample size may play a role in explaining the difference between the LDA results of the subset data and the complete data set in regards to elevation and total exposure. Where it was shown that there was much overlap in terms of the selected variables between coastal barren and forest points, there is a chance that any subsample of points consisting of a significantly lower number of samples may have different results through chance alone.

The rate of forest encroachment differed among sites, and these differences can be explained in terms of topographic and climatic differences across the range of barrens habitat in Nova Scotia. The Baleine site showed the lowest encroachment rate, remaining relatively stable over the past 70 years and also contained the highest number of rare plant species (Oberndorfer and Lundholm 2009). Rare species generally require the persistence of a suitable habitat for a relatively long period of time as these species generally have low dispersal ability and require longer time periods to become established in a particular area (Latham 1996; Latham 2003). This site is on the southeastern tip of Cape Breton and experiences high amounts of fog and rain as well as high levels of wind exposure. These harsh growing conditions can be seen in the krummholtz growth forms of trees that are found at this site (S. Burley pers. obs.). These factors slow tree growth rate and create conditions that may not promote tree seedling establishment. The macrotopography of Baleine is generally homogeneous consisting of low relief ranging from approximately 0 to 35 meters over the entire site (Figure A-1, Appendix A). This relatively flat topography offers little protection from the driving wind and rain, compared with other sites such as Canso and Peggy's Cove, both of which are more topographically heterogeneous and have higher relief, and have higher rates of forest expansion. Forests at the latter sites tend to be found along valley bottoms and on areas having intermediate slope angles which may offer more protection from the elements and allow for the accumulation of soils, creating more suitable conditions for forest establishment.

Points representing coastal barren at Peggy's Cove and Baleine were found to have a lower average elevation than points representing forest. This was opposite to the overall model which showed forest generally at lower elevations than coastal barren. This can be explained by the topography of these two sites in which elevation is very low at the coast and gradually increases with increased distance from the coast (Figures A-2 and A-4, Appendix A). The greater detail provided by the CT analysis shows that at Peggy's Cove, forests tended to occur at intermediate elevations, with coastal barren habitat at lower and higher elevations. Higher elevations at Peggy's Cove tend to be associated with areas of exposed bedrock and increased wind exposure which might allow for the persistence of barren communities. Alternatively, coastal barren habitat located below ten meters elevation may be associated with areas close to the coast which are subject to extreme coastal effects creating conditions which maintain coastal barrens. These elevations may also be influenced by the proximity to the water table and may be too wet for forests to develop, allowing for bogs to persist in these areas.

Taylor's Head and Chebucto Head were found to match the general pattern across sites where coastal barren was generally found at higher elevations and close to the coast (Figures A-5 and A-3, Appendix A). However Taylor's Head was found to differ in terms of landscape position where forests are found to occupy an average position higher in the valleys than coastal barren habitat. The values for this variable are very similar between the two habitat types and this deviation from the overall model may be a result of the low representation of coastal barren habitat at this site.

Points representing forests at Canso were also, on average, closer to the coast than coastal barrens points, in contrast to the other sites. This may be an artefact of the sample design where the area studied may not have extended far enough inland to capture more forest habitat (Figure A-2, Appendix A). Boundary delineation was based on a previous study and may not have extended far enough inland in this case to capture enough of the continuous forest. This site consists of a large matrix of forest patches intermixed with coastal barren habitat that extends into a rural community where the northern boundary was established. Because of this, the area sampled adequately represents this matrix but does not extend far enough inland to show where this patchwork of forest/coastal barren habitat stops and the continuous forest begins across the entire site. Based on observations from the field, closed canopy forests do become prominent farther inland

and the occurrence of barren habitat ceases. Had the sample area extended into the closed canopy forest, the results of the analysis would show that coastal barrens are typically found closer to the coast.

The distribution of coastal barren and forest may help explain the relatively fast rate of forest encroachment that occurred at Canso compared to other study sites. Where coastal barren is located at greater distances inland, coastal effects may not have as much of an influence on barren persistence. The presence of charcoal was detected in many areas at Canso indicating that these open shrublands, located farther inland, may have originated from a past disturbance such as fire that removed the tree species. These inland areas now show a typical forest successional pathway. Similar to Canso, Peggy's Cove shows evidence of fire disturbance with barren habitat also extending at least two kilometres inland. The majority of coastal barren habitat that was found to experience forest encroachment occurred at distances greater than approximately 500 meters from the coast. With diminishing coastal effects and in the absence of repeated fires, these areas may represent early successional communities that over time become reforested. Chebucto Head was also sampled for charcoal as part of a pilot study and only one out of all points sampled contained charcoal (S. Burley, Unpublished data), and this site had very similar species composition to Taylor's Head and Peggy's Cove (Oberndorfer and Lundholm 2009). The complete absence of charcoal at Taylor's Head, at least for barrens close to the coast, suggests that fire is not required for the long-term maintenance of this vegetation. Fire might act to increase the area covered by barrens, over and above the effects of coastal influence or shallow soils, and may have been historically important in increasing the area available for rare barrens species and vegetation types. Nevertheless, the absence of fire evidence at several sites that have similar overall vegetation to sites that burned suggests that while fire can increase barrens area, it is not required for the long-term persistence of barrens in coastal Nova Scotia within 500 m of the coast.

Based on the results of this study, there are at least two kinds of barrens in these systems: *successional* barrens that develop into forests over time in the absence of disturbance and *persistent* barrens maintained by shallow soils and coastal effects. Inland sites that experienced fire are more likely to have persistent barrens in exposed headlands. Therefore, disturbance, topography and edaphic conditions determine the position and extent of barrens further inland (also see Arabas 2000). The presence of both persistent and successional barrens in the larger barrens complexes complicates management of these systems. The current study provides a set of environmental factors that can help managers identify areas that are most likely to require disturbance to remain open, and suggests that the most important areas to protect from further human impact are the persistent barrens typically located closest to the coast. We speculate that the persistent barrens act as sources of plants for colonization of successional barrens after disturbance.

While this idea of persistent barrens intermixed with successional barrens has not been generally recognized, there are many examples of temperate barrens or heathlands that show a similar pattern to that described for the coastal barrens studied here: a relatively small, peripheral area of open barren persists near the coast or inland where extreme edaphic conditions resist pedogenesis, but the extent of similar vegetation is greatly increased due to natural and/or human disturbances such as burning and grazing that prevent forest succession. This "peripheral refugium" idea is supported by studies of coastal heathlands and sandplain grasslands in New England (Motzkin and Foster 2002), limestone pavement in Ontario (Stark et al. 2004), and alvar grassland in Estonia (Pärtel et al. 1999). In Europe, the larger barrens areas outside of the peripheral (coastal) refugia are often accorded conservation value and the disturbance regimes that maintain the inland range expansion of the communities can be well-known (Rosén 1988). In some cases, the disturbance-dependent vegetation shows important differences from that in coastal or edaphic refugia (Motzkin and Foster 2002) but in other cases, vegetation may be very similar (Schaefer and Larson 1997). This idea finds further support in studies showing that plant species that make up old-field vegetation in North America (Marks 1983) and grasslands in the UK (Grubb 1976) were once much less abundant prior to large scale land clearing, and that these species had refugia in peripheral habitats kept free of forest due to shallow soils or coastal influences. In general, managers of rock barrens or heathland vegetation need to determine to what extent their system is successional and where the long-term refugia are for the vegetation in case the majority of the sites represent disturbance-maintained vegetation types (e.g. Asselin et al. 2006).

Finally, while the overall trend when there was change in these systems was the replacement of open barrens by forest, other studies suggest that rising sea level may spread coastal effects further inland (Crawford 2003). Thus current day coastal barrens may exist as a balance between forest spread from successional inland barrens and coastal effects with an increasing extent inland. Coastal barrens at low elevation sites might be expected to shift inland with a loss of the habitat closest to the coast, whereas barrens that have high elevations closest to the coast might expand inland due to increased salt deposition with no loss of habitat due to rising sea levels.

Conclusions

Coastal barren vegetation in Nova Scotia provides habitat for a number of rare plant species, contain unique community types, and provide important socioeconomic functions for tourism. Areas highlighted by this study that are found to resist forest encroachment may represent stable, climax communities and may offer refugia for unique species assemblages. This study suggests that barrens systems exhibiting the proposed "peripheral refugium" concept may require attention for two distinct issues: protection of coastal or edaphic refugia and decisions on whether management should be conducted to increase the area of successional barrens that are experiencing forest encroachment. While this study represents a "snapshot" in ecological time, it is also important to acknowledge the potential for further forest encroachment resulting in the further loss to coastal barren habitat. In particular where this study found similarities in abiotic conditions between certain areas classified as coastal barren and those classified as forests, conditions at these areas may be conducive to forest establishment and over time may eventually become forested as propagules reach these areas.

References

Anderson, R.C.; Fralish, J.S.; and Baskin, J.M. (eds.). 1999. Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, New York, New York. 470 p.

Andrés, C. and Ojeda, F. 2002. Effects of afforestation with *Pinus pinaster* on biodiversity of Mediterranean heathlands in South Spain. *Biodiversity and Conservation* 11: 1511-1520.

Arabas, K.B. 2000. Spatial and Temporal Relationships among Fire Frequency, Vegetation, and Soil Depth in an Eastern North American Serpentine Barren. *Journal of the Torrey Botanical Society*, Vol. 127: 51-65.

Asselin, H.; Belleau, A.; and Bergeron, Y. 2006. Factors responsible for the co-occurrence of forested and unforested rock outcrops in the boreal forest. *Landscape Ecology* 21: 271-280.

Bakker, J. P., E. S. Bakker, E. Rosen, G. L. Verweij, and R. M. Bekker. 1996. Soil seed bank composition along a gradient from dry alvar grassland to Juniperus shrubland. *Journal of Vegetation Science* **7**:165-176.

Bazzaz, F.A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics*. 10: 351-371.

Bradley, R.L.; Titus, B.D.; and Fyles, J.W. 1997. Nitrogen acquisition and competitive ability of Kalmia angustifolia L., Paper Birch (Betula papyrifera Marsh.) and Black Spruce (Picea mariana (Mill.) B.S.P.) seedlings grown on different humus forms. *Plant and Soil* 195: 209-220.

Burbanck, M. P., and R. B. Platt. 1964. Granite outcrop communities of the Piedmont plateau in Georgia. *Ecology* 45: 292-306.

Commission of Conservation Canada (CCC). 1912. Forest Distribution in Nova Scotia. Cape Breton, Truro, and Halifax map Sheets.

Crawford R.M, 2003. Seasonal differences in plant responses to flooding and anoxia. *Canadian Journal of Botany* 81 (12): 1224-1246.

Curt, T.; Prevosto, B.; Klesczewski, M.; and Lepart, J. 2003. Post-grazing Scots pine colonization of mid-elevation heathlands: population structure, impact on vegetation composition and diversity. *Annals of Forest Science* 60: 711-724.

Dunwiddie, P.W.; Zaremba, R.E.; and Harper, K. 1996. A classification of Coastal Heathlands and Sandplain Grasslands in Massachusetts. *Rhodora* 98 (94): 117-145.

Ehrenfeld, J.G.; Zhu, W.; and Parsons, W.F.J. 1995. Above- and below-ground characteristics of persistent forest openings in the New Jersey Pinelands. *Bulletin of the Torrey Botanical Club* 122 (4): 298-305.

Environment Canada 2006. Canadian Climate Normals or Averages 1971-2000. Viewed October 10, 2008. Available [online] http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

ESRI 2006. ArcView 9.2. Redlands, USA.

Faison, E.K.; Foster, D.R.; Oswald, W.W.; Hansen, B.S.C.; and Doughty E. 2006. Early Holocene openlands in southern New England. *Ecology* 87 (10): 2537-2547.

Foster, D.R. and Motzkin, G. 2003. Interpreting and conserving the openland habitats of coastal New England: insights from landscape history. *Forest Ecology and Management* 185: 127-150.

Gotelli, N.J. and Ellison, A.M. 2004. A Primer of Ecological Statistics. Sinauer Associates, Inc. Sunderland, Massachusetts.

Greene, D.F.; Zasada, J.C.; Sirois, L.; Kneeshaw, D.; Morin, H.; Charron, I; and Simard, M. J. 1998. A review of the regeneration dynamics of North American boreal forest tree species. *Canadian Journal of Forest Research* 29: 824-839.

Griffiths, M.E. and Orians, C.M. 2004. Salt spray effects on forest succession in rare coastal sandplain heathlands: evidence from field surveys and *Pinus rigida* transplant experiments. *Journal of the Torrey Botanical Society* 131 (1): 23-31.

Grubb, P.J. 1976. A theoretical background to the conservation of ecologically distinct groups of annuals and biennials in the chalk grassland ecosystem. *Biological Conservation* 10: 53-76.

Harper, K.A. 1995. Effect of expanding clones of Gaylussacia baccata (black huckleberry) on species composition in sandplain grassland on Nantucket Island, Massachusetts. *Bulletin of the Torrey Botanical Club* 122 (2): 124-133.

Jaderlund, A.; Zackrisson, O.; Dahlberg, A.; and Nilsson, M. 1997. Interference of *Vaccinium myrtillus* on establishment, nutrition, and growth of *Picea abies* seedlings in a northern boreal site. *Canadian Journal of Forest Research* 27: 2017-2025.

Krahulec, F.R.E. and van der Marrel, E. 1986. Preliminary classification and ecology of dry grassland communities on Olands Stora Alvar (Sweden). *Nord. J.Bot.* 6: 797-808.

Krause, C. 2006. Growth development of balsam fir (*Abies balsamea* (L.) Mill.) originating from layering. *Dendrochronologia* 23: 139-143.

Kuiters, A.T. and Slim, P.A. 2002. Regeneration of mixed deciduous forest in a Dutch forest-heathland, following a reduction in ungulate densities. *Biological Conservation* 105: 65-74.

Larson, D. W., U. Matthes, and P. E. Kelly. 2000. Cliff Ecology. Cambridge University Press, Cambridge.

Latham, E.R. 2003. Shrubland longevity and rare plant species in the Northeastern United States. *Forest Ecology and Management* 185: 21-39.

Latham, E.R.; Thompson, J.E.; Riley, S.A.; and Wibiralske A.W. 1996. Pocono till barrens: shrub savannah persisting on soils favoring forests. *Bulletin of the Torrey Botanical Club* 123 (4): 330-349.

Laycock, W.A., 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. *Journal of Range Management* 44 (5): 427–433.

Legendre, P. and Legendre, L. 1998. Numerical Ecology. Elsvier Scientific Publishing Company, Amsterdam.

Leone, A.P.; Menenti, M.; Buondonno, A; Letizia, A.; Maffei, C.; and Sorrentino, G. 2007. A field experiment on spectrometry of crop response to soil salinity. *Agricultural Water Management* 89: 39-48.

Maggio, M.; De Pascale, S.; Ruggiero, C.; and Barbieri, G. 2005. Physiological response of field-grown cabbage to salinity and drought stress. *European Journal of Argonomy* 23: 57-67.

Mallik, A.U. 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. *Critical Reviews in Plant Science* 22 (3&4): 341-366.

Mallik, A.U. 1995. Conversion of temperate forests into heaths: Role of ecosystem disturbance and Ericaceous plants. *Environmental Management* 19 (5): 675-684.

Marks, P.L. 1983. On the origin of the field plants of the northeastern United States. *The American Naturalist* 122: 210-228.

Maurice, K.R.; Welch, J.M.; Brown, C.P.; and Latham, R.E. 2004. Pocono mesic till barrens in retreat: topography, fire and forest contagion effects. *Landscape Ecology* 19: 603-620.

McVaugh, R. 1943. The vegetation of the granitic flat-rocks of the southeastern United States. *Ecol. Monogr.* 13:119-166.

Mitchell, R. J.; Auld, M. H. D.; Le Duc, M. G.; and Marrs, R. H. 2000. Ecosystem stability and resilience: a review of their relevance for the conservation management of lowland heaths. *Perspectives in Plant Ecology Evolution and Systematics* 3 (2): 142-160.

Mitchell, R.J.; Marrs, R.H.; LeDuc M.G.; and Auld, M.H.G. 1997. A study of succession on lowland heaths in Dorset, southern England: changes in vegetation and soil chemical properties. *Journal of Applied Ecology* 34: 1426-1444.

Motzkin G. and Foster, D.R. 2002. Grasslands, shrublands, and heathlands in coastal New England: historical interpretations and approaches to conservation. *Journal of Biogeography* 29: 1569-1590.

