Substrate Characteristics of Braya Habitat on the Limestone Barrens, Great Northern Peninsula, Newfoundland.

by
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A thesis in partial fulfilment of the requirements for the degree of Bachelor of Science, Joint Honours (Geography and Earth Sciences)

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April 2002
Acknowledgements

In writing this thesis I have learned many things from many people but my greatest thanks goes to my supervisor, Dr. Trevor Bell, without him this would have simply been an idea.

I would also like to thank Dr. Luise Hermanutz, Laura Noel, and Kim Parsons from the Department of Biology at Memorial University of Newfoundland who answered all my botanical questions and much, much more. Thanks for the patience ladies.

Of course I have to thank my mom and dad for all their support. Not only did they believe in me but they actually travelled to the Northern Peninsula and stayed a couple of nights with me. I think maybe even collected a sediment sample or two.

I am also in great debt to my Aunt, Marilyn Rose, who allowed me to latch on at 23 Mount Cashel Road for the past four years and listened to the sound of my printer throughout the night during the final stages of this thesis.

Finally I would like to thank Karyn Butler from the Geography Department at Memorial University of Newfoundland for her patience and guidance throughout the duration of my studies at Memorial.
Abstract

This paper describes substrate characteristics and their relationship to the distribution of *Braya longii* and *Braya fernaldii*, two arctic-alpine plants designated by the Committee on the Status of Endangered Wildlife in Canada as endangered and threatened species. Their worldwide distribution, enclosing less than ~10,000 plants, is restricted to a 120 km-long coastal strip on the Great Northern Peninsula of Newfoundland. Braya preferentially grow on open, vegetation-free, disturbed substrates; however, this type of habitat occurs in less than 10% of their distribution range. Human activities, such as limestone quarrying, threaten braya habitat and raise concerns for braya survival.

Specifically, the following objectives were addressed in this study; (i) to describe the different types of land cover/substrate occurring at known braya locations and to determine the presence/absence of braya within each; (ii) to measure specific characteristics of substrates containing braya to determine whether these characteristics limit braya growth or affect population structure; (iii) to employ results from the braya substrate studies to locate new braya habitat elsewhere on the limestone barrens.

Within the natural substrates the highest concentrations of braya were found growing in the diamicton class, which only covers ~16% of the study area. High concentrations also occurred on human-modified substrates. Within the diamicton class, braya were most concentrated in areas that experienced moderate amounts of frost heave (2-8 cm/year of upfreezing) and had a texture similar to local glaciomarine drift. Human-modified substrates generally experienced less frost heave (<2 cm/year of upfreezing) and had at least 50% more gravel than natural substrates. These differences may account for the variations observed in population structure between braya growing on human-modified and natural substrates. An airphoto survey identified other locations on the limestone barrens that are potential habitat for braya. Of those mapped, 24% were field-checked revealing 18 previously unknown braya populations. Implications of the research results for braya conservation and protection are discussed.
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Chapter 1 – Introduction

The Strait of Belle Isle Ecoregion, located on Newfoundland’s Great Northern Peninsula contains an ecosystem called the limestone barrens (Fig. 1.1). This area is underlain by carbonate-rich rocks (e.g., limestone, dolomite) and supports a unique mixture of Gulf of St. Lawrence endemics, calciphiles and arctic-alpine plant species, some of which are very rare (Meades, 1990). Two particularly rare calciphile species are *Braya longii* and *Braya fernaldii* (Fig. 1.2). Their entire global distribution is restricted to a small stretch of coast on the western side of the Great Northern Peninsula measuring ~120 kilometres long by 4 kilometres wide (Fig. 1.3). Braya are pioneering plants that grow predominantly in cryogenically disturbed and exposed soils. In 1997, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated *B. longii* as endangered, and *B. fernaldii* as threatened\(^1\); this was reconfirmed in May 2000 (Hermanutz, 2001). The destruction of braya habitat by human disturbance is considered to be the primary reason for their designated status.

In 1998 a multi-disciplinary Braya Recovery Team was created to assess the present distribution and dynamics of braya plants and their habitat along with developing conservation strategies to ensure the long term stability and viability of these species (Hermanutz, 1998). It had been generally noted that braya grow at relatively high densities in human-modified areas (>30 plants/m\(^2\)) and at much lower densities in natural areas (<15 plants/m\(^2\)), but exact habitat and population characteristics of both environments remained unknown (Noel, 2000). Under the

\(^1\) According to the Committee on the Status of Endangered Wildlife in Canada an endangered species is, “a species facing imminent extirpation or extinction throughout its range.” A threatened species is defined as, “a species likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction.”
The research presented in this paper, which is part of the Braya Recovery Team project, focusses on the mechanisms and physical characteristics of the substrates within natural and human-modified habitats for both braya species. The primary goal of this study is to understand and describe the role of substrate in defining important braya habitat. This information is then used to identify potential suitable habitat beyond previously recognized areas which can be employed to locate new braya populations.
Figure 1.2 A) Braya fernaldii, a small plant with white to pink flowers, is shown here growing in a natural setting at Anchor Point. The tallest stem on the plant in this picture is between 5 and 6 cm. B) Braya longii, shown here growing on the edge of the airstrip in Sandy Cove, is usually slightly larger than B. fernaldii and has only been observed with white flowers. The tallest stem on the plant in this picture is between 9 and 10 cm (photos courtesy of L. Hermautz).
1.1 - Background

*Braya longii* and *Braya fernaldii* are both members of the Brassicaceae (Mustard) family and are endemic to the limestone barrens of Newfoundland. Both species are caespitose perennials with an average height and basal diameter between 1 and 10 cm (Meades, 1996 a,b; Noel, 2000). *B. fernaldii* is distinguished from *B. longii* by its smaller size and pubescent siliqua compared to the
smooth silique of *B. longii* (Meades, 1996 a,b). Braya are pioneering plants that do not compete well with other species. They appear to be concentrated in areas of moderate to high substrate disturbance and are adapted to this environment (Noel, 2000). For example, long stout taproots help ensure that the plant remains anchored in the substrate (Fig. 1.4).