Neily, P.; McCurdy, D.; Stuart, B.; and Quigley, E. 2004. Coastal Forest Communities of the Nova Scotian Eastern Shore Ecodistrict. *Forest Research Report* 74. Nova Scotia Department of Natural Resources Forest Management Planning.

Nova Scotia Museum of Natural History. 1997a. *Natural History of Nova Scotia VolumeI: Topics and Habitats.* Nova Scotia Museum of Natural History, Nova Scotia.

Nova Scotia Museum of Natural History. 1997b. *Natural History of Nova Scotia VolumeII: Theme Regions.* Nova Scotia Museum of Natural History, Nova Scotia.

Oberndorfer, E., and Lundholm, J.T. 2009. Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. In press, Biodiversity and Conservation.

Oosting, H. J. and Anderson, L. E. 1939. Plant succession on granite rock in eastern North Carolina. *Bot. Gaz.* 100: 750-768.

Partel, M.; Kalamees, R.; Zobel, M.; and Rosen, E. 1999. Alvar grasslands in Estonia: variation in species composition and community structure. *Journal of Vegetation Science* 10: 561-568.

R version 2.5.1 (2007-06-27). The R Foundation for Statistical Computing. ISBN 3-900051-07-0.

Rejmanek, M. and Rosen, E. 1988. The effects of colonizing shrubs (*Juniperus communis* and *Potentilla fruticosa*) on species richness in the grasslands of Stora Alvaret, Oeland (Sweden). *Acta phytogeogr. suec.* 76: 67-72.

Rhoades, C.; Miller, S. P.; and Skinner, D. L. 2005. Forest vegetation and soil patterns across glade-forest ecotones in the knobs region of northeastern kentucky, USA. *American Midland Naturalist* 154 (1): 1-10.

Rosen, E. 1988. Shrub expansion in alvar grasslands on Oeland. *Acta phytogeogr. suec.* 76: 87-100.

Saldarriaga, J.G.; West, D.C.; Tharp, M.L.; and Uhl, C. 1988. Long-term chronosequence of forest succession in the Upper Rio Negro of Columbia and Venezuela. *The Journal of Ecology* 76 (4): 938-958.

Saha, A. 2008. Classification Tree in Excel. http://www.geocities.com/adotsaha/CTree/CtreeinExcel.html. Viewed 12 March, 2008.

Schaefer, C.A. and Larson, D. W. 1997. Vegetation, environmental characteristics and ideas on the maintenance of alvars on the Bruce Peninsula, Canada. *Journal of Vegetation Science* 8: 797-810.

Stark, K. E., J. T. Lundholm, and D. W. Larson. 2003. Relationships between seed banks and spatial heterogeneity of North American alvar vegetation. *Journal of Vegetation Science* 14:205-212.

Stark, K. E., J. T. Lundholm, and D. W. Larson. 2004. Arrested development of soil on alvars of Ontario, Canada: implications for conservation and restoration. *Natural Areas Journal* 24:95-100.

Suding, K.N.; Gross, K.L.; and Houseman, G.R. 2004. Alternative states and positive feedback in restoration ecology. *Trends in Ecology and Evolution* 19 (1): 46-53.

Wells, B.W. and Shunk, I.V. 1938. Salt spray: an important factor in coastal ecology. *Bulletin of the Torrey Botanical Club* 65 (7): 485-492.

Appendix A
Maps of Five Coastal Barren Study Sites

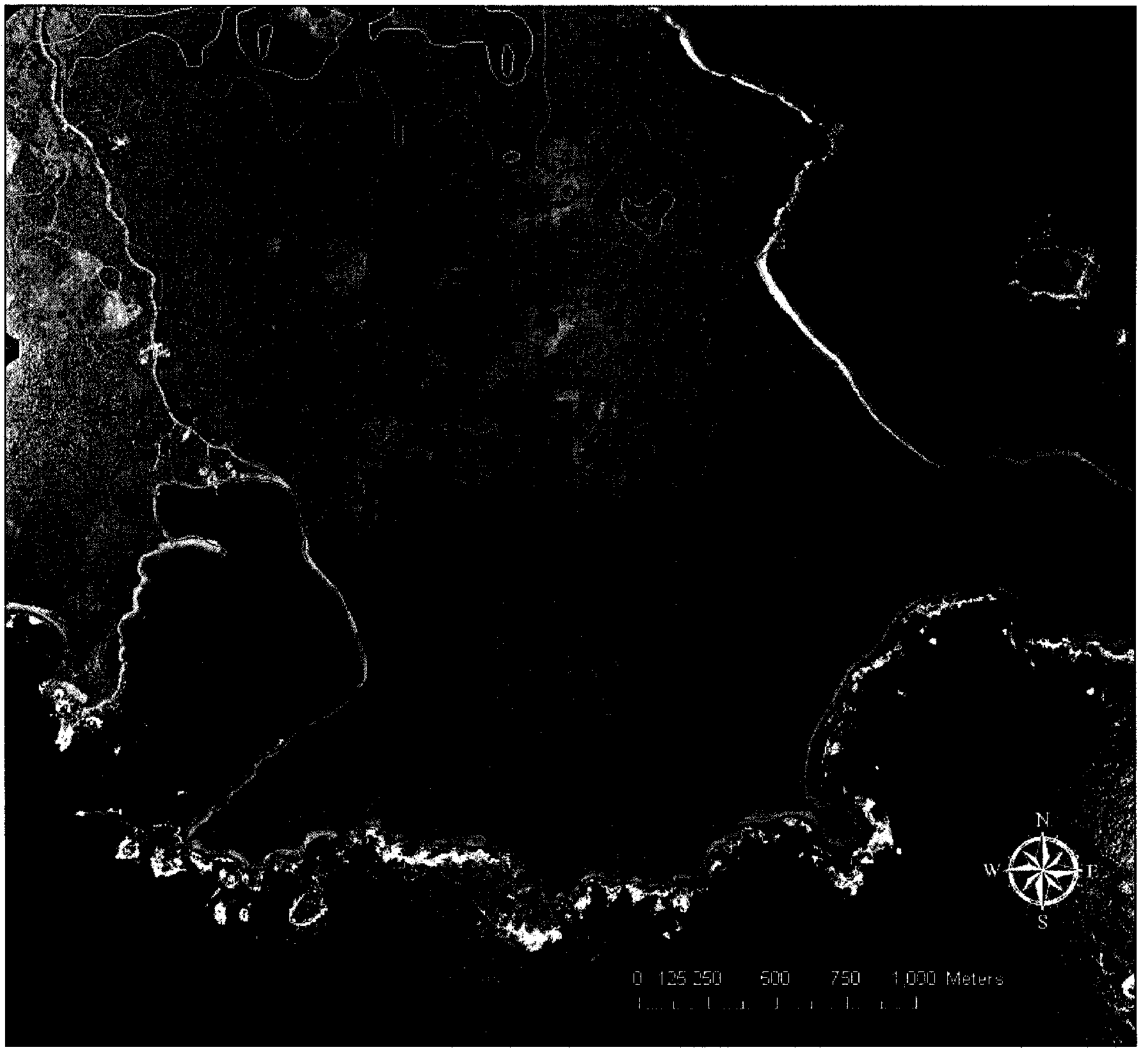


Figure A-1. Site map of Baleine study site with contours lines showing elevation where red indicates a lower elevation; orange indicates an intermediate elevation; and yellow indicates a higher elevation.

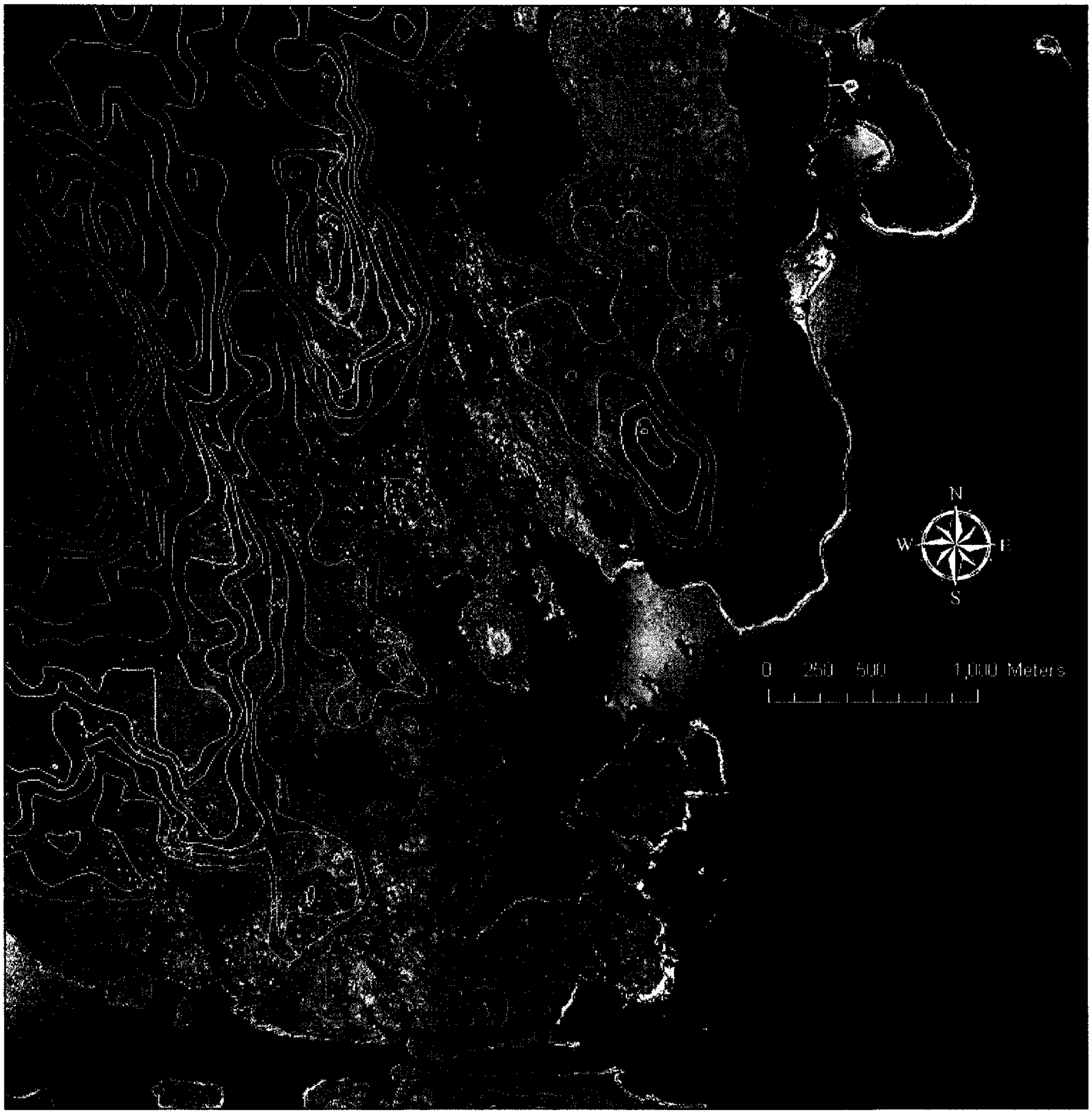


Figure A-2. Site map of Canso study site with contours lines showing elevation where red indicates a lower elevation; orange indicates an intermediate elevation; and yellow indicates a higher elevation. The black portion illustrates the limits of aerial photo coverage.

Figure A-3. Site map of Chebucto Head study site with contours lines showing elevation where red indicates a lower elevation; orange indicates an intermediate elevation; and yellow indicates a higher elevation. The black portion illustrates the limits of aerial photo coverage.

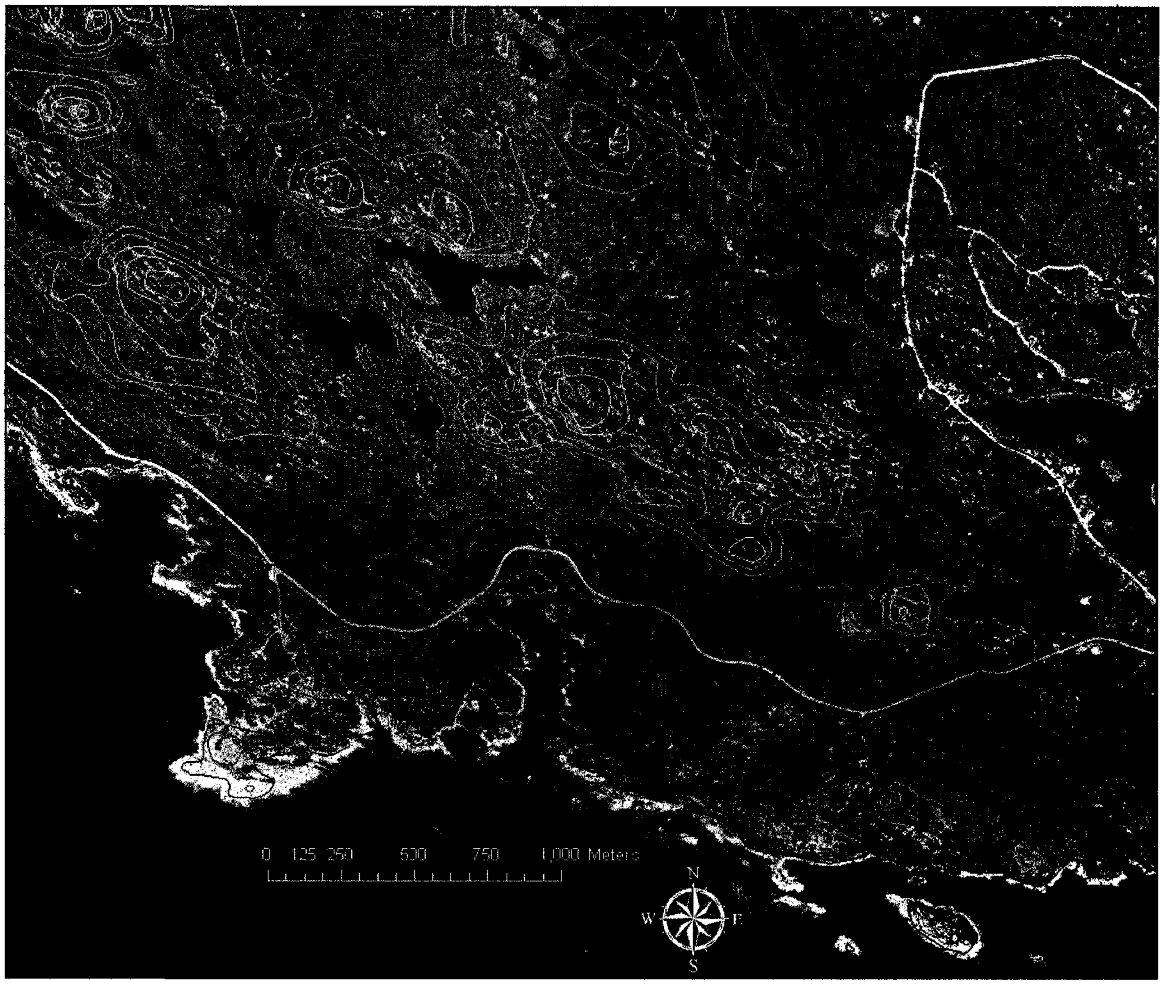


Figure A-4. Site map of Peggy's Cove study site with contours lines showing elevation where red indicates a lower elevation; orange indicates an intermediate elevation; and yellow indicates a higher elevation. The black portion illustrates the limits of aerial photo coverage.