![Figure 1.4 The deep taproots of *B. fernaldii* anchor the plant and allow it to colonize disturbed areas. Even the roots of a seedling are relatively long (~5 cm in this picture).](image)

*B. longii* and *B. fernaldii* were first discovered by two Harvard botanists, M.L. Fernald and Bayard Long, in 1924 and 1925, respectively (Meades, 1996 a,b). At that time *B. longii* was found along a stretch of coastline ~ 6km in length between Yankee Point and Sandy Cove Point, while *B. fernaldii* was considered to be fairly common in various locations along ~120 km of coast from St.
Barbe to Burnt Cape (Meades, 1996 a, b; Fig. 1.3). Current ranges are essentially the same as they were in 1925 with the exception of a small population of *B. fernaldii* located near Port au Choix, ~70 km south of the limit as mapped by Fernald (1926).

Only five of the original fifteen documented locations of *B. fernaldii* were relocated by Meades in 1995 and 1996 (Hermanutz, 2001). There were a total of ~500 plants in these five populations and one site contained only a single plant. The concentrated efforts of the Braya Recovery Team during surveys in 1998 and 1999 led to the discovery of another four of the original *B. fernaldii* sites and the identification of ~1500 plants.

The three *B. longii* sites are in the locations first discovered in 1925 but now the vast majority of the populations lie within human-modified habitat. Surveys by Meades in 1995 and 1996 estimated that *B. longii* population comprised only 235 plants and therefore concern of extinction was very high. However, the 1998 and 1999 surveys documented a larger total population of ~6000 plants (Hermanutz, 2001).

Although the efforts of the Braya Recovery Team in the 1998 and 1999 surveys alleviated some anxiety about braya extinction, a number of important concerns still remained: (i) *B. fernaldii* are present in a number of locations along the limestone barrens but the total number of plants is very low; (ii) *B. longii* have a relatively higher total population size but they occur at fewer locations and are therefore more susceptible to a single event extinction. *B. longii* populations are also principally located on human-modified substrates and are consequently more susceptible to human destruction.

In 1998, Hilary Janes, a Geography honours student at Memorial University of Newfoundland, investigated the magnitude and timing of human modification on the limestone barren at known braya locations during the mid to late 1900s (Janes, 1999). She concluded that
between 1968 and 1995 there was an 80% decline in available braya habitat. The major reasons for loss of habitat has been attributed to the construction of the Northern Peninsula highway (Route 430), quarrying of limestone aggregate and expanding infrastructure in the communities along the coast (eg. the construction of an airstrip, clearing of land for new houses and buildings).

The following year, Laura Noel, a Biology honours student at Memorial University of Newfoundland, studied the relationships between braya population structure and substrate disturbance regime. Noel separated both species into four different size and age classes and mapped the abundance of braya growing in each class on natural and human-modified substrates. Her results revealed that braya growing on human-modified substrates were mostly seedlings, suggesting that recruitment is high and persistence is low. In contrast, the majority of braya growing on natural substrates were older, implying that recruitment is lower and persistence is higher. In addition, she discovered that braya preferentially grow in specific zones within natural substrates. This will be discussed in more detail in chapter 4, section 4.1.5.

1.2 - Literature Review

Results from other scientific work offer insight on relationships and processes that may exist on the limestone barrens. In addition, other scientific studies may indicate how to test the reason for braya growth in particular substrates. The following section is an investigation of the current literature on important relationships and processes that are, or may be taking place on the limestone barrens.

1.2.1 - Frost Action

Seasonal cryogenic freezing and thawing of soils causes disturbance. The term “cryogenic” refers to the processes and dynamics occurring within frozen ground (below 0°C). The term frost
Frost heave is a particularly important frost action process that involves the volumetric expansion of soil as a result of the 9% expansion of water upon freezing. There are generally two types of frost heave: primary and secondary (Perfect and Miller, 1988; Williams and Smith, 1991; French, 1996). French (1996) as well as Williams and Smith (1991), define primary heave as vertical movement of soil associated with the formation of needle ice and segregated ice lenses as the frost line advances down or up through substrate. Secondary heave occurs within frozen substrates and involves the growth of segregated ice lenses by the slow migration of unfrozen water through the ice structure. Needle ice acts to lift small amounts of the upper portion of the substrate while ice lenses lift the substrate as a coherent mass. Maximum vertical displacement occurs during secondary heave in midwinter.

One important characteristic of frost heaving is the upward movement of stones and objects during expansion. This process, called upfreezing, has important practical and scientific consequences in regions that undergo intense frost action (Anderson, 1988 a). For example, frost heave damages things like crops, roads, foundations, and pipelines by applying upward pressure on the whole or particular parts of the object (French, 1996). The exact mechanism of upfreezing is still not completely understood but the general process involves the upward movement of coarser material relative to the rest of the substrate during freezing. Once moved the object leaves a space beneath it which is filled with finer material by lateral freezing and infilling during thaw (Anderson, 1988a; French, 1996). Both of these processes effectively block the object from returning to its original position.
The magnitude and timing of upfreezing is dependant on a variety of environmental factors. Some primary influences include:

a) Substrate texture - Substrates dominated by grain sizes of 0.01 mm (very fine sand) or smaller are the most susceptible to frost heave because their matrix geometry supports high moisture retention and movement necessary for maximum ice lensing (Fahey, 1978; French, 1996).

b) Vegetation and snow cover - Vegetation and snow cover act to insulate underlying substrates by reducing near-surface wind speed and decreasing the amount of surface area directly exposed to the air. This retards the advance of the freezing front which delays and decreases frost heave (James, 1971; Williams and Smith, 1991; Benedict, 1992).

c) Soil Water Chemistry - The presence of a high concentration of total dissolved solids in soil water depresses the freezing temperature below 0°C.

d) Temperature - If temperature fluctuates around the freezing point a number of freeze-thaw cycles can occur which increases the total amount of heave a substrate will experience in a frost season.

e) Topography and Aspect - Changes in topography and slope aspect affect air temperature and ground freezing. For example, in the northern hemisphere south-facing slopes are warmer than north-facing slopes. Low lying areas tend to accumulate water which increases the amount of water available for ice lense formation and leads to more frost heave. The effects of topography and aspect can be applied to both regional and local scale situations.

1.2.2 - Patterned Ground

In arctic and subarctic regions, cryogenic processes, particularly frost heave, have been linked to the vertical and horizontal sorting of substrates producing patterned ground (Washburn,
1956; Williams and Smith, 1991; French, 1996). Patterned ground is a collective term introduced by A.L. Washburn (1956) to describe surfaces that exhibit regular to irregular surface patterning developed mainly by intensive frost action.

There are many different types of patterned ground (e.g. sorted circles, sorted stripes, unsorted nets) all of which are classified using two main criteria: (i) a discernable pattern, and (ii) presence or absence of sorting (Washburn, 1956). Sorted types of patterned ground are defined by differences in the alternation between fine and coarse debris while the unsorted varieties are described more by their micro-relief and vegetation cover.

Although there have been many hypotheses examining the mechanisms of formation (Washburn, 1956, 1988; Hallet, 1985, 1988), the exact method of their creation still remains debatable. The most common types of patterned ground encountered during this study were sorted circles and polygons. These features vary in size with approximate diameters of 1 and 3 m and have a fine grained centre surrounded by a coarse grained border (Washburn, 1956; Henderson, 1968; Hallet & Prestrud, 1985; Hallet et al., 1988). The most widely accepted mechanism for their formation involves a frost induced soil circulation in which upfreezing and radial movement of coarser material from the centre to the borders sorts the substrate into repeated patterns (Hallet, 1985; French, 1987; Anderson, 1988b; Washburn, 1988; Ballantyne and Harris, 1994).

It has been suggested that because of this circulation sorted sediments tend to have higher nutrient concentrations that the surrounding stable substrates (Jonasson and Sköld, 1983). In addition, Jonasson and Sköld (1983) found that nutrient concentrations decreased from the centres to the borders of sorted polygons.
1.2.3 - Plants and Patterned Ground

Plants growing in areas with high levels of frost heave are also directly affected by the disturbance. It has been found that different vegetation zones will form according to the level of disturbance (Jonasson, 1983, 1986; Noel, 2000). These zones vary with respect to vegetation type and amount of cover. Studies by Jonasson and Sköld (1983) and Jonasson (1986) describe changes in plant communities across sorted polygons. For example, Jonasson and Sköld (1983) found that the amount of heath vegetation increased with increasing distance from the centre of sorted polygons. The marginal success within the central zones is attributed to elevated levels of disturbance. This is understandable considering that central areas of sorted circles have been commonly observed to experience surface heave values of 10 to 30 cm per year (Fahey, 1978; French, 1987; Washburn, 1988; Hallet, 1998).

Noel (2000) observed a zonation of vegetation across the sorted circles found on the limestone barrens of the Northern Peninsula of Newfoundland. Brayna were most frequently found growing between the central and border regions of sorted circles, while competitive heath vegetation were most commonly found in the border zones. Rarely was vegetation found growing in the centres of sorted circles. Pioneering plants have developed stout taproots to help resist the effects of frost heave; however intensive upfreezing may result in ejection of even well anchored plants (Perfect, 1988). Perfect (1988) points out that the amount of disturbance caused by primary heave would not be great enough to eject well anchored plants. Also, Brink (1964) showed that the diurnal formation of needle ice during primary frost heave is a major cause of seedling mortality.

1.3 Study Objectives
The previous efforts of Meades in 1995 and 1996 and the Braya Recovery Team in 1998 and 1999 revealed that areas with known braya habitat have a limited distribution. The limestone barrens cover ~500 km$^2$ yet observations have revealed that <10% of this contains braya habitat (Hermanutz, 2001). As a result, one of the priorities of the Braya Recovery Team was to find out more about braya habitat. The team suggested that substrate is a particularly important component of this habitat affecting braya growth (Hermanutz, 1998, 1999). The objectives of this research focus on studying the substrates in which braya grow in an attempt to provide new information on these substrates and species/substrate relationships.