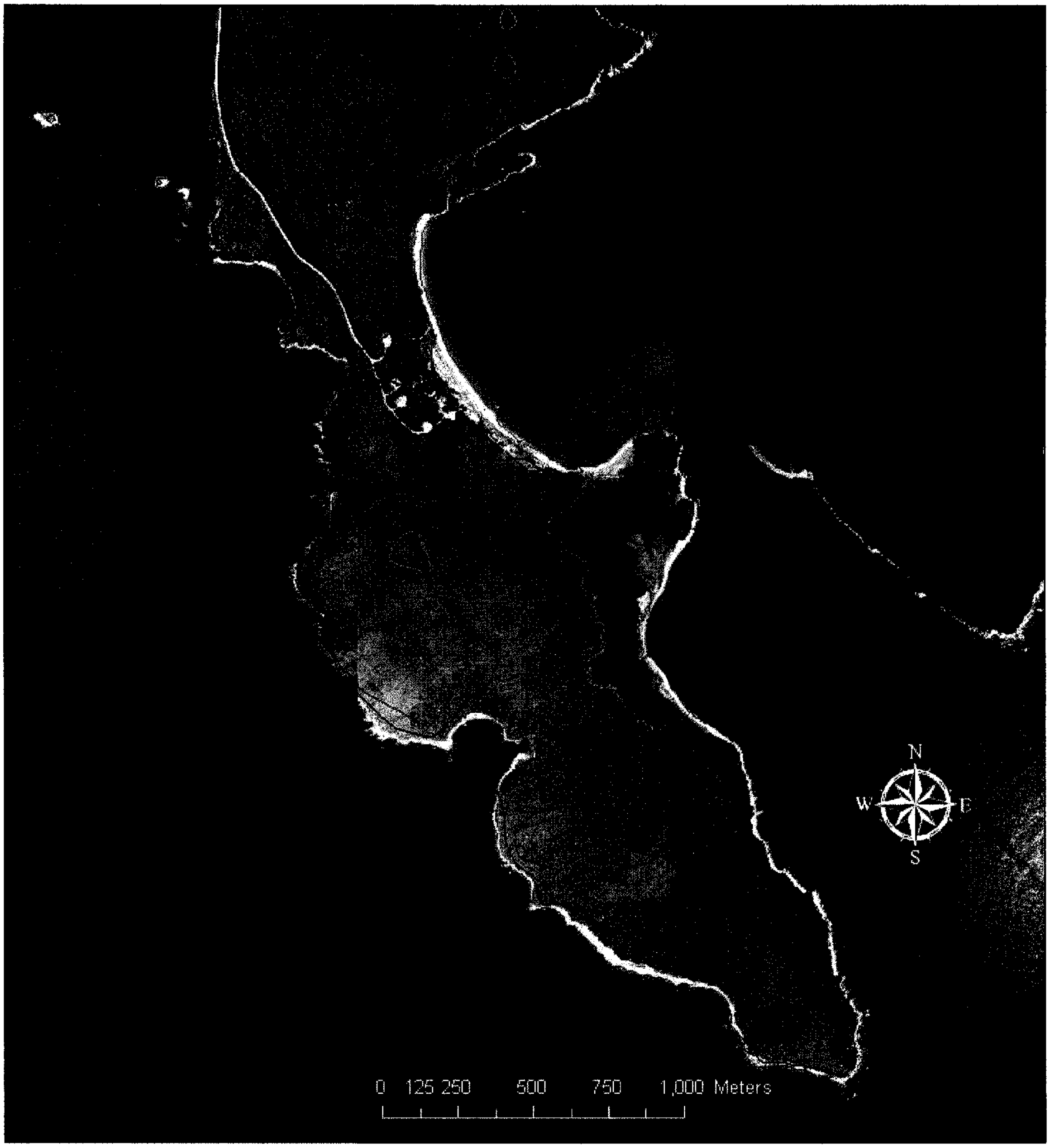


Figure A-5. Site map of Taylor's Head study site with contours lines showing elevation where red indicates a lower elevation; orange indicates an intermediate elevation; and yellow indicates a higher elevation. The black portion illustrates the limits of aerial photo coverage.

Appendix B
Linear Discriminant Analysis (LDA) Results Table

Note - For the following tables: ***Northerly aspect*** *= determines what direction the slope is facing relative to North where 1 is due North and -1 is due South.* ***Easterly aspect*** *= determines what direction the slope is facing relative to East where 1 is due East and -1 is due West.* ***Total Exposure*** *= records how many of the eight compass directions are exposed or protected, 8 being completely exposed and 0 being completely protected.* ***Exposure to coast*** *= based on the angle of the coast to each point.* ***Landscape position*** *= determines whether point is in a valley or on a ridge top where a positive value indicates a valley bottom position; a value of approximately 0 indicates an intermediate location; and a negative number indicates the point is on top of a ridge.* ***Elevation*** *= elevation in meters compared to mean sea level.* ***Distance to coast*** *= the distance in meters each point is located in relation to the ocean coast line.* ***Slope*** *= the angle of the ground at each point measured in degrees.* ***LD1*** *represents the discriminant function used to classify the points into one of the two successional statuses. The* ***group means*** *in LDA tables represent the standardized means for each variable.*

Table B-1. Linear discriminant analysis (LDA) for points located at Baleine classified into 2 successional groups (CBU and FOU) correctly classifying 52 % of the test data.

Environmental Variable	LD1	CBU Mean	FOU Mean
Northerly aspect	**0.0699**	0.0513	-0.0820
Easterly aspect	**0.0956**	-0.0549	0.0299
Total exposure	**0.0290**	-0.0462	-0.0002
Exposure to coast	**0.1198**	0.0322	-0.0271
Landscape position	**0.1252**	0.0263	0.0414
Elevation	**0.6613**	-0.5312	0.5549
Distance to coast	**0.5478**	-0.4854	0.4972
Slope	**0.4160**	-0.2858	0.3008

Table B-2. Actual means and ranges for the measured environmental variables for points located at Baleine classified into two successional groups (CBU and FOU).

	CBU			FOU		
Environmental Variables	**Mean ± SE**	**max**	**min**	**Mean ± SE**	**max**	**min**
Distance to coast (m)	399.00 ± 17.24	6.23	1360.70	806.35 ± 21.48	25.31	1646.51
Elevation (m)	7.07 ± 0.34	-0.30	27.50	15.39 ± 0.41	0.89	33.98
Northerly aspect	(-) 0.21 ± 0.04	-1.00	1.00	(-) 0.31 ± 0.03	-1.00	0.99
Easterly aspect	0.12 ± 0.04	-1.00	1.00	0.15 ± 0.04	-1.00	1.00
Slope (degrees)	1.39 ± 0.07	0.02	8.49	2.06 ± 0.07	0.04	7.84
Total exposure	4.01 ± 0.03	2.00	7.00	4.037 ± 0.04	0.00	8.00
Exposure to coast	1.87 ± 0.06	0.00	3.00	1.81 ± 0.06	0.00	3.00
Landscape position (m)	(-) 0.00 ± 0.00	-0.43	0.14	0.00 ± 0.00	-0.12	0.31
Landscape position (m x 1000)	(-) 0.09 ± 1.92	-432.08	139.35	0.23 ± 1.69	-124.67	309.38

Table B-3. Linear discriminant analysis (LDA) for points located at Canso classified into 2 successional groups (CBU and FOU) correctly classifying 58% of the test data.

Environmental Variable	LD1	CBU Mean	FOU Mean
Northerly aspect	**0.1289**	-0.0582	0.0663
Easterly aspect	**-0.0266**	0.0263	-0.0047
Total exposure	**0.0339**	0.0929	-0.0225
Exposure to coast	**-0.1041**	0.0330	0.0007
Landscape position	**0.1364**	-0.1647	0.1235
Elevation	**-1.7543**	0.3902	-0.2664
Distance to coast	**1.0341**	0.1613	-0.1052
Slope	**0.5571**	-0.0832	0.0858

Table B-4. Actual means and ranges for the measured environmental variables for points located at Canso classified into two successional groups (CBU and FOU).

	FOU			CBU		
Environmental Variables	**Mean ± SE**	**max**	**min**	**Mean ± SE**	**max**	**min**
Distance to coast (m)	544.48 ± 15.79	1.58	1603.49	483.07 ± 16.35	0.39	1744.90
Elevation (m)	26.81 ± 0.63	1.69	62.16	17.82 ± 0.46	0.85	56.17
Northerly aspect	(-) 0.15 ± 0.03	-1.00	1.00	(-) 0.06 ± 0.03	-1.00	1.00
Easterly aspect	0.27 ± 0.03	-1.00	1.00	0.23 ± 0.03	-1.00	1.00
Slope (degrees)	3.08 ± 0.09	0.00	13.53	3.61 ± 0.11	0.05	17.29
Total exposure	4.06 ± 0.03	0.00	8.00	3.98 ± 0.03	0.00	8.00
Exposure to coast	2.14 ± 0.05	0.00	3.00	2.07 ± 0.04	0.00	3.00
Landscape position (m)	(-) 0.01 ± 0.00	-0.53	0.43	0.01 ± 0.00	-0.47	0.68
Landscape position (m x 1000)	(-) 10.56 ± 2.79	-530.75	432.08	8.71 ± 2.73	-468.85	678.82

Table B-5. Linear discriminant analysis (LDA) for points located at Chebucto Head classified into 2 successional groups (CBU and FOU) 75 % of the test data.

Environmental Variable	LD1	CBU Mean	FOU Mean
Northerly aspect	**-0.1039**	0.2255	-0.0493
Easterly aspect	**0.0793**	0.1212	-0.0913
Total exposure	**-0.2739**	0.2110	-0.0862
Exposure to coast	**-0.0329**	0.1312	-0.1057
Landscape position	**0.1445**	-0.1995	0.0928
Elevation	**-0.3983**	0.0950	-0.0174
Distance to coast	**1.1131**	-0.5750	0.2706
Slope	**0.1889**	0.0955	-0.0319

Table B-6. Actual means and ranges for the measured environmental variables for points located at Chebucto Head classified into two successional groups (CBU and FOU).

	FOU			CBU		
Environmental Variables	**Mean ± SE**	**max**	**min**	**Mean ± SE**	**max**	**min**
Distance to coast (m)	541.43 ± 32.03	8.23	1992.37	939.13 ± 23.95	17.50	1948.08
Elevation (m)	25.52 ± 0.78	3.07	49.83	24.23 ± 0.45	5.43	45.01
Northerly aspect	0.14 ± 0.05	-1.00	1.00	(-) 0.07 ± 0.03	-1.00	1.00
Easterly aspect	0.19 ± 0.05	-1.00	1.00	(-) 0.08 ± 0.04	-1.00	1.00
Slope (degrees)	3.61 ± 0.24	0.16	17.92	2.98 ± 0.11	0.11	11.47
Total exposure	4.146 ± 0.04	3.00	6.00	3.99 ± 0.03	2.00	7.00
Exposure to coast	1.97 ± 0.08	0.00	3.00	1.71 ± 0.06	0.00	3.00
Landscape position (m)	(-) 0.01 ± 0.01	-0.30	0.31	0.00 ± 0.00	-0.16	0.28
Landscape position (m x 1000)	(-) 14.16 ± 5.13	-303.45	310.84	0.63 ± 2.04	-155.63	280.16

Table B-7. Linear discriminant analysis (LDA) for points located at Peggy's Cove classified into 2 successional groups (CBU and FOU) 58 % of the test data.

Environmental Variable	LD1	CBU Mean	FOU Mean
Northerly aspect	**-0.0961**	0.0776	0.0182
Easterly aspect	**0.1033**	-0.0930	0.0473
Total exposure	**-0.0238**	0.0788	-0.0775
Exposure to coast	**0.0530**	0.0342	-0.0485
Landscape position	**0.2541**	-0.1454	0.1361
Elevation	**-0.6223**	-0.1039	0.1043
Distance to coast	**1.4367**	-0.4328	0.3349
Slope	**0.3179**	-0.0012	0.0178

Table B-8. Actual means and ranges for the measured environmental variables for points located at Peggy's Cove classified into two successional groups (CBU and FOU).

	FOU			CBU		
Environmental Variables	**Mean ± SE**	**max**	**min**	**Mean ± SE**	**max**	**min**
Distance to coast (m)	389.21 ± 16.31	2.29	1579.50	767.90 ± 20.52	7.92	1746.31
Elevation (m)	17.32 ± 0.50	1.68	43.90	19.22 ± 0.36	1.44	45.14
Northerly aspect	(-) 0.06 ± 0.04	-1.00	1.00	(-) 0.13 ± 0.03	-1.00	1.00
Easterly aspect	(-) 0.04 ± 0.03	-1.00	1.00	0.05 ± 0.03	-1.00	1.00
Slope (degrees)	4.22 ± 0.15	0.14	16.39	4.10 ± 0.14	0.04	19.83
Total exposure	4.08 ± 0.04	1.00	8.00	3.97 ± 0.03	0.00	7.00
Exposure to coast	1.88 ± 0.06	0.00	3.00	1.79 ± 0.05	0.00	3.00
Landscape position (m)	(-) 0.01 ± 0.00	-0.43	0.48	0.01 ± 0.00	-0.38	0.79
Landscape position (m x 1000)	(-) 13.35 ± 4.52	-433.80	481.22	10.38 ± 4.62	-377.40	790.54

Table B-9. Linear discriminant analysis (LDA) for points located at Taylor's Head classified into 2 successional groups (CBU and FOU) 90 % of the test data.

Environmental Variable	LD1	CBU Mean	FOU Mean
Northerly aspect	**0.1043**	-0.1761	-0.0111
Easterly aspect	**0.2637**	-0.2424	0.0348
Total exposure	**-0.1163**	0.0077	-0.0122
Exposure to coast	**-0.3505**	0.2353	-0.0640
Landscape position	**-0.9254**	0.1959	0.0279
Elevation	**-1.0826**	0.2486	0.0200
Distance to coast	**0.7107**	-0.0873	0.0953
Slope	**-0.1999**	0.1740	-0.1296

Table B-10. Actual means and ranges for the measured environmental variables for points located at Taylor's Head classified into two successional groups (CBU and FOU).

	FOU			**CBU**		
Environmental Variables	**Mean ± SE**	**max**	**min**	**Mean ± SE**	**max**	**min**
Distance to coast (m)	165.59 ± 15.62	17.02	391.12	162.33 ± 7.28	2.53	465.14
Elevation (m)	12.16 ± 0.84	2.18	20.90	9.51 ± 0.32	1.19	21.04
Northerly aspect	(-) 0.21 ± 0.10	-1.00	0.98	0.02 ± 0.05	-1.00	1.00
Easterly aspect	(-) 0.11 ± 0.11	-1.00	1.00	0.01 ± 0.05	-1.00	1.00
Slope (degrees)	2.63 ± 0.26	0.21	7.60	2.50 ± 0.12	0.09	9.61
Total exposure	4.10 ± 0.09	3.00	5.00	4.01 ± 0.05	0.00	6.00
Exposure to coast	2.60 ± 0.10	1.00	3.00	2.22 ± 0.07	0.00	3.00
Landscape position (m)	0.00 ± 0.01	-0.19	0.13	(-) 0.00 ± 0.00	-0.48	0.26
Landscape position (m x 1000)	2.66 ± 8.38	-185.31	132.32	(-) 4.62 ± 4.00	-481.61	261.22

Chapter 3
Vegetation composition, structure and soil properties across the forest–barren ecotone in coastal Nova Scotia

Abstract

Coastal barrens are scattered along the Atlantic coast of Nova Scotia in areas with little soil cover and patches of exposed bedrock. Open habitats such as coastal barrens are important for conservation as they may contain rare species and uncommon plant communities. These areas can represent early successional communities that develop into forests or they can persist as islands in a forested landscape and remain relatively unchanged for hundreds of years. Species interactions and environmental conditions within the ecotone or edge between forests and coastal barren may determine the successional status of coastal barrens. Study objectives were to determine if forest expansion into coastal barren habitat was occurring from forest patches and to assess changes in plant species composition and soil properties across the forest – barren ecotone. Dendrochronological samples, soil properties and species compositions were sampled along transects across the forest–barren ecotone. Results show that forest expansion is occurring from forest patches located within the coastal barren study sites. Vegetation composition and structure indicate three distinct vegetation communities including: forest communities; edge communities; and open coastal barren communities. Soil properties did not significantly differ across the ecotone. Forest patches located within coastal barrens provide a seed and propagule source from which forest encroachment can occur.

Keywords: forest succession, rock barrens, heathland, conservation biology, landscape dynamics, ecotone, disturbance

Introduction

Coastal barrens are scattered along the Atlantic coast of Nova Scotia in areas with little soil cover and patches of exposed bedrock. These habitats are relatively open areas consisting of sparse tree cover and are dominated by shrubby vegetation primarily from the Ericaceae such as *Gaylussacia baccata* (Black Huckleberry) and *Vaccinium angustifolium* (Low-bush Blueberry) (Dunwiddie et al. 1996). Coastal barrens in northeastern North America have high cultural, aesthetic, and biological values and are important habitats for conservation (Oberndorfer and Lundholm 2009).

Within a forested landscape, open habitats can represent an early successional stage that emerges following a disturbance that removes the canopy and/or alters the vegetation composition of the area (Saldarriaga et al. 1988; Bazzaz 1979; and Nova Scotia Museum of Natural History 1997). These openings can persist for many years and even decades before forest encroachment occurs (Bradley et al. 1997; Ehrenfeld et al. 1995; Faison et al. 2006; Latham et al. 1996; Mallik 1995; 2003). Other rocky habitats that persist as islands in a forested landscape have been shown to last for hundreds of years without significant development of soil and succession into forest (Stark et al. 2003; 2004). Prior to this study it was unclear which combination of successional categories coastal barrens in Nova Scotia represented.

It is important to examine ecosystem interactions occurring within the ecotone or edge between two community types when studying the temporal dynamics of forests and coastal barren habitats. An ecotone is defined as a transitional area between two distinct ecological communities (Brewer 1979; Fortin 1994; Freedman 2004). Such areas can represent the greatest rate of change in terms of environmental variables and can result in one community type influencing the processes such as transfers of matter or energy acting in the other. This may also result in both communities influencing processes acting within each other (Breshears 2006). This edge influence is said to increase with increased contrast between habitat types (Harper et al. 2005; Esseen et al. 2006). This area can also be the source of expansion or reduction of either ecological community into the other depending on the result of the interactions brought on by the edge influence (Harper et al. 2005; Maurice et al. 2004).

Maurice et al. (2004) found that proximity to forest edge influences the rate of forest succession into open shrubland habitats. Barrens located within a forest matrix exposed to high amounts of forest edge may be less persistent than open "core" barrens due to edge effects that alter local environmental conditions, potentially enabling the spread of tree species. Tree species not only modify the local area directly underneath them but also influence the area surrounding them by affecting the amount of light that reaches the ground and influencing the distribution of water and nutrients (Breshears 2006). An increase in surface area of open barrens exposed to forest edge could potentially increase these effects thus increasing the rate of forest expansion.

Forests surrounding coastal barrens in Nova Scotia are generally dominated by coniferous tree species including *Picea glauca* (White Spruce), *Picea rubra* (Red Spruce), *Larix laricina* (Tamarack), and *Abies balsamea* (Balsam Fir) (Neily et al. 2004; Oberndorfer and Lundholm 2009). The common regeneration strategy for these species is sexual reproduction through seed dispersal and pollination. However, Greene et al. (1998) noted that these most of these species can also reproduce asexually through layering, which consists of regeneration by means of vegetative propagation. Trees may be able to spread onto barrens and out-compete dominant shrub species, thus facilitating forest succession (Krause 2006; Greene et al. 1998).

Rare plant species may be associated with open barrens dominated by creeping shrubs and their abundances are negatively correlated with vegetation height (Oberndorfer and Lundholm 2009). Patches of trees on the barrens are associated with different vegetation and may replace uncommon assemblages such as those dominated by *Empetrum* sp., *Corema conradii* and *Prenanthes nana*, thus forest encroachment represents the potential for loss of rare species and community types (Latham 2003).

Oberndorfer and Lundholm (2009) define coastal barrens as a matrix of open, low growing shrub communities interspersed with forest patches of various sizes and ages. The ecotone between these two habitat types varies in extent and structure. In some areas there is a noticeable boundary between community types whereas in other patches there is a more gradual shift. It is unclear whether these tree islands act as a seed and propagule source from which forests are expanding onto barrens or if these areas are relatively stable, experiencing little change over time.

The first goal of this study was to examine tree age and size across the ecotone between forest patches and coastal barren habitat in order to determine if these forest patches are expanding into coastal barrens. The second goal of this study was to assess changes across the forest-barren transition zone in vegetation species composition and structure and physical and chemical properties of the soil to predict the effects of forest expansion on coastal barren habitat.

Methods

In Nova Scotia, the majority of coastal barren habitat is located along the Atlantic coast consisting of isolated patches along the length of the province. Three coastal barren study sites were chosen to address the objectives of this study (Figure 1). These areas were chosen as they represent a wide spatial distribution of coastal barren habitat occurring in Nova Scotia. They include Peggy's Cove (44° 29' 35" N and 63° 55' 00" W), Taylor's Head Provincial Park (44° 49' 06" N and 62° 33' 46" W), and Canso Coastal Barren Wilderness Area (45° 17' 12" N and 61° 05' 21" W).

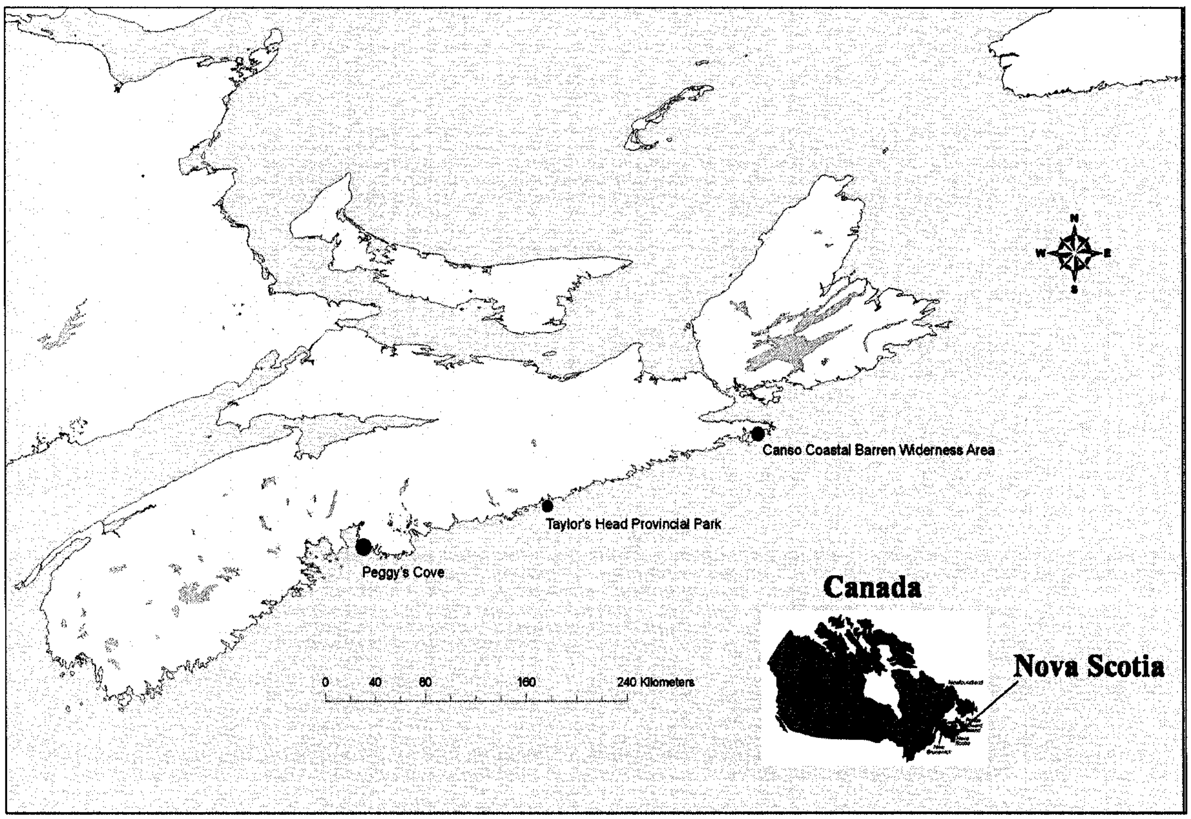


Figure 1. Locations of three coastal barren study sites along the Atlantic coast of Nova Scotia, Canada including: Peggy's Cove, Taylor's Head, and Canso.

In order to assess changes in soil properties and vegetation patterns across the barren – forest ecotone, plot sampling along transects was conducted at 18 randomly selected forest patches distributed among the three study sites. Aerial photos of each of the three study sites were examined. Each forest patch observed was delineated and assigned a number from which eighteen patches were randomly selected for study. At each of the three study sites, three forest patches were randomly selected within 500m of the coast and three patches were selected beyond 500m of the coast for a total of six patches at each site. We were interested in assessing the effect of proximity to coast on the dynamics of the ecotone between forests and barrens.

Transects were established perpendicular to the south-facing forest patch edge, on the ocean-facing side (Figure 2). The southernmost limit of the continuous forest canopy where the edge was estimated to begin was deemed the point of origin for establishing each transect. Each transect extended six meters towards the interior of the reference forest from the point of origin, and at least twelve meters towards the reference barren habitat (in the opposite direction). This was to ensure capture of both the relative reference forest conditions as well as the transitional area between the forest patch and reference barren.

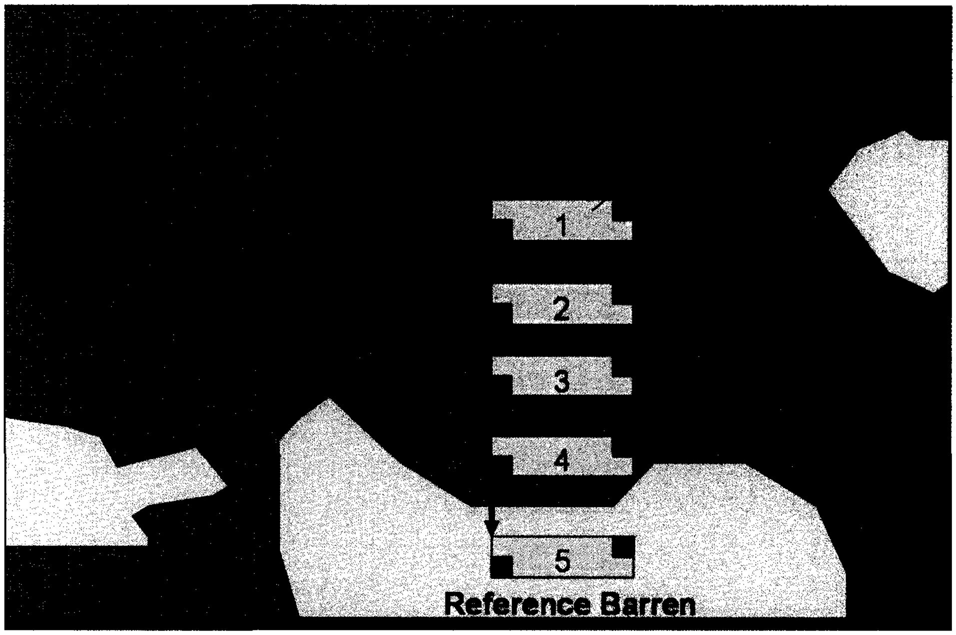


Figure 2. Sample design illustrating the transects established in order to conduct plot sampling across the forest-barren ecotone for eighteen forest patches located in three coastal barren study sites along the southeast coast of Nova Scotia.

Along each transect, 2m x 5m plots were established every four meters (spacing of 2 m between plots) for the first four plots starting with the end of the plot in the reference forest. Plots 1 and 2 were in the reference forest and Plots 3 and 4 spanned the area extending from the closed canopy forest. The transect was extended from the fourth plot (farthest away from forest) in order to establish a fifth 2m x 5m plot, where possible along the same direction, in an area classified as open coastal barren. The distance of this fifth plot varied depending on the distance required to travel in order to contact open barren. In order to be classified as open coastal barren, the entire plot had to contain less than 1% tree canopy cover. Two 1m x 1m subplots were established in the southwest and northeast corners of each of the 2m x 5m plots to study vegetation composition (Table 1).

Table 1. Summary of sample scheme for conducting transect sampling at three coastal barren study sites.

Sample Scale	# Sites	# Transects	# Plots	# Sub plots
Per Plot				2
Per Transect			5	10
Per Site		6	30	60
Total	3	18	90	180

Soil properties including depth, development, and chemical composition were assessed within the 2m x 5m plots. Soil depth was measured at five sampling points including one at each corner and one directly in the middle of each plot using a soil auger that was driven into the ground until it reached bedrock (or resistance prevented it from going any further down). Soil development was also assessed using these cores and classified as: **0** - no soil development (*i.e.* bare rock, litter, or humus only); **1** - organic layer present; **2** - 'A' horizon present; or **3** - 'B' horizon present. Soil was collected for analysis of nutrient content from the same five points as soil depth was measured within each of the 2m x 5m plots and combined into a single sample per plot. Where possible, at least one cup of soil was collected in each plot from the lowest layer of soil and sent to the Agricultural College in Truro, Nova Scotia for chemical analysis.

Tree demography including age, diameter at breast height, and height was assessed within each of the 2m x 5m plots. At one meter intervals across each plot, including zero and five meters, the two closest trees (>1.6 dbh) were selected for sampling. A core from each tree was extracted using a Swedish increment borer and analysed under a dissecting microscope. Each core was sampled as near to the base of the tree as possible in order to insure a more accurate estimate of age and to ensure consistent sampling procedures. Age of the selected tree was assessed by counting the annual growth rings of each tree. For each tree, dbh was measured at breast height (1.3m) and tree height was assessed using a clinometer.

The 1m x 1m subplots were used to sample the herbaceous vegetation layer. The point intercept method consisting of a quadrat containing 25 intercepting points was used to assess the frequency of each species. All individuals (vascular plants, mosses and ground macrolichens) touching a metal rod, placed vertically at each intercepting point, were identified to species. Canopy cover was estimated in each of the 1m x 1m subplots using a convex densitometer. Vegetation height was measured at three points located diagonally across each plot and averaged.

The goal of this study was to assess the processes occurring within transition areas between coastal barrens and forests on a regional level. Therefore priority was given to increasing the number of transects at the cost of gathering detailed information at any given forest patch. Vegetation surveys were conducted only once for each plot therefore this procedure represents a sample of the vegetation present and does not represent a comprehensive species list of each plot.

Statistical Analysis

A randomization test was used to detect differences in abiotic variables and vegetation composition and structure between reference forest plots and plots located at various distances along transects. This test was used in Mascarua et al. (2006) and consists of an updated version of the Critical Values Approach (Harper and Macdonald 2001). This analysis is useful since it is not restricted by the assumptions of most parametric tests such as spatial independence as well as homogeneity of variances (Harper and Macdonald 2001). By incorporating the forest and edge data into the randomization, this program takes into account the natural variability of forest composition, structure, and processes.

The analysis compares the difference between the mean of reference conditions and the mean at a given distance from the edge to a distribution of randomized differences of the entire data set. In this analysis, values of reference conditions are combined with values at a given distance from the reference. Subsamples of these values are randomly selected to represent the reference habitat with the remaining values representing a given distance from the reference. Differences in the means of the selected values and the means of the remaining unselected values are then calculated. These two steps are repeated 5000 times to create a distribution of mean differences for the randomized data. The percentile of the observed difference in the distribution of randomized distributions is then determined. Critical values for a two-tailed test (α = 0.05) are the lower 2.5 and upper 97.5 percentiles of the permuted differences (Mascarua et al. 2006). These analyses were conducted separately using the forest plots as the reference and using coastal barren plots as the reference. This allowed for the detection of significant differences both between forest patches and given distances from the edge as well as differences between coastal barren habitat and given distances from the edge. Assessing potential differences in both directions will enable the detection of the influence of the edge on coastal barren habitat as well as forests and determine the nature of the transition zone between the two habitats.

Detrended Correspondence Analyses (DCA) were conducted using the vegan package in R version 2.5.1 (2007) to visually examine differences in species composition between plots located along transects. DCA follows the same principles as a Correspondence Analysis (CA) in that it performs reciprocal averaging to describe graphically describe the best fit of the data in ordination space where species are organized based on similarities so that species occurring in the same plots are plotted closer together (Økland 1990). In a CA, scores at the extreme ends of the axis are compressed which can inflate similarity. A DCA divides the gradient into 26 segments and rescales the data in an attempt to reduce this arch effect. In an attempt to minimize distortion, plots containing < 5 species as well as species occurring in < 2 plots were removed from the analyses. The scores from the first two DCA axes were analyzed using randomization test to test the significance of the difference in species composition depicted in the DCA.

Canonical Correspondence Analyses (CCAs) were also conducted using the vegan package in R version 2.5.1 (2007) to examine potential relationships between species composition and environmental gradients along transects. This analysis is another ordination technique that attempts to graphically depict relationships between data points based on similarities. CCAs attempt to simultaneously plot species and environmental scores in the same ordination space while optimizing the species dataset (Økland 1990).

Results

Overall results indicate a number of general patterns in vegetation composition and structure across the forest – barren ecotone. There is an overall decrease in vegetation height as dominant vegetation changes with distance from the forest patch. As distance increases from the forest center, dominance shifts from tree species such as *Picea rubens* and *Abies balsamea* to tall shrub species such as *Nemopanthes mucronatus* and *Viburnum nudum*. With an increase in distance into the transition zone from the forest patch, dominance shifts again to include shorter shrubs such as *Vaccinium* *angustifolium* and short forms of *Gaylussacia baccata.* Finally low growing species such as *Empetrum nigrum* and *Juniperus communis* establish dominance at the final distance from the forest, the reference coastal barrens.