Qualitative observations made by the Braya Recovery Team suggest that within natural substrates braya appear to grow best in substrates that are open, free of vegetation and contain an unconsolidated fine grained sediment (Hermanutz, 1999, 2000). However, it was also observed that braya grow in higher numbers and densities on human-modified substrates which lack any substantial amount of fine grained sediment. Substrates that support braya, whether natural or human-modified, comprise a small portion of the limestone barrens making it important to describe them. Therefore, the first objective of this study is;

- to describe the different types of land cover/substrate occurring at known braya locations and to determine the presence/absence of braya within each.

It is widely accepted that sorted circles have a characteristic zonation with distinctive centre and border zones (Hallet, 1985; French, 1987; Anderson, 1988b; Washburn, 1988; Ballantyne and Harris, 1994). Noel (2000) noted that braya preferentially grow in certain zones of sorted circles. In addition, she found that population structure varies between natural and human-modified substrates. The second objective is;
to measure specific characteristics of substrates containing braya to determine whether these characteristics limit braya growth or affect population structure.

Each summer the Braya Recovery Team conducts surveys to find new braya populations. Generally these surveys are conducted at sites visible from the main roads and tracks existing on the limestone barrens. It was recognized that there was a need for a more systematic approach that could recognize all potential areas throughout the whole of the limestone barrens. The third objective then is;

- to employ results from the braya substrate studies to locate new braya habitat elsewhere on the limestone barrens.
Chapter 2 - Study Area

According to Damman's scheme (1983) the study area falls within the Strait of Belle Isle Ecoregion (Fig 2.1). The region is bordered by the Strait of Belle Isle to the north and west, the Labrador Sea to the east and the Long Range Mountains to the south and east. The region is characterised by limestone bedrock, relatively low elevation/relief, a cold climate, and distinctive vegetation assemblages. Much of the area contains a mixture of bare bedrock, limestone heath, stunted boreal forest, and localized patches of thin (1-2 m thick) glacial and marine sediment.

2.1 – Physiography

The Northern Peninsula comprises two major physiographic units: (i) the Long Range Mountains and Midlands, (ii) the West Newfoundland Coastal Lowland (Grant, 1992; Fig. 2.1) The Long Range Mountains rise to maximum elevations of ~800 m above sea level and form the spine and main body of the Northern Peninsula. The mountains are principally composed of Precambrian (~1000 Ma) gneiss and granite (Bostock, 1983). On their eastern flanks the mountains plunge abruptly into the Labrador Sea while on the western flanks they rise sharply from the West Newfoundland Coastal Lowland. This lowland, developed on carbonate rocks, is an exposed section of the East St. Lawrence Lowland (Grant, 1994). It varies in width from ~2 km near Castors River to roughly 60 km between Hare Bay and Flower's Cove. Elevations are commonly between 50 and 70 m with local relief usually below 10 m. The lowland adjoins the Long Range Mountains at ~150 m via a series of faults that are roughly aligned NNE to SSW.
2.2 - Bedrock Geology

The dominant rock types within The Strait of Belle Isle Ecoregion are part of the carbonate platform sequences on which the West Newfoundland Coastal Lowland is developed. These rocks are part of a series of strata formed in tropical seas that once existed off the continental shelf of the North American landmass between the middle Cambrian (~520 Ma) and Middle Ordovician (~470 Ma).
Ma; Cummings, 1983). Three bedrock formations outcrop in the limestone barrens: Eddies Cove, St George's and Table Head (Fig. 2.2).

The oldest of these is the Eddies Cove Formation which is primarily composed of dolomite and shale that outcrop along the coast between Eddies Cove and St. Barbe. This formation is of particular interest because the only known populations of *B. longii* are located on it.

The St. George's Formation, which conformably overlies the Eddies Cove Formation, is the most widely exposed unit within the limestone barrens. It outcrops along the coast from Port au Choix to St. Barbe and from Eddies Cove to Cape Norman. This formation is largely composed of dolomite and limestone. Many of the *B. fernaldii* populations are underlain by the St. Georges's Formation.

The youngest formation is the Table Head Formation which consists mainly of limestone and shale. It outcrops along the coast from Cape Norman to Shallow Bay and is also exposed at Burnt Cape and Port au Choix where *B. fernaldii* populations are located.
Figure 2.2 Bedrock geology of the Great Northern Peninsula subdivided into three main groups. The autochthonous rocks have been subdivided to reveal the distribution of the main carbonate rock formations. Autochthonous refers to rocks formed in place meaning they are in-situ. Allochthonous refers to rocks that have been transported and moved to their present location. In this case the allochthonous rocks were thrust upon the autochthonous rocks from their site of deposition as part of an old sea floor.
2.3 - Quaternary Geology

Quaternary sediments cover ~40 to 45% of the northern half of the Northern Peninsula (Fig. 2.3). During the last glaciation all of the limestone barrens was covered by glacial ice originating from the Long Range Mountains and Labrador (Grant, 1992). Many sediments deposited by the glaciers on the lowlands were reworked by marine processes when coastal regions of the Northern Peninsula were inundated by the sea. Submergence was greatest in the north with maximum sea level being ~150 m higher than present day (Grant, 1992). Eventually sea level dropped exposing marine sediments that were in turn reworked and distributed by frost action and fluvial processes.