The randomization tests conducted using the environmental data from all 18 forest patches combined showed a number of significant environmental gradients across the forest –barren ecotone (Table 2). Tree age and tree height were found to significantly decrease extending away from the forest center toward the open barren (Figure 3). Vegetation height and canopy cover also decreased significantly extending from the second plot located within the forest towards the open barren (Figure 3).

Table 2. Mean ± 1 SE of abiotic variables and vegetation composition and structure sampled from 18 transects across the transition area between coastal barren and forest patches at three Nova Scotia coastal barrens including Peggy's Cove, Taylor's Head, and Canso. Values in bold indicate a significant difference from the **reference forest**. Distance refers to the distance of each plot from the **reference forest plot**.

Distance (m)	**2 m**	**6 m**	**10 m**	**Barren >= 14 m**
Plot #	**2**	**3**	**4**	**5**
Environmental Variables				
Vegetation Height (m)	2.8 ± 0.7	**1.2 ± 0.2**	**0.9 ± 0.1**	**0.4 ± 0**
Canopy Cover (%)	50 ± 6	**9 ± 5**	**10 ± 4**	**0 ± 0**
Soil Depth (cm)	47.4 ± 5.9	38.9 ± 5.8	34.2 ± 6.6	35.2 ± 6.2
Soil Development	2 ± 0	2 ± 0	2 ± 0	2 ± 0
Tree Age (years)	**46 ± 4**	**29 ± 6**	**25 ± 8**	**6 ± 4**
% Organic	9.10± 0.23	5.82 ± 0.17	12.06 ± 0.30	12.50 ± 0.27
pH	4.40 ± 0.05	4.18 ± 0.04	4.05 ± 0.04	4.25 ± 0.37
P	88.57 ± 0.69	47.17 ± 0.58	80.29 ± 0.78	81.94 ± 0.84
K	55.80 ± 0.41	68.92 ± 0.60	68.56 ± 0.57	87.63 ± 0.50
CA	181.00 ± 0.98	192.42 ± 1.27	260.57 ± 1.29	288.67 ± 1.08
Mg	180.67 ± 1.26	142.33 ± 1.05	251.14 ± 1.16	197.75 ± 0.86
Na	88.33 ± 0.63	68.75 ± 0.61	82.79 ± 0.49	74.75 ± 0.44
S	87.33 ± 0.47	57.00 ± 0.64	65.36 ± 0.48	51.25 ± 0.33
Fe	214.33 ± 1.09	164.92 ± 1.05	213.64 ± 1.02	209.63 ± 0.85
Mn	1.80 ± 0.08	1.67 ± 0.08	1.21 ± 0.05	1.63 ± 0.08
Cu	0.10 ± 0.00	0.19 ± 0.05	0.10 ± 0.00	0.10 ± 0.00
Zn	1.76 ± 0.06	2.54 ± 0.14	2.49 ± 0.09	2.66 ± 0.10
B	0.12 ± 0.02	0.12 ± 0.02	0.13 ± 0.02	0.15 ± 0.02
CEC	11.23 ± 0.15	10.67 ± 0.17	12.50 ± 0.18	11.00 ± 0.13
%N	0.37 ± 0.04	0.28 ± 0.04	0.36 ± 0.04	0.28 ± 0.04
Tree Height (m)	**3.65 ± 0.32**	**2.34 ± 0.54**	**1.38 ± 0.31**	**0.21 ± 0.15**
Species Richness (# species)	11 ± 1	11 ± 1	13 ± 0	13 ± 1
DCA 1st axis (moss/lichen)	-0.5226	-0.0123	**0.4062**	**1.1295**
DCA 1st axis (Vascular)	-0.6339	**-0.0137**	**0.3485**	**0.8126**

Results of the randomization test (Table 3) conducted using the open barren as reference showed tree age, tree height, canopy cover, and vegetation height all increasing significantly across the ecotone towards closed canopy forest (Figure 3). Species richness was significantly lower in plots two and three (representing the edge) than the open barren reference plots but not significantly different than the reference forest plots. Soil nutrients (with the exception of Sulphur having significantly higher levels in plot two than the reference coastal barren), soil development, and soil depth were all not significantly different across the forest-barren ecotone in either direction.

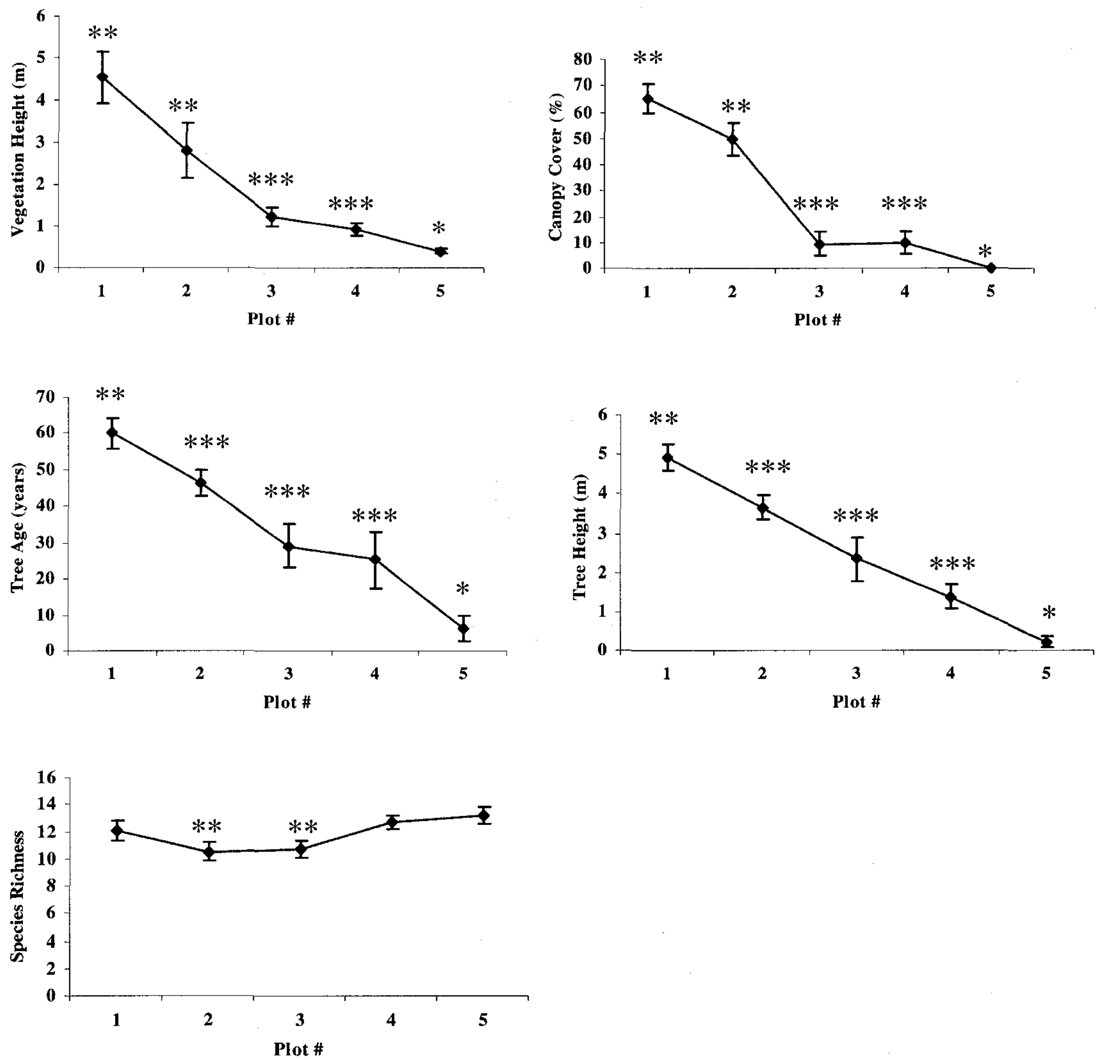


Figure 3. Summary of the analyses of environmental gradients across the forest-barren ecotone. Plot 1 represents the reference forest plot; plots 2-4 represent the transition area; and plot 5 represents the reference coastal barren plot. Points indicate mean value ± 1 SE. *indicates plots significantly different from reference forest. **indicates plots significantly different from reference coastal barren. ***indicates plots significantly ($\alpha = 0.05$)different from both forest and coastal barren reference plots.

A randomization test was conducted using the first two DCA axes in order to determine if there is significant shift in vascular species composition (including ferns) across the barren-forest ecotone. In this case, only the first DCA axis was found to be significant, therefore only this axis will be reported. The results of this analysis indicate that there is a significant change in vascular species composition in all plots extending from the coastal barren reference plots into reference forests (Table 3). Similarly, significant differences in vascular species composition were detected between reference forest plots and plots three, four, and five (Table 2).

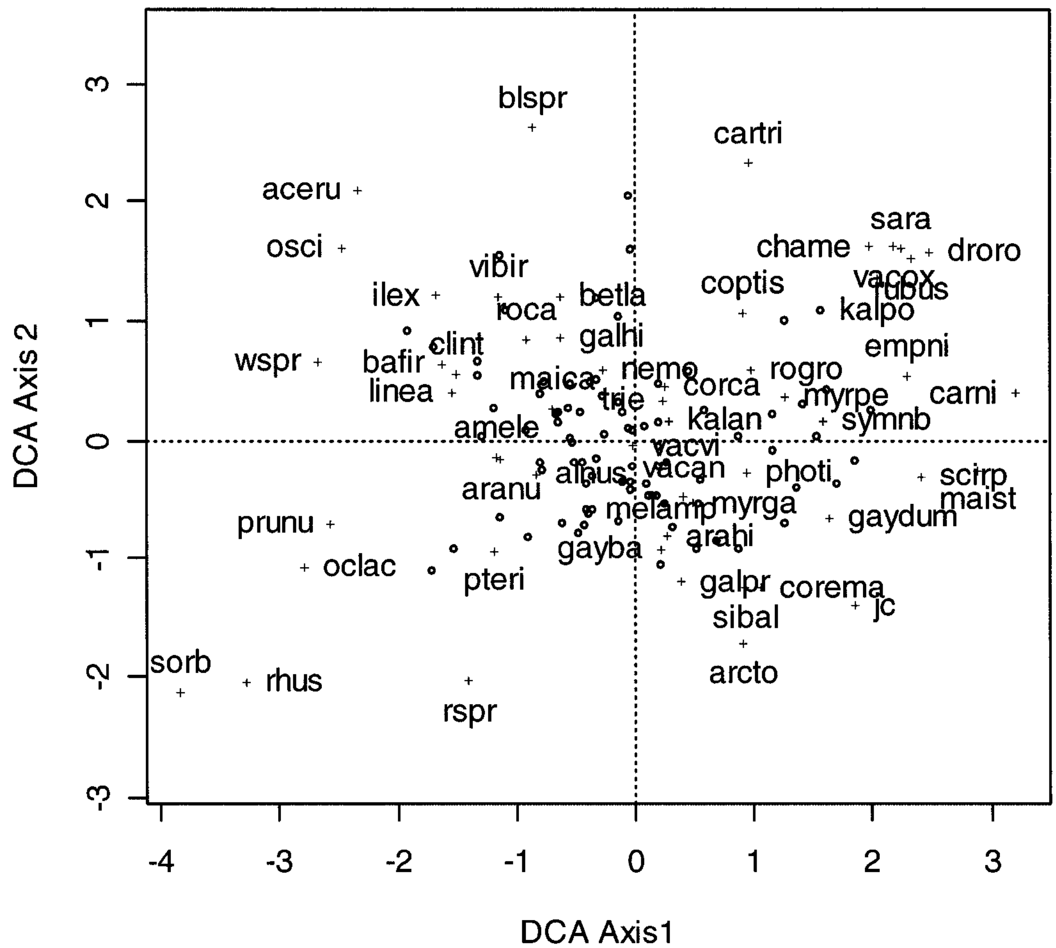
This procedure was conducted again using the DCA axis representing the moss and lichen species data. This analysis (Table 3) showed that there is a significant change in moss and lichen species from the reference coastal barrens extending from the third plot into the second and reference forest plots (plot 1). Alternatively distances found to differ significantly from the reference forests were only plots four and the reference coastal barren (plot five) (Table 2).

Table 3. Abiotic variables and vegetation structure mean ± 1 SE sampled from 18 transects along the transition area between coastal barren and forest patches at three Nova Scotia coastal barrens including Peggy's Cove, Taylor's Head, and Canso. Values in bold indicate a significant difference from the **reference coastal barren**. Distance refers to the distance of each plot from the **reference coastal barren plot**.

Distance (m)	**>= 2 m**	**>= 6 m**	**>= 10 m**	**Forest >= 14 m**
Plot #	**4**	**3**	**2**	**1**
Environmental Variables				
Veg Height (m)	**0.9 ± 0.1**	**1.2 ± 0.2**	**2.8 ± 0.7**	**4.5 ± 0.6**
Canopy Cover (%)	**10 ± 4**	**9 ± 5**	**50 ± 6**	**65 ± 5**
Soil Depth (cm)	34.2 ± 6.6	38.9 ± 5.8	47.4 ± 5.9	48.3 ± 7.5
Soil Development	2 ± 0	2 ± 0	2 ± 0	2 ± 0
Tree Age (years)	**25 ± 8**	**29 ± 6**	**46 ± 4**	**60 ± 4**
% Organic	12.06 ± 0.30	5.82 ± 0.17	9.10± 0.23	11.52 ± 0.27
pH	4.05 ± 0.04	4.18 ± 0.04	4.40 ± 0.05	4.24 ± 0.04
P	80.29 ± 0.78	47.17 ± 0.58	88.57 ± 0.69	78.81 ± 0.50
K	68.56 ± 0.57	68.92 ± 0.60	55.80 ± 0.41	70.94 ± 0.49
CA	260.57 ± 1.29	192.42 ± 1.27	181.00 ± 0.98	183.75 ± 0.96
Mg	251.14 ± 1.16	142.33 ± 1.05	180.67 ± 1.26	145.94 ± 0.95
Na	82.79 ± 0.49	68.75 ± 0.61	88.33 ± 0.63	71.81 ± 0.45
S	65.36 ± 0.48	57.00 ± 0.64	**87.33 ± 0.47**	64.31 ± 0.46
Fe	213.64 ± 1.02	164.92 ± 1.05	214.33 ± 1.09	214.56 ± 0.80
Mn	1.21 ± 0.05	1.67 ± 0.08	1.80 ± 0.08	2.63 ± 0.13
Cu	0.10 ± 0.00	0.19 ± 0.05	0.10 ± 0.00	0.10 ± 0.00
Zn	2.49 ± 0.09	2.54 ± 0.14	1.76 ± 0.06	2.02 ± 0.07
B	0.13 ± 0.02	0.12 ± 0.02	0.12 ± 0.02	0.13 ± 0.02
CEC	12.50 ± 0.18	10.67 ± 0.17	11.23 ± 0.15	11.13 ± 0.15
%N	0.36 ± 0.04	0.28 ± 0.04	0.37 ± 0.04	0.41 ± 0.05
Tree Height (m)	**1.38 ± 0.31**	**2.34 ± 0.54**	**3.65 ± 0.32**	**4.92 ± 0.34**
Species Richness (# species)	13 ± 0	**11 ± 1**	**11 ± 1**	12 ± 1
DCA 1st axis (moss/lichen)	-0.4904	**-0.5226**	**-0.0123**	**0.4062**
DCA 1st axis (Vascular)	**-0.7007**	**-0.6339**	**0.0555**	**0.2631**

The vegetation survey conducted within the 1 m x 1 m plots along 18 transects found a total of 59 vascular species, 19 lichen species, and 27 moss and liverwort species (Table A-1, A-2 and A-3, Appendix A). Results of the DCA conducted for the vascular species encountered during the sample period illustrate a species turnover along the forest-barren ecotone (Figure 4). Vascular species sampled in at least one reference coastal barren plot not encountered in the reference forest plots include *Aralia hispida, Amelenchier sp, Arctostaphylos uva-ursi, Calamagrostis pickeringii, Carex nigra,* *Chamaedaphne calyculata, Corema conradii, Drosera rotundifolia, Gaylussacia dumosa, Juniperus communis, Kalmia polifolia, Larix laricina, Melampyrum lineare, Myrica gale, Photinia floribunda, Rubus chamaemorus, Scirpus cespitosa, Sibbaldiopsis tridentata, Symphyotrichum novi-belgii,* and *Vaccinium oxycoccos.* Vascular species encountered in at least one reference forest plot not sampled in the reference coastal barren plots include *Acer rubrum, Betula papyrifera, Deschampsia flexuosa, Hamamelis virginiana, Picea mariana, Prunus pensylvanica, Rhus typhina,* and *Sorbus americana.*

A.