Primary glacial sediment or till consists of a heterogeneous mixture of unconsolidated sediments that are concentrated around the contact of Precambrian and carbonate shelf rocks (Grant, 1992). Depending on thickness and extent, they may be classified as a veneer (discontinuous cover, 1-2 m thick), blanket (completely covers bedrock, 2-5 m thick) or plain with large end moraines (complete cover forming extensive plains, 5-25 m thick) (Grant, 1992). Till is mainly restricted to the interior of the peninsula and is therefore not a major sediment type on the limestone barrens.

Marine sediments are concentrated primarily within 1 to 2 km of the present coastline and consist of a mixture of deep marine gravel muds as well as nearshore/shoreface gravel veneers and deltas (Grant, 1992). Fluvial deposits are rare whereas organic deposits are more plentiful and are represented as numerous peat bogs, fens and marshes.
2.4 - Vegetation

The Strait of Belle Isle Ecoregion has mostly rocky coastal barren vegetation completely without forest (Meades, 1990). The limestone heath of the area is “the most tundra-like vegetation on the island” and “is a unique mixture of calciphile, Gulf of St. Lawrence Endemics, arctic-alpine, and Cordilleran and Amphi-Atlantic disjunct species” (Meades, 1990). Species such as Mountain Avens (*Dryas integrifolia*), Purple Saxifrage (*Saxifraga oppositifolia*), Yellow-Mountain Saxifrage (*Saxifraga aizoides*), and Oxytropis (*Oxytropis terraenovae*) are some of the common plants found...
within the limestone heath. Tuckamore of balsam fir (*Abies balsamea*) as well as white and black spruce forest (*Picea glauca* and *Picea mariana*) are also common. Small, shallow, minerotrophic peatlands and ponds dot the area.

**2.5 - Climate**

The information on climate is derived from the climatic normals recorded between 1946 and 1990 at the Daniel's Harbour station, located at the southern extent of the limestone barrens (Fig. 1.1). The daily maximum averages in the months of July and August (hottest months) are 17.5°C and 17.6°C with extremes of 28.9°C and 26.7°C, respectively. January and February, the two coldest months, have daily minima of -11.3°C and -12.9°C, with extremes of -39.4°C and -34.5°C, respectively. The mean date of the first autumn frost falls between September 21st and 30th, while the mean date of the last spring frost is between June 11th and 20th. The mean number of frost-free days decreases from 120 near Port au Choix to less than 100 at Cape Norman (Banfield, 1983). This translates to an annual average number of growing degree-days (base of 5°C) that decreases from ~900 near Port au Choix to 600 at Cape Norman.

The prevailing westerly winds are also an important component of the climate on the Northern Peninsula. Average monthly wind speeds are > 20 km/hr and extreme gust speeds range from a low of 77 km/hr in July to a high of 148 km/hr in January. When the region's low temperatures are combined with these high winds the wind chill index can drop as low as -90°C. Sea ice is commonly present in the Strait of Belle Isle from December to June and retards the arrival of spring (Banfield, 1983).

Precipitation throughout the Strait of Belle Isle Ecoregion is moderate, ranging from an average of 1200 mm/ year in the south to 1599 mm/ year in the north. The region receives ~186
days with measurable snow and there is often complete snow cover from January until the end of March (Banfield, 1983).

2.6 - Settlement History

The first “permanent” residence along the Strait of Belle Isle was established in the late 17th and early 18th centuries as European fishermen (mainly French, English, Irish) settled in the area to exploit the cod fishery (Bell et al., 1997). The dominance of the fishing industry has remained throughout the years and subsequently all 32 communities presently listed from Port au Choix to Cook’s Harbour are located directly on the coast. Over the years lobster, crab and shrimp fisheries have also become important.

The construction of houses, expansion of community infrastructure, limestone quarrying and the construction of the Northern Peninsula highway (route 430) in the early 1950's to mid 1970's are the main processes that have been destroying braya habitat. As mentioned, settlements are concentrated along the coast as are braya. The sharing of this space makes the study of human modification to natural substrates an important component in the study of braya.
Chapter 3 - Approach, Methods and Study Sites

The following chapter explains the techniques used in this study as well as the particular reasons for their selections. A description of study sites and the techniques used at each, is also given.

3.1 Mapping Substrates

Chapter 1 described the qualitative observations relating braya distribution to specific limestone barrens substrates. The first objective of the research was to confirm these associations by looking at the general substrate types of the limestone barrens and examining braya presence/absence in each. A site representative of a typical braya location on the limestone barrens was selected for intensive study. The *B. longii* population at Sandy Cove was chosen because of its central position within the limestone barrens, the endangered status of this species, and the juxtaposition of natural and human modified substrates that both contain braya.

A grid survey was used to map land cover/substrate classes that were created on the basis of differences in % bedrock exposure, % vegetation cover, sediment texture, sediment sorting and degree of disturbance (natural or human). Land cover/substrate classes were mapped on the ground using a 390 x 90 m grid, subdivided into 30 x 30 m blocks (Fig. 3.1). Within each class the presence/absence of braya was determined by checking an average of 8 randomly selected 1x1 m quadrats within in each class. For those classes containing braya the amount of braya-supporting substrate was also recorded.
Belt transects measuring 1 to 2 m wide by 5 to 21 m long were used for detailed mapping of specific substrate classes. This mapping was done in conjunction with braya population studies described in Noel (2000). Within each belt transect substrate type and braya distribution were mapped at a sub-decimetre scale (Fig. 3.2). Substrate class was subdivided according to sediment texture and sorting. From these maps percent occurrence and cover values for both substrate type and braya were generated.

Figure 3.1 Aerial view of the Sandy Cove study site and the approximate location of the 390 x 90 m grid survey used for land cover/substrate mapping. This area is one of the original B. longii sites discovered by Fernald and Long in 1924 and 1925. Braya are found growing in the natural area under the grid as well as on the edge of the airstrip.
Figure 3.2 This picture shows a portion of the 1x1m quadrat placed over a sorted circle at Sandy Cove. The quadrat was sub-divided into 10x10 cm outlined here by the white string. This allowed more accurate location of braya plants and substrate zones.

3.2 Measuring Substrate Characteristics

With the completion of the grid and belt transect surveys, the focus turned to documenting the main characteristics of braya substrates. The comparison of characteristics between natural and human-modified substrates may determine whether substrate limits braya growth or affects
population structure. Analysis was done of three substrate characteristics; upfreezing, texture and nutrient concentration, that are considered important to plant growth on the limestone barrens.

3.2.1 - Upfreezing

Insertion of wooden dowels was used to measure the magnitude of upfreezing. This method was picked because it is cheap, easy to install and has been proven to work in a number of other studies (Hallet and Prestrud, 1985; Washburn, 1988; Benedict, 1992). Small wooden dowels (5 mm diameter) were placed in various substrates, both natural and human-modified, where braya plants are found. Dowels were inserted in lines of different depths (5 cm, 10 cm, 15 cm) to ensure an accurate measure of frost heave within the root zone. Dowel tops were painted yellow for easy identification and marked to record the ground surface position upon insertion. The dowels were inserted in late summer and retrieved the following summer after the height of the marker line above the substrate surface was recorded.

Dowel lines were installed over two frost seasons; in 1999, a pilot study was carried out using 8 dowel lines, while in 2000 another 15 dowel lines were installed at various sites to compare coastal and inland areas as well as cryogenically and human-modified areas.  

3.2.2 - Texture

Thirty three sediment samples were taken from substrates containing braya to determine whether or not a direct relationship exists between texture and braya growth. All samples relevant to this study were taken from substrates directly containing or in close proximity (< 1m) to braya plants. Samples were retrieved at 10 cm depth and stored in sealed plastic bags.
Grain size analysis was conducted using a standard wet-sieving procedure on those samples with sediment smaller than pebble size (20mm) (Allen, 1975). A 1N sodium hexametaphosphate (calgon) solution was used to help break down hardened mud samples. All samples were then dry sieved and grain sized fractions combined to determine the percent pebble-gravel, sand, and silt/clay.

3.2.3 - Nutrient Concentration

A total of 33 samples collected from Yankee Point, Anchor Point and Sandy Cove sites during the summers of 1999 and 2000 were sent to the Government of Newfoundland and Labrador, Department of Forest Resources and Agrifoods for nutrient analysis. Samples were analysed for pH, % nitrogen and ppm potassium, phosphorus, magnesium and calcium. Blind duplicates were also submitted to check analytical precision and accuracy. Percent nitrogen was determined using combustion with a LECO CHN Analyzer (detection limit 0.1%). Parts per million of calcium (detection limit 5 ppm), magnesium (detection limit 2 ppm), and potassium (detection limit 1 ppm) were determined using a Mehlich No. 3 Soil Extraction with a Varian Atomic Absorption Spectrometer. Parts per million of phosphorus was determined using a Mehlich No. 3 Soil Extraction with a Technicon Auto Analyzer (detection limit 5 ppm).

3.3 Identifying Potential Locations

To protect and conserve braya on the limestone barrens it is important to know how much area they may potentially occupy. By applying knowledge gained from the substrate mapping and
characteristic experiments, an airphoto survey was carried out to determine the availability of braya habitat in other areas of the limestone barrens.

The air photo survey covered ~160 km of coast from New Ferolle to Boat Harbour using 1:12,500 scale colour aerial photography taken in 1993 and 1995. The airphoto coverage extended inland up to ~6 km and reached maximum contour elevations of ~60 m above sea level. After the areas were mapped ground visits were made to field check as many of the areas as possible. Observations were made on the presence/absence of suitable braya substrate and braya plants. No quantitative estimates of population size were made.

### 3.4 - Study Sites

Three major sites were selected from known braya populations; Sandy Cove, Anchor Point, and Yankee Point (Fig. 1.3). These sites were selected for comparison of inland vs. coastal as well as natural vs. human-modified sites.

#### 3.4.1 - Sandy Cove

Located in the community of Sandy Cove, the focal point of this site was a gravel airstrip and an adjacent natural limestone heath, both located on a small stretch heathland between Sandy Cove and Savage Cove (Fig 3.1). The site is within a few hundred metres of the active shoreline and rises sharply through a series of limestone steps (Eddies Cove Formation). Most of the study site lies between 13 and 15 m above sea level and is relatively level.

The airstrip was built between 1974 and 1979 and is composed of rounded to subrounded limestone gravel from local quarries at Sandy Cove and Yankee Point. The airstrip is used to service
the area when the Strait of Belle Isle is unnavigable due to sea ice as well as for local seasonal forestry activities (spraying, monitoring).