B.

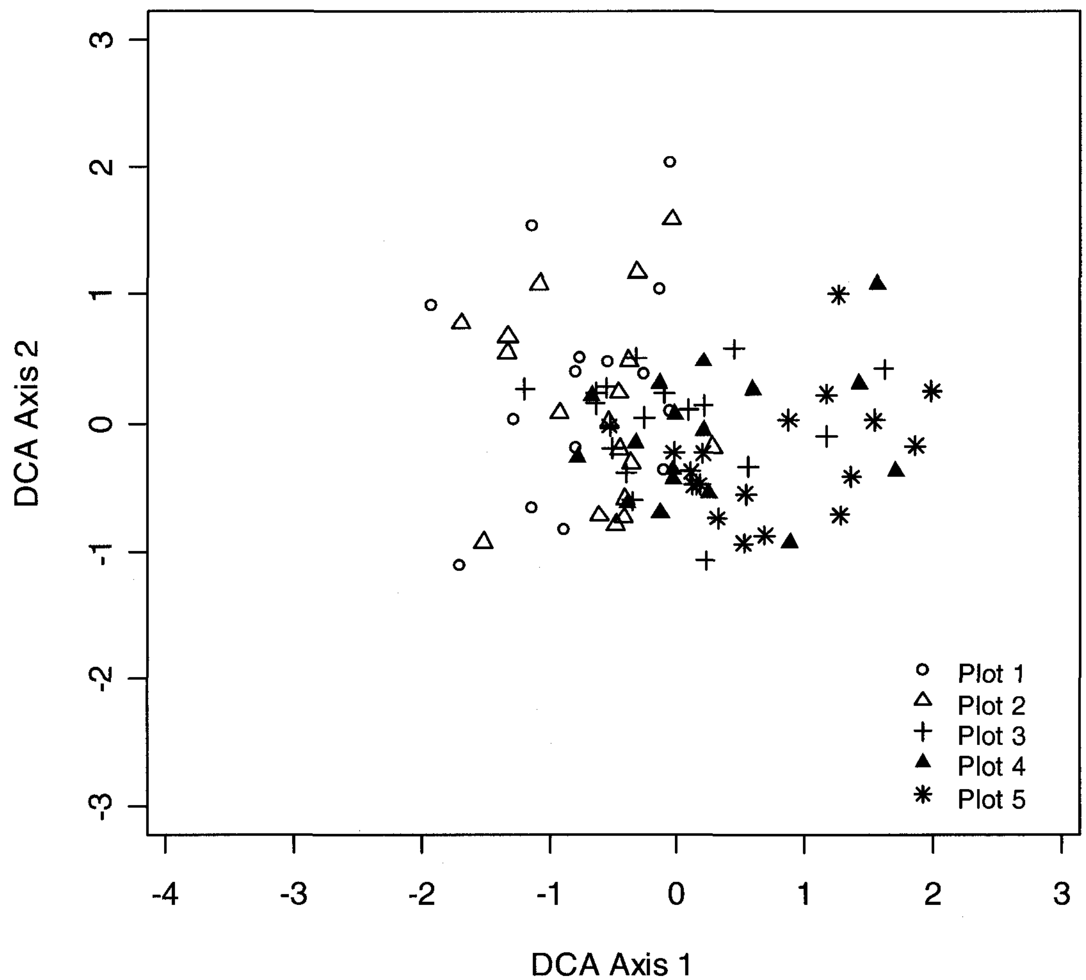


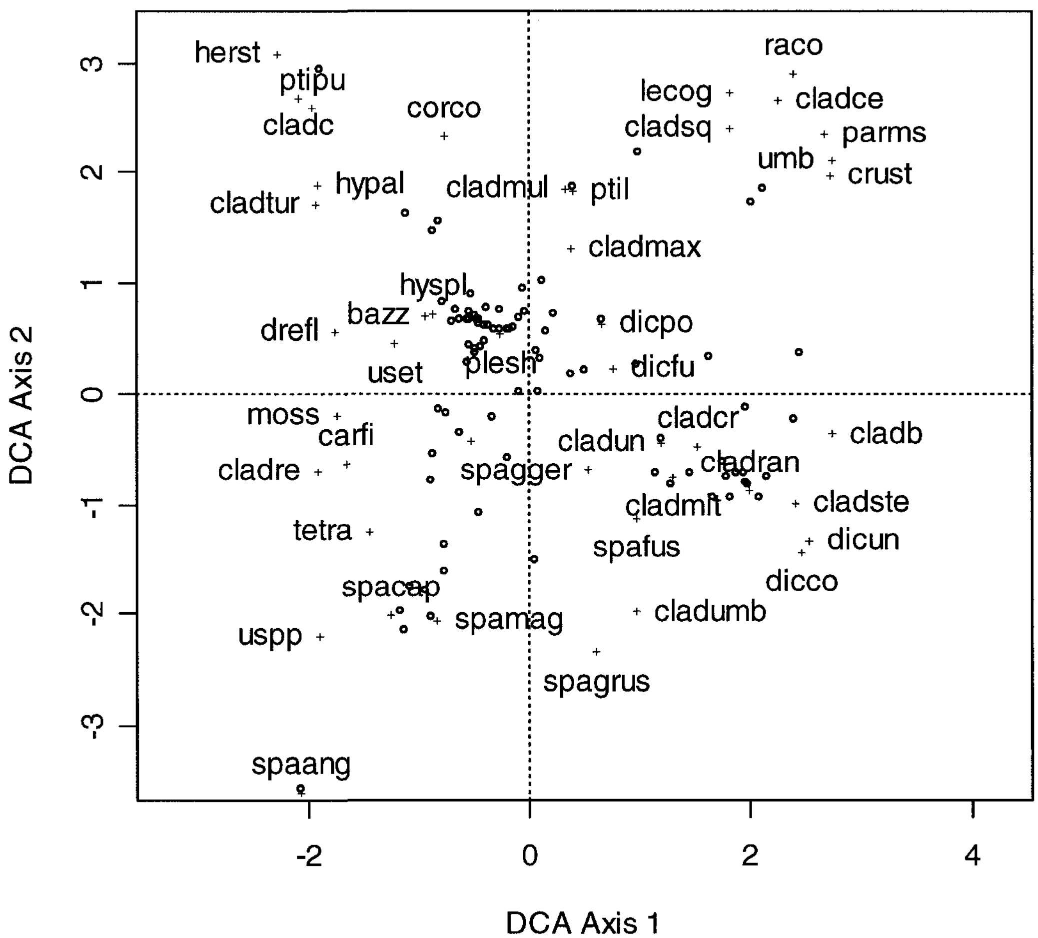
Figure 4. DCA ordination with the first two axes showing the distribution of vascular species composition along 18 transects across forest-barren transition zones at three study sites including Peggy's Cove, Taylor's Head, and Canso. Graph A represents the species scores while graph B illustrates the plots scores. DCA axis 1 eigen value = 0.4390; DCA axis 2 eigen value = 0.3357. Plot 1 represents reference forest plots while plots 2-4 represent the transition zone (edge), and plot 5 represents reference coastal barrens. Five species were removed from this analysis as they were found to occur in < 2 plots, having <= 3 hits within the plot, including; *Deschampsia flexuosa Empetrum eamesii, Hamamelis virginiana, Larix laricina*, and *Prenanthes trifoliolata*. Four plots were removed as they were found to contain < 5 species (three #1 plots and one #4 plot).

Table 4. Vascular species names and abbreviations that correspond to the DCA diagram in Figure 4A.

Species	Abbreviation	Species	Abreviation
Abies balsamea	balfir	*Maianthemum canadense*	mayflo
Acer rubrum	redmap	*Melampyrum lineare*	melamp
Alnus viridis	alnus	*Myrica gale*	swgale
Amelanchier sp	amelen	*Myrica pensylvanica*	bayber
Aralia hispida	aralhis	*Nemopanthus mucronatus*	nemo
Aralia nudicalus	aralnud	*Oclemena acuminata*	asterac
Arctostaphylos uva-ursi	arctous	*Osmunda cinnamomea*	cinfern
Betula papyrifera	betulap	*Photinia floribunda*	aronia
Calamagrostis pickeringii	calama	*Picea glauca*	wspr
Carex nigra	caraxni	*Picea mariana*	blspr
Carex trisperma	caretri	*Picea rubens*	rspr
Chamaedaphne calyculata	chame	*Prunus pensylvanica*	prunus
Clintonia borealis	clint	*Pteridium aquilinum*	pterid
Coptis trifolia	coptis	*Rhododendron canadense*	rodora
Corema conradii	corema	*Rhododendron groenlandicum*	ledum
Cornus canadensis	cornca	*Rhus typhina*	rhus
Drosera rotundifolia	drosera	*Rubus chamaemorus*	rubus
Empetrum nigrum	empnig	*Sarracenia purpurea*	sarac
Gaultheria hispidula	gualhis	*Scirpus cespitosus*	scirpus
Gaultheria procumbens	gaulpro	*Sibbaldiopsis tridentata*	potent
Gaylussacia baccata	gaybac	*Sorbus americana*	ash
Gaylussacia dumosa	gaydum	*Symphyotrichum novi-belgii*	asternb
Ilex verticillata	ilexvet	*Trientalis borealis*	star
Juniperus communis	jc	*Vaccinium angustifolium*	bluber
Kalmia angustifolia	kalang	*Vaccinium oxycoccos*	vacsoxy
Kalmia polifolia	kalpol	*Vaccinium vitis-idaea*	mocran
Linnaea borealis	linnea	*Viburnum nudum var. cassinoides*	raisin

Results of the DCA conducted to examine moss and lichen species shift between coastal barren and forest habitat show species being differentiated based on habitat requirements corresponding to the different plot locations (Figure 5). Lichen species reported in at least one coastal barren plot not encountered in forest plots include: Cladonia boryi, Cladonia crispate, Cladonia cenotea, Cladonia squamosa, Cladonia stellaris, and Umbilicaria muehlenbergii. Moss species encountered in coastal barren plots not recorded in forest plots include: Dicranum condensatum, Leucobryum glaucum, Racomitrium fasiculare, and Sphagnum russowii. Moss species encountered in forest plots that were not recorded in coastal barren plots include: *Conordia compacta, Cratoneuron filicinum, Dicranum scoparium, Drepanocladus fluitans, Herzogiella striatella, Hypnum pallescense var. protuberans*, moss sp., *Sphagnum angustifolium*, and *Tetraphis pelucidia*. Lichen species not recorded in coastal barren plots include: *Cladonia chlorophaea, Cladina rei, Cladonia uncialis, Usnea trichodea,* and *Usnea sp.*

A.



B.

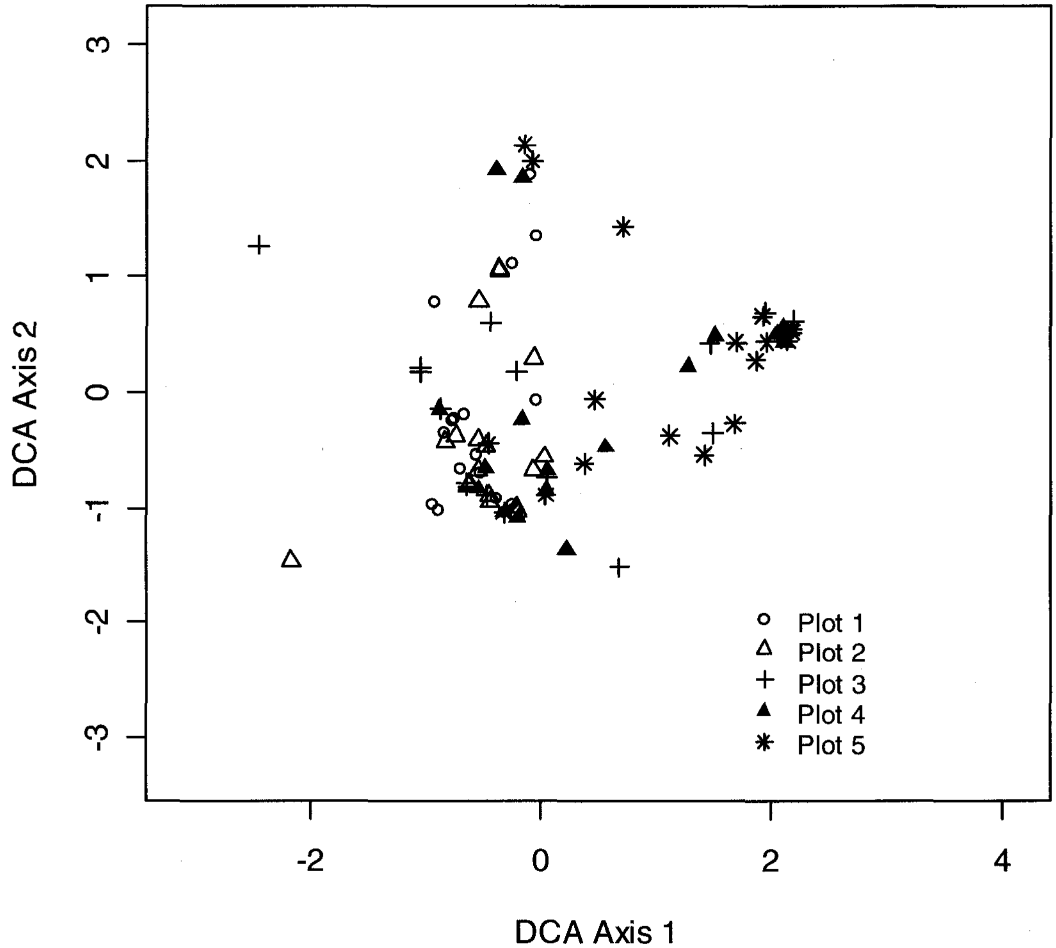


Figure 5. DCA ordination with the first two axes showing the distribution of moss, liverwort, and lichen species composition along 18 transects across forest-barren transition zones at three study sites including Peggy's Cove, Taylor's Head, and Canso. Graph A represents the species scores while graph B illustrates the plot scores. DCA axis 1 eigen value = 0.6822; DCA axis 2 eigen value = 0.6055. Plot 1 represents reference forest plots while plots 2-4 represent the transition zone (edge), and plot 5 represents reference coastal barrens. Two plots were removed from the analysis as no moss or lichen species were recorded (two #3 plots). The unlabeled dots in Graph A represent the plot scores which are depicted more clearly in Graph B.

Table 5. Moss and Lichen species names and abbreviations that correspond to the DCA diagram in Figure 5A.

Species	Abbrev.	Species	Abbrev.
Cladonia boryi	clabo	Dicranum fuscesens	dicfu
Cladonia chlorophaea	clach	Herzogiella striatella	herst
Cladonia crispata	clacr	Hylocomium splendens	hylsp
Cladonia cenotea	clace	Hypnum pallescense var. protuberans	hypa
Cladonia maxima	clama	Leucobryum glaucum	legl
Cladonia mitis	clami	Moss 1	moss
Cladina rei	clare	Pleurozium schreberi	plsch
Cladonia rangiferina	clara	Ptilium crista-castrenscens	ptili
Cladina umbricola	claum	Sphagnum angustifolium	sphan
Cladonia squamosa	clasq	Sphagnum capillifolium	sphca
Cladonia stellaris	clast	Sphagnum fuscum	sphfu
Cladonia uncialis	claun	Sphagnum magellanicum	sphma
Umbilicaria muehlenbergii	umbmu	Sphagnum russowii	sphru
Crustose lichen sp	crusp	Sphagnum girgensohnii	sphge
Conordia compacta	coco	Tetraphis pelucidia	tetra
Dicranum polysetum	dicpo	Bazzania trilobata	bazz
Dicranum scoparium	dicsco	Ptilidium pulcherimum	ptlipu

Although there was a significant change in species composition across the forest-barren transition zone, there were a number of species that were found to occur regularly at all distances such as *Kalmia angustifolia, Gaultheria procumbens, Vaccinium angustifolium, Vaccinium vitis-idea*, and *Cornus canadensis*. The only moss or lichen species found to occur at all distances was *Pleurozium schreberi* although this species was found more often in forest plots and less often in the reference coastal barren plots. *Sorbus americana, Prunus pensylvanica*, and *Cladina umbriocla* were all typically absent from both the reference forest and reference coastal barren plots occurring mainly within the plots representing the ecotone.