Adjacent to the airstrip is a natural limestone heath containing exposed bedrock, patchy vegetation and patterned ground. Parts of the natural area displays various degrees of human modification such as scraped limestone bedrock, stockpiled limestone aggregate, access roads, dragger cable and fish nets. All practices with the exception of the limestone scraping/quarrying of bedrock remain active to date. The Sandy Cove site was selected because it offers a good location for the study of $B. \textit{longii}$ in a relatively undisturbed natural environment as well as being adjacent to a human disturbed setting.

All study methods described in Chapter 3 were carried out at Sandy Cove. Two belt transects, measuring 2x21 m and 2x3 m were mapped on the natural area while three more, measuring between 1x5 m and 1x6 m, were completed on the human-modified area. Fifteen dowel lines (4 in 1999, 11 in 2000) were installed at Sandy Cove; 4 in the airstrip gravels and 11 in the natural substrates. Thirty-seven sediment samples were taken for textural and nutrient analysis, seven from the gravel airstrip and thirty from the natural substrates.

3.4.2 - Anchor Point

The Anchor Point site is ~ 1.2 km south of the community of Anchor Point (Fig. 3.3). It is located 1-1.5 km farther inland than the Sandy Cove site and is commonly separated from the coast by boreal woodland and limestone heath. The elevation of the site is generally 15 - 20 m above sea level, and the study area encompasses ~ 30,000 m$^2$.

The limestone heath and exposed bedrock of the site are surrounded by boreal forest mixed with balsam fir, white and black spruce and scattered bog. Patterned ground and other natural
disturbances (eg. moose trampling) are present at Anchor Point but there are no obvious signs that human disturbance of substrate has ever taken place.

Techniques applied at Anchor Point were similar to those at Sandy Cove with the exception of the grid survey. Three belt transects measuring between 1 and 2 m wide and between 5 and 16 m long were mapped and seven dowel lines were installed (4 in 1999, 3 in 2000). Twenty-four sediment samples were collected for texture and nutrient analysis.

Figure 3.3 The Anchor Point site A) Aerial view; outlined are (red) B) A ground shot; the black arrow on A indicates the direction in which the picture was taken. A number of sorted circles can be seen in the foreground.

3.4.3 - Yankee Point

Located 2.5 km southwest of the Sandy Cove site, Yankee Point is a human-modified site (Fig 3.4). Yankee Point was the proposed location for the entrance to a tunnel that was to extend beneath
Figure 3.4 The Yankee Point site A) Aerial view; the Strait of Belle is to the left of the picture. The study area (outlined in red) is located at the entrance to the limestone gravel lot B) Ground shot; the black arrow on A indicates the direction the photograph was taken.
the Strait of Belle Isle to Labrador. Some preliminary site preparation was completed in the early
to mid 1970s, however no further work was done. All that remains are some scraps of metal and a
large limestone gravel lot (~0.12 km$^2$).

The study site is approximately 200-300 m from the active shoreline and located on the large
limestone gravel lot at an elevation of 18 m above sea level. The area is set amongst a mixture of
bog limestone heath and stunted boreal forest. The rounded to subrounded limestone gravel at the
site was most likely brought from nearby quarries. The lot is still used for access to local gardens
and general access to Yankee Point.

Only one belt transect, measuring 1x4 m, was completed at this site because of the uniform
nature of the substrate and time constraints. Two dowel lines were installed in the 2000 field season
and eleven sediment samples taken.
Results of field experiments and laboratory analysis are presented in this chapter. Data are split into three main sections based on the three main study objectives. The combined total of all four sections is a data set that provides detailed information on the distribution and characteristics of the substrates that braya support.

Note: No distinction has been made between the substrates of *B. longii* or *B. fernaldii*.

### 4.1 - Substrate Mapping

Land cover/substrates that support braya were mapped using a grid survey at the Sandy Cove site. The survey covered an area of ~ 35,000 m$^2$, or roughly 90% of the natural *B. longii* habitat at this site. Four distinct land cover/substrate classes were identified and mapped (Fig. 4.1; table 4.1).

<table>
<thead>
<tr>
<th>Substrate Class</th>
<th>Cover (%)</th>
<th>Braya Substrate (%)</th>
<th>Braya Substrate/ Cover (%) (n) = # of quadrats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
<td>39</td>
<td>0.0</td>
<td>0.0 (7)</td>
</tr>
<tr>
<td>Bedrock</td>
<td>30</td>
<td>0.3</td>
<td>0.8 (11)</td>
</tr>
<tr>
<td>Human-modified</td>
<td>15</td>
<td>0.1</td>
<td>0.7 (6)</td>
</tr>
<tr>
<td>Diamicton - unsorted</td>
<td>6</td>
<td>2.6</td>
<td>47.0 (6)</td>
</tr>
<tr>
<td>Diamicton - sorted (high density)</td>
<td>7</td>
<td>2.6</td>
<td>43.3 (8)</td>
</tr>
<tr>
<td>Diamicton - sorted (low density)</td>
<td>3</td>
<td>0.7</td>
<td>22.9 (7)</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>6.3</td>
<td>----</td>
</tr>
</tbody>
</table>
Figure 4.1 Composite substrate map done from grid survey.
4.1.1 - Vegetation

This class includes areas > 6 m² that are covered by vegetation and have little or no substrate exposure (Fig. 4.2). The vegetation is mostly limestone heath (e.g. mountain avens, swamp birch, dwarf willow) and tuckamore of fir and stunted spruce. Small areas (ave. < 6 m²) of wetland, open water, bog or calcareous fens are also included in this class. Vegetation covers nearly 40% of the survey area.