Of the 18 abiotic variables sampled, canopy cover (canopy), tree height (treehei), soil depth (soildep), cation exchange capacity (CEC), percent organic matter (X.org), Iron (FE), and Calcium (CA) were all found to have the highest loadings in the CCA conducted to examine potential relationships between understory vascular species composition and environmental gradients (Figure 6). The first three CCA axes represent the majority (58%) of inertia explained by the model where the entire model explains 77% of the total inertia (4.3583) (Table 6).

Table 6. CCA scores for 18 selected environmental variables for the first three CCA Axes represent the majority (58%) of the total inertia explained by the model where the entire model explains 77% of the total inertia (4.3583).

Env. Variable	**CCA 1**	**CCA 2**	**CCA3**
Canopy Cover (%)	-0.9105	-0.04827	0.186782
Soil Depth (cm)	-0.1195	-0.71077	0.162162
Tree Height (m)	-0.9059	0.1555	0.006242
CEC	0.1142	0.67508	0.568257
Ca	0.1871	0.04169	0.433416
Fe	-0.1644	0.52913	-0.37079
% Organic Matter	0.1474	-0.20173	0.564334

The first axis represents a canopy cover and tree height gradient where forest understory species such as *Oclemena acuminata, Rhus typhina, Linnaea borealis, Clintonia borealis*, and *Gaultheria hispida* were found to be positively correlated with this gradient (Figure 6). These species occur more often in areas with taller trees and greater canopy cover. Shade intolerant species such as *Drosera rotundifolia, Empetrum nigrum,* and *Gaylussacia dumosa* were found to be negatively correlated with this gradient and tend to occur in more open areas with less canopy cover.

The second CCA axis represents a soil depth gradient in one direction and CEC gradient in the opposite direction. Species associated with shallow soils and high CEC values include *Arctostaphylos uva-ursi, Corema conradii,* and *Sibbaldiopsis tridentata.* These species are generally found extending clonally over rock outcrops in areas with very shallow soils. Species associated with deep soils and low CEC values include *Carex trisperma, Kalmia polifolia, Sarracenia purpurea, Scirpus cespitosa*, and *Vaccinium* *oxycoccos.* These species are associated with bog habitats which generally have very deep peat and organic accumulation.

The third CCA axis represents a group of soil properties where CEC, soil depth, and percent organic matter all score high on this axis. Tall shrub species such as *Sorbus americana,* and *Prunus pensylvanica* are positively correlated with this axis indicating these species tend to occur in areas with well developed soil. Species such as *Aralia hispida* and *Juniperus communis* are negatively associated with this axis and are more typically found in areas with less soil development.

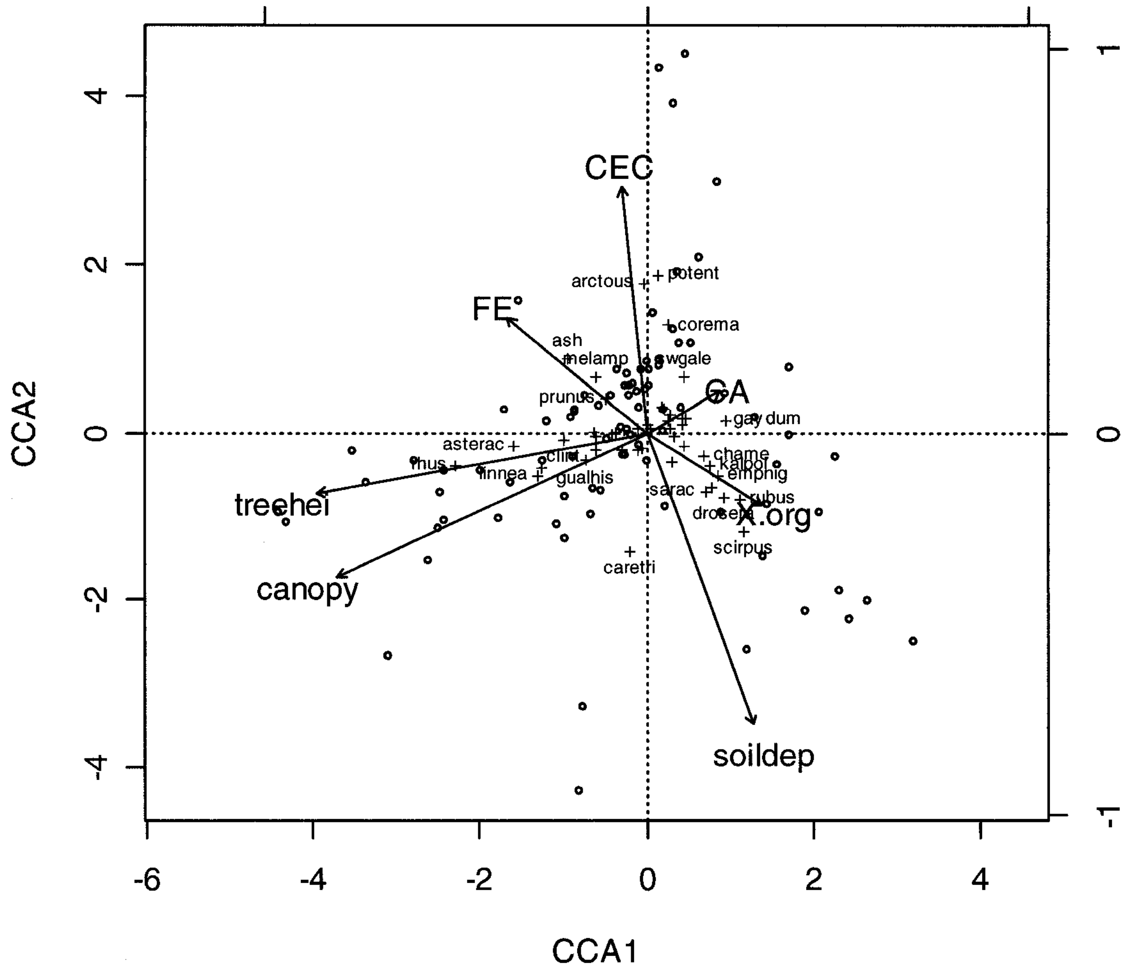


Figure 6. CCA ordination with the first two axes showing the distribution of understory vascular species composition relative to seven environmental variables along 18 transects across forest-barren transition zones at three study sites including Peggy's Cove, Taylor's Head, and Canso. Species abbreviations are explained in Table 4 (above). Five species were removed from this analysis as they were found to occur in < 2 plots and having <= 3 hits within the plot, including; *Deschampsia flexuosa, Empetrum eamesii, Hamamelis virginiana, Larix laricina*, and *Prenanthes trifoliolata.* Canopy species including *Acer rubrum, Betula papyrifera, Picea rubens, P. glauca,* and *P. mariana* were also removed from the analysis. Four plots were removed as they were found to contain < 5 species (three #1 plots; and one #4 plot).

Discussion

Results of this study suggest that forests have expanded outward toward coastal barren habitat from teed patches. The general vegetation transition across the forest - barren ecotone detected in this study represents a typical forest successional pathway where creeping or ground shrubs give way to short shrubs, which are then out competed by taller shrubs and finally tree species become dominant (Saldarriaga et al. 1988; Bazzaz 1979).

If tree demography within these forest patches showed a similar pattern across all distances from the reference forest plot (i.e., same age and size) this would indicate a more static state. In this case these forest patches may represent post-disturbance relicts that remain following an event such as a fire or wind storm, and expansion is restricted by the post-disturbance environment. Tree demography results from this study, however, do show that trees are older and larger within forest patches and gradually decrease in size and age with an increase in distance from the forest patch. This pattern suggests that these forest patches may be acting as seed and propagule sources for forest expansion into barren habitat.

These results do not suggest that forest patches will expand into coastal barren habitat indefinitely, as the rate and amount of which each forest patch can expand is essentially determined by the local environment and species interactions within the forest-barren ecotone (Breshears 2006; Maurice et al. 2004). These results merely suggest that there has been forest expansion from these patches in the past and may continue depending on the result of species interactions and abiotic factors acting within the transition zone.

Forests patches examined in this study showed a significant shift in vegetation composition and structure beyond four meters from the reference forest plots into the transition zone. This shift is represented by three distinct vegetation communities including; a forest community represented by plots 1 and 2; an edge community, represented by plots 3 and 4; and a coastal barren community, represented by plot 5. Canopy cover and tree height would be expected to differ between plots 2 and 3 as this was a predetermined point chosen based on canopy cover to ensure capturing both forest and edge conditions. However since there is another significant shift in composition and structure between plots 4 and the reference barren plots, this shows that there is a distinct vegetation gradient rather than an abrupt switch between forests and barrens.

Species richness was not found to differ between reference forest and reference barren plots. This indicates that forest encroachment does not so much represent a loss of total number of species as it is more of a shift or replacement of low growing, open species such as *Arctostaphylos uva-ursi, Chamaedaphne calyculata, Corema conradii,* and, *Gaylussacia dumosa* by shade tolerant forest understory species and canopy tree species including *Acer rubrum, Betula papyrifera* and *Drepanocladus fluitans*.

A number of studies have suggested the concept of an increase in biotic diversity within edge environments compared to adjacent forests (e.g., Fraver 1994; Harris 1988); although more recent studies have found little to no effect on species richness within edges (Harper and MacDonald 2002; Lloyd et al. 2000). Total species richness within transition zones on Nova Scotia coastal barrens was not significantly different from reference forest plots and was, in fact, significantly lower in plots 2 and 3 than the reference coastal barren plots. These areas consisted of very dense shrub cover which may result in the loss of ground species such as *Trientalis borealis* due to thick accumulations of leaf litter and dense shrubby stems resulting in a lower number of species.

Results of the ordinations show community divergence following distinct environmental gradients. As expected, forest understory species were positively related to forest structure variables such as tree height and canopy cover. Similarly, peatland species such as *Sarracenia purpurea* and *Drosera rotundifolia* were found to occupy areas with high percent organic matter. Tree or tall shrub species such as *Prunus pensylvanica* and *Sorbus americana* are positively related to iron content in the soils. Iron is generally found in the B horizon which is the zone of accumulation as nutrients are leached from the above layers. This correlation is an indication that these species are found in areas with well developed soils and may signal the potential for forest development as these species also represent early successional tree species.

Canopy cover was expected to negatively impact rock outcrop species such as *Arctostaphylos uva-ursi, Corema conradii*, and *Sibbaldiopsis tridentata* as these species are generally found in open, full light environments. Results of this study found that this was not the case in that these species were found to be strongly associated with shallow soil depth but orthogonally related to canopy cover and tree height (i.e, no relationship with canopy cover or tree height). This may indicate that lack of soil and environmental conditions offered by exposed rock outcrops may be more important to the persistence of these communities than the lack of tree cover and increased shade.

Forest stands, in particular Jack pine and spruce stands, developing in areas with exposed outcrops containing species such as *Corema conradii*, and *Sibbaldiopsis* *tridentata* were found within the study sites (S. Burley pers. observ.). These tree species were found to occupy spaces and crevasses between exposed rock outcrops that are relatively devoid of soil. These conditions may represent a lag in vegetation response to forest encroachment where rock species such as *S. tridentata* are able to persist in spite of increased canopy cover. As soil develops over these exposed rocks as a result of litter accumulation and decomposition from the surrounding trees, rock outcrop species may be replaced by, more typical forest understory species such as *Linnea borealis* and *Clintonia borealis*. A more detailed examination of species interactions between rock outcrop species and forest understory species is recommended in order to further explain this pattern.

Conclusion

Coastal barren communities in Nova Scotia are important for a number of rare plant species, contain unique vegetation types, and provide important socioeconomic functions. This study determined that forest patches located within coastal barrens are not static relicts of pre-disturbance conditions, but show signs of expansion into surrounding vegetation over time. This is not to say that forest patch expansion will occur indefinitely into coastal barren habitat, as the temporal dynamics of this system fluctuate based on environmental factors and species interactions. This forest patch expansion does however pose a potential threat to the uncommon assemblages and rare species occurring on coastal barrens as further expansion of these forest patches may extend the influence of edge on species composition into barren habitat and replace rare coastal barren communities. These forest patches may represent seed and propagule sources from which forest expansion can occur further into coastal barren habitat.

References

Atlantic Canada Conservation Data Center (ACCDC). 2005a. Provincial Lists and Ranks. Viewed October 13, 2008. Available online: http://www.accdc.com/products/lists/

Atlantic Canada Conservation Data Center (ACCDC). 2005b. Glossary. Viewed October 13, 2008. Available online: http://www.accdc.com/glossary/index.php#rank

Bazzaz, F.A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics*. 10: 351-371.

Bradley, R.L.; Titus, B.D.; and Fyles, J.W. 1997. Nitrogen acquisition and competitive ability of Kalmia angustifolia L., Paper Birch (Betula papyrifera Marsh.) and Black Spruce (Picea mariana (Mill.) B.S.P.) seedlings grown on different humus forms. *Plant and Soil* 195: 209-220.

Breshears, D.D. 2006. The grassland-forest continuum: trends in ecosystem properties for woody plant mosaics? *Frontiers in Ecology and the Environment* 4 (2): 96-104.

Brewer, R. 1979. Principles of Ecology. W.B. Saunders Company. Philadelphia, PA.

Brodo, E., Sharnoff, S.D., and Sharnoff, S. 2001. *Lichens of North America.* Yale University Press, New Haven.

Crum, H. 1983. *Mosses of the Great Lakes Forest,* 3rd edition. University of Michigan, Ann Arbour.

Dunwiddie, P.W.; Zaremba, R.E.; and Harper, K. 1996. A classification of Coastal Heathlands and Sandplain Grasslands in Massachusetts. *Rhodora* 98 (94): 117-145.

Ehrenfeld, J.G.; Zhu, W.; and Parsons, W.F.J. 1995. Above- and below-ground characteristics of persistent forest openings in the New Jersey Pinelands. *Bulletin of the Torrey Botanical Club* 122 (4): 298-305.

Esseen, P.; Jansson, K.U.; and Nilsson, M. 2006. Forest edge quantification by line intersect sampling in aerial photographs. *Forest Ecology and Management* 230: 32-42.

Faison, E.K.; Foster, D.R.; Oswald, W.W.; Hansen, B.S.C.; and Doughty E. 2006. Early Holocene openlands in southern New England. *Ecology* 87 (10): 2537-2547.

Fortin, M.J. 1994. Edge Detection Algorithms for Two-Dimensional Ecological Data. *Ecology* 75 (4): 956-965.

Fraver, S. 1994. Vegetation responses along edge-to-interior gradients in the mixed hardwood forests of the Roanoke River basin, North Carolina. *Conserv. Biol.* 8: 822-832.

Freedman, B. 2004. Environmental Science: a Canadian Perspective. Pearson Education Canada Inc. Toronto, Ont.

Greene, D.F.; Zasada, J.C.; Sirois, L.; Kneeshaw, D.; Morin, H.; Charron, I; and Simard, M. J. 1998. A review of the regeneration dynamics of North American boreal forest tree species. *Canadian Journal of Forest Research* 29: 824-839.

Harper, K.A. and Macdonald, S.E. 2001. Structure and composition of riparian boreal forest: new methods for analyzing edge influence. *Ecology* 82: 649-659.

Harper, K.A. and Macdonald, S.E. 2002. The critical values program for assessing edge influence. *Bull. Ecol. Soc. Am.* 83: 61-62.

Harper, K.A., Macdonald, S.E., Burton, P.J., Chen, J., Brosofske, K.D., Saunders, S.C., Euskirchen, E.S., Roberts, D., Jaiteh, M.S., Esseen, P.-A., 2005.
Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology* 19: 768–782.

Harris, L.D. 1988. Edge effects and conservation of biotic diversity. *Conserv. Biol.* 2: 330-332.

Krause, C. 2006. Growth development of balsam fir (*Abies balsamea* (L.) Mill.) originating from layering. *Dendrochronologia* 23: 139-143.

Latham, E.R. 2003. Shrubland longevity and rare plant species in the Northeastern United States. *Forest Ecology and Management* 185: 21-39.

Latham, E.R.; Thompson, J.E.; Riley, S.A.; and Wibiralske A.W. 1996. Pocono till barrens: shrub savannah persisting on soils favoring forests. *Bulletin of the Torrey Botanical Club* 123 (4): 330-349.

Lloyd, K.M., McQueen, A.A.M., Lee, B.J., Wilson, R.C.B., Walker, S. & Wilson, J.B. 2000. Evidence on ecotone concepts from switch, environmental and anthropogenic ecotones. *J. Veg. Sci.* 11: 903-910.

Mallik, A.U. 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. *Critical Reviews in Plant Science* 22 (3&4): 341-366.

Mallik, A.U. 1995. Conversion of temperate forests into heaths: Role of ecosystem disturbance and Ericaceous plants. *Environmental Management* 19 (5): 675-684.

Mascarúa, L.E.; Harper, K.A. and P. Drapeau 2006. Edge influence on forest structure in large forest remnants, cutblock separators, and riparian buffers in managed black spruce forests. *Ecoscience* 13 (2): 226-233.

Maurice, K.R.; Welch, J.M.; Brown, C.P.; and Latham, R.E. 2004. Pocono mesic till barrens in retreat: topography, fire and forest contagion effects. *Landscape Ecology* 19: 603-620.

Neily, P.; McCurdy, D.; Stuart, B.; and Quigley, E. 2004. Coastal Forest Communities of the Nova Scotian Eastern Shore Ecodistrict. *Forest Research Report* 74. Nova Scotia Department of Natural Resources Forest Management Planning.

Nova Scotia Museum of Natural History. 1997. *Natural History of Nova Scotia VolumeI: Topics and Habitats*. Nova Scotia Museum of Natural History, Nova Scotia.

Oberndorfer, E., and Lundholm, J.T. 2009. Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. In press, Biodiversity and Conservation.

Økland, R.H. 1990. Vegetation ecology: theory, methods and applications with reference to Fennoscandia. Sommerfeltia Supplement. University of Oslo.

R version 2.5.1 (2007-06-27). The R Foundation for Statistical Computing. ISBN 3-900051-07-0.

Roland, A.E., Smith, E.C., 1963. The Flora of Nova Scotia. Nova Scotian Institute of Science. Halifax, Nova Scotia.

Saldarriaga, J.G.; West, D.C.; Tharp, M.L.; and Uhl, C. 1988. Long-term chronosequence of forest succession in the Upper Rio Negro of Columbia and Venezuela. *The Journal of Ecology* 76 (4): 938-958.

Stark, K. E., J. T. Lundholm, and D. W. Larson. 2003. Relationships between seed banks and spatial heterogeneity of North American alvar vegetation. *Journal of Vegetation Science* 14:205-212.

Stark, K. E., J. T. Lundholm, and D. W. Larson. 2004. Arrested development of soil on alvars of Ontario, Canada: implications for conservation and restoration. *Natural Areas Journal* 24:95-100.

Appendix
Vegetation Species List

Table A-1 List of 59 vascular species encountered in 18 transects distributed among three coastal barren study sites including Peggy's Cove, Taylor's Head and Canso. S Ranks (where available) are from the Atlantic Canada Conservation Data Centre (2008a). The S rank indicates the Nova Scotia rarity status where; S1- extremely rare, 5 or fewer occurrences; S2 – rare, 6 to 20 or fewer occurrences; S3 – uncommon, 21-100 occurrences; S4 – widespread, fairly common, >100 occurrences; S5 – abundant, demonstrably widespread (ACCDC 2008b). The last two columns indicate whether the species was encountered in at least one of the reference forest plots or reference coastal barren plots respectively. Nomenclature was based on Roland and Smith (1963).

Species	**Family**	**Abreviation**	**S-rank**	**Sampled in Forest (Y/N)**	**Sampled in Coastal Barren (Y/N)**
Abies balsamea	Pinacea	balfir	S5	Y	Y
Acer rubrum	Aceraceae	redmap	S5	Y	N
Alnus viridis	Betulaceae	alnus	S5	Y	Y
Amelanchier sp.	Rosaceae	amelen	N.A.	N	Y
Aralia hispida	Araliaceae	aralhis	S5	N	Y
Aralia nudicalus	Araliaceae	aralnud	S5	Y	Y
Arctostaphylos uva-ursi	Ericaceae	arctous	S4	N	Y
Betula papyrifera	Betulaceae	betulap	S5	Y	N
Calamagrostis pickeringii	Poaceae	calama	S4S5	N	Y
Carex nigra	Cyperaceae	caraxni	S5	N	Y
Carex trisperma	Cyperaceae	caretri	S5	Y	Y
Chamaedaphne calyculata	Ericaceae	chame	S5	N	Y
Clintonia borealis	Liliaceae	clint	S5	Y	Y
Coptis trifolia	Ranunculaceae	coptis	S5	Y	Y
Corema conradii	Empetraceae	corema	S4	N	Y
Cornus canadensis	Cornaceae	cornca	S5	Y	Y
Deschampsia flexuosa	Poaceae	desch	S5	Y	N
Drosera rotundifolia	Droseraceae	drosera	S5	N	Y
Empetrum eamesii	Empetraceae	empem	S2S3	N	N
Empetrum nigrum	Empetraceae	empnig	S5	Y	Y
Gaultheria hispidula	Ericaceae	gualhis	S5	Y	Y
Gaultheria procumbens	Ericaceae	gaulpro	S5	Y	Y
Gaylussacia baccata	Ericaceae	gaybac	S5	Y	Y
Gaylussacia dumosa	Ericaceae	gaydum	S4	N	Y
Hamamelis virginiana	Hamamelidaceae	whitch	S5	Y	N
Ilex verticillata	Aquifoliaceae	ilexvet	S5	Y	Y
Juniperus communis	Cupressaceae	jc	S5	N	Y
Kalmia angustifolia	Ericaceae	kalang	S5	Y	Y
Kalmia polifolia	Ericaceae	kalpol	S5	N	Y
Larix laricina	Pinacea	larix	S5	N	Y
Linnaea borealis	Caprifoliaceae	linnea	S5	Y	Y
Maianthemum canadense	Liliaceae	mayflo	S5	Y	Y
Melampyrum lineare	Scrophulariaceae	melamp	S5	N	Y
Myrica gale	Myricaceae	swgale	S5	N	Y

Myrica pensylvanica	Myricaceae	bayber	S5	Y	Y
Nemopanthus mucronatus	Aquifoliaceae	nemo	S5	Y	Y
Oclemena acuminata	Asteraceae	asterac	S5	Y	Y
Osmunda cinnamomea	Osmundaceae	cinfern	S5	Y	Y
Photinia floribunda	Rosaceae	aronia	S5	N	Y
Picea glauca	Pinacea	wspr	S5	Y	Y
Picea mariana	Pinacea	blspr	S5	Y	N
Picea rubens	Pinacea	rspr	S5	Y	Y
Prenanthes trifoliolata	Asteraceae	prenan	S5	N	N
Prunus pensylvanica	Rosaceae	prunus	S5	Y	N
Pteridium aquilinum	Dennstaedtiaceae	pterid	S5	Y	Y
Rhododendron canadense	Ericaceae	rodora	S5	Y	Y
Rhododendron groenlandicum	Ericaceae	ledum	S5	Y	Y
Rhus typhina	Anacardiaceae	rhus	S4S5	Y	N
Rubus chamaemorus	Rosaceae	rubus	S4	N	Y
Sarracenia purpurea	Sarraceniaceae	sarac	S5	Y	Y
Scirpus cespitosus	Cyperaceae	scirpus	S5	N	Y
Sibbaldiopsis tridentata	Rosaceae	potent	S5	N	Y
Sorbus americana	Rosaceae	ash	S5	Y	N
Symphyotrichum novi-belgii	Asteraceae	asternb	S5	N	Y
Trientalis borealis	Primulaceae	star	S5	Y	Y
Vaccinium angustifolium	Ericaceae	bluber	S5	Y	Y
Vaccinium oxycoccos	Ericaceae	vacsoxy	S5	N	Y
Vaccinium vitis-idaea	Ericaceae	mocran	S5	Y	Y
Viburnum nudum var. cassinoides	Caprifoliaceae	raisin	S5	Y	Y

Table A-2 List of 19 lichen species encountered in 18 transects distributed among three coastal barren study sites including Peggy's Cove, Taylor's Head and Canso. S Ranks (where available) are from the Atlantic Canada Conservation Data Centre (2008a). The S rank indicates the Nova Scotia rarity status where; S1- extremely rare, 5 or fewer occurrences; S2 – rare, 6 to 20 or fewer occurrences; S3 – uncommon, 21-100 occurrences; S4 – widespread, fairly common, >100 occurrences; S5 – abundant, demonstrably widespread (ACCDC 2008b). The last two columns indicate whether the species was encountered in at least one of the reference forest plots or reference coastal barren plots respectively. Nomenclature was based on Brodo et al. (2001)

Species	**Family**	**Abbrev.**	**S-Rank**	**Present in Forest (Y/N)**
Cladonia boryi	Cladoniaceae	clabo	N.A.	N
Cladonia chlorophaea	Cladoniaceae	clach	N.A.	Y
Cladonia crispata	Cladoniaceae	clacr	N.A.	N
Cladonia cenotea	Cladoniaceae	clace	N.A.	N
Cladonia maxima	Cladoniaceae	clama	N.A.	Y
Cladina multiformis	Cladoniaceae	-	N.A.	N
Cladonia mitis	Cladoniaceae	clami	N.A.	Y
Cladina rei	Cladoniaceae	clare	N.A.	Y
Cladonia rangiferina	Cladoniaceae	clara	N.A.	Y
Cladina umbricola	Cladoniaceae	claum	N.A.	N
Cladonia squamosa	Cladoniaceae	clasq	N.A.	N
Cladonia stellaris	Cladoniaceae	clast	N.A.	N
Cladina turgida	Cladoniaceae	-	N.A.	N
Cladonia uncialis	Cladoniaceae	claun	N.A.	Y
Parmelia sulcata	Parmeliaceae	-	N.A.	N
Umbilicaria muehlenbergii	Umbilicariaceae	umbmu	N.A.	N
Usnea trichodea	Parmeliaceae	-	N.A.	Y
Usnea sp. 1	Parmeliaceae	-	N.A.	Y
Crustose lichen sp	-	crusp	N.A.	N

Table A-3 List of 27 moss and liverwort species encountered in 18 transects distributed among three coastal barren study sites including Peggy's Cove, Taylor's Head and Canso. S Ranks (where available) are from the Atlantic Canada Conservation Data Centre (2008a). The S rank indicates the Nova Scotia rarity status where; S1- extremely rare, 5 or fewer occurrences; S2 – rare, 6 to 20 or fewer occurrences; S3 – uncommon, 21-100 occurrences; S4 – widespread, fairly common, >100 occurrences; S5 – abundant, demonstrably widespread (ACCDC 2008b). The last two columns indicate whether the species was encountered in at least one of the reference forest plots or reference coastal barren plots respectively. Nomenclature was based on Crum (1983).

Species	Family	Abbrev.	S-rank	Sampled in Forest (Y/N)
Conordia compacta	Amblystegiaceae	coco	S1	Y
Cratoneuron filicinum	Amblystegiaceae	-	S2	Y
Dicranum polysetum	Dicranaceae	dicpo	N.A.	Y
Dicranum scoparium	Dicranaceae	dicsco	N.A.	Y
Dicranum fuscesens	Dicranaceae	dicfu	N.A.	Y
Dicranum undulatum	Dicranaceae	-	N.A.	N
Dicranum condensatum	Dicranaceae	-	N.A.	N
Drepanocladus fluitans	Amblystegiaceae	-	N.A.	Y
Herzogiella striatella	Hypnaceae	herst	N.A.	Y
Hylocomium splendens	Hylocomiaceae	hylsp	N.A.	Y
Hypnum pallescense var. *protuberans*	Hypnaceae	hypa	N.A.	Y
Leucobryum glaucum	Leucobryaceae	legl	N.A.	N
Moss 1	-	moss	N.A.	Y
Pleurozium schreberi	Hylocomiaceae	plsch	N.A.	Y
Ptilium crista-castrenscens	Hylocomiaceae	ptili	N.A.	Y
Racomitrium fasiculare	Grimmiaceae	-	N.A.	N
Sphagnum angustifolium	Sphagnaceae	sphan	S1	Y
Sphagnum capillifolium	Sphagnaceae	sphca	N.A.	Y
Sphagnum fuscum	Sphagnaceae	sphfu	N.A.	Y
Sphagnum magellanicum	Sphagnaceae	sphma	N.A.	Y
Sphagnum russowii	Sphagnaceae	sphru	N.A.	N
Sphagnum girgensohnii	Sphagnaceae	sphge	N.A.	Y
Tetraphis pelucidia	Tetraphidaceae	tetra	N.A.	Y
Bazzania trilobata	Liverwort	bazz	N.A.	Y
Lepedoza repens	Liverwort	-	N.A.	N
Liverwort spp	Liverwort	-	N.A.	N
Ptilidium pulcherimum	Liverwort	ptlipu	N.A.	N

Chapter 4
Synthesis and General Conclusions

Open habitats such as coastal barrens support high biological and cultural values while contributing to regional and local biodiversity. A previous study on Nova Scotia coastal barrens found eleven provincially designated rare species in six coastal barren study sites (Oberndorfer and Lundholm 2009). This is similar to other open habitats such as the Pocono till barrens in Pennsylvania that were found to contain at least 30 regionally rare and 10 globally rare and endangered plant and animal species (Latham et al.1996) and rock barrens known to function globally as refugia for rare species and habitat types (Anderson et al. 1999, Larson et al. 2000). Growing knowledge concerning the landscape dynamics and community structure of these habitats has contributed to the understanding for the need to protect and conserve these unique ecosystems as threats from coastal development, climate change and forest encroachment increase.

Results of this current study show that forests are encroaching into coastal barrens representing a change in structure and shift in dominant species. The first part of this study described the landscape level dynamics of these systems where it was found that when a change in vegetation occurred over time, the general pattern consisted of a loss of coastal barren to forest. These results also describe areas of coastal barrens that were found to resist forest encroachment either through environmental conditions such as coastal effects or edaphic factors, species interactions or as a result of the temporal scale of the study where forests have not had the chance of reaching areas otherwise conducive to tree establishment. These persistent barrens may act as refugia for this unique vegetation type while maintaining important conditions for rare species dependant on these open habitats.

The second part of this study examined forest islands located within coastal barren matrices in an attempt to describe the forest-barren interface at a finer scale. In this study, tree demography indicates that these forest patches are expanding outward toward open barren habitat, further threatening rare species and uncommon vegetation communities. Species turnover across this transition zone further supports the hypothesis that forest encroachment represents a loss of these unique vegetation communities as these become replaced by common forest communities over time.

When combining the results from both studies the overall picture shows that although succession may be slower in coastal barrens than more inland sites, forest encroachment is occurring both from the continuous inland forest, and isolated forest patches scattered within coastal barrens. This pattern shows a wave of forest encroachment from inland areas as well as a "leap frog" pattern where tree species are reaching and becoming established in various areas within coastal barren habitat providing seed and propagule sources to support further forest expansion.

This study shows that there are areas of coastal barrens that have resisted forest encroachment and based on historical records (Degarthe 1956; LICBU 2006; Livesay 1944; Nova Scotia Museum 1997), have remained relatively stable for hundreds of years. Coastal development and perhaps fire suppression has, however, resulted in a small area available for long-term persistence of low shrub barrens communities. Given this information managers of open barrens in Nova Scotia must decide how much of this habitat should be conserved in order to provide suitable refugia in the wake of further forest encroachment that will allow for the persistence of these communities over time. Using results of this study, current coastal barrens can be examined to determine the potential for further forest encroachment from which decisions can be made as to how active conservation strategies must be in order to provide an adequate representation of this habitat type in the region. At the very least priority should be given to conserving the remaining coastal barren habitat by eliminating or reducing further human impact on these ecosystems.

References

Anderson, R.C.; Fralish, J.S.; and Baskin, J.M. (eds.). 1999. Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, New York, New York. 470 p.

Degarthe, W.E. 1956. This is Peggy's Cove Nova Scotia, Canada. Nova Scotia Archives, Halifax, NS.

Larson, D. W., U. Matthes, and P. E. Kelly. 2000. Cliff Ecology. Cambridge University Press, Cambridge.

Latham, E.R.; Thompson, J.E.; Riley, S.A.; and Wibiralske A.W. 1996. Pocono till barrens: shrub savannah persisting on soils favoring forests. *Bulletin of the Torrey Botanical Club* 123 (4): 330-349.

Livesay, J.F.B. 1944. Peggy's Cove. The Ryerson Press. Toronto, Canada.

Louisbourg Institute of Cape Breton University (LICBU). 2006. Viewed June 2 , 2008. The official research site for the Fortress of Louisbourg National Historic Site of Canada. available [online] http://fortress.uccb.ns.ca/search/List_gen.html.

Nova Scotia Museum of Natural History. 1997. *Natural History of Nova Scotia VolumeII: Theme Regions*. Nova Scotia Museum of Natural History, Nova Scotia.

Oberndorfer, E., and Lundholm, J.T. 2009. Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. In press, Biodiversity and Conservation.