Figure 4.2 The vegetation land cover/substrate class mostly contains the yellowish white grasses and sedges seen in this picture. Tuckamore, seen in the top right corner of the picture, and heath are also a major component. The Strait of Belle Isle is in the background.

4.1.2 - Bedrock

The bedrock substrate class covers roughly 30% of the survey area and is characterised by areas of bare bedrock and frost shattered blocks, predominantly dolomite and limestone (Eddies Cove Formation; Fig. 4.3). Frost shattering and dissolution has reduced much of the bedrock surface
to angular cobble and boulder size clasts. In places, there are very small (< 1 m²) isolated pockets of fine sand and mud accumulation, but they represent less than 1% of this land cover class.

Figure 4.3 Bedrock land cover class. A) These bedrock blocks have experienced karst weathering as is evident by the linear dissolution troughs known as grikes. Heath vegetation, such as mountain avens (*Dryas integrifolia*), are commonly found growing in the grikes. In the background is the Strait of Belle Isle as well as a bulldozed pile of shattered limestone (human-modified land cover class). B) The bedrock rubble shown in this picture is very angular as a result of frost shattering.
4.1.3 - Diamicton

This class is characterised by angular boulders, cobbles and pebbles in a muddy matrix. It is most likely of glacial origin, but may also include marine mud. This class was sub-divided based on the degree of sediment sorting.

Unsorted Diamicton

As suggested by the name this sub-division lacks sediment sorting (Fig 4.4). Lack of vegetation cover and the vertical alignment of some clasts suggest that frost heave and upfreezing are active in this sediment but no sorting pattern exists. Of the total survey area, only 6% is covered by unsorted diamicton.

Sorted Diamicton

This sub-division applies to areas where sediments have been sorted to produce patterned ground, which according to Washburn's (1956) classification, would be classified as sorted circles, polygons and nets. For simplicity and because they are in the majority, patterned ground features are collectively referred to as sorted circles in this study. The sorted circles at Sandy Cove had diameters ranging between 1 and 2.5 m, whereas those at Anchor Point were between 0.5 m and 1.5 m wide.

Sorted circles were observed at both high and low densities (Fig. 4.4). High density refers to circle spacing of < 1 m, whereas spacing in low density is > 1 m. High density areas also contain a greater amount of fine grained sediment and a higher level of pronounced sorting compared to low density areas. High and low-density sorted circles made up 7% and 3% of the total survey area, respectively.

Three zones were identified in sorted circles based on predominant grain size of sediment and degree of sorting: border zone, intermediate zone and central zone (Fig. 4.5). Belt transects were
established in the high density sorted diamicton to investigate the possible relationship between braya
Figure 4.4 Diamicton land cover class. A) Sorted diamicton: sorted circles are best seen by looking for the light brown sediment marking the central and intermediate zones of the circles. This is an area of high density circles. B) Unsorted diamicton lacks the sorted structure and zonation present in the sorted diamicton.
occurrence and sediment sorting (Fig 4.6). Cover values for each zone at Sandy Cove and Anchor Point are summarized in Table 4.2.

<table>
<thead>
<tr>
<th></th>
<th>Border zone</th>
<th>Intermediate</th>
<th>Central</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy Cove (35)</td>
<td>89.9</td>
<td>7.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Anchor Point (38)</td>
<td>61.6</td>
<td>10.6</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The central zone is a matrix-supported, relatively stone-free fine-grained sediment void of vegetation. It occupies ~3% of the sorted diamicton class at both study sites. In contrast, the border zone is dominated by cobble to boulder clast-supported diamicton. This zone marks the outer edge of the sorted circles and is typically covered by a vegetation mat. It accounts for ~90% and 60% of the Sandy Cove and Anchor Point belt transect areas, respectively. Between the central and border zones is the intermediate zone which contains a matrix supported diamicton with pebble to boulder-size clasts and sparse scattered plant cover. The intermediate zone represents between 8 and 10% of the two study sites.
Figure 4.5 Substrate zonation of sorted circles. A) This is a sketch of an idealized sorted circle. The fine-grained centre is a relatively stone-free mud, virtually free of vegetation. Bordering this is the intermediate zone which is slightly coarser and sparsely populated by pioneering plant species. The border zone is a clast-supported coarse substrate covered by relatively large vegetation mats of limestone heath species. B) Shown here is part of a sorted circle from the Sandy Cove study site. Approximate boundaries of substrate zones are outlined.
Figure 4.6 Simplified examples of maps from the belt transects at Sandy Cove and Anchor Point. The structure of sorted polygons can be seen in both, although they do not always have the ideal concentric zonation as seen in Figure 4.5. Large clasts were included in the mapping to help ensure the exact relocation of the transects for long term monitoring of braya plants within the transects. The divisions seen on the maps are 1 metre spacings.
4.1.4 - Human Modified

The grid survey was carried out in an area considered relatively undisturbed by human activities; however, in some parts of the survey area there was clear evidence of disturbance though grading of the surface to construct a road and bulldozing of shattered bedrock (Fig. 3.1 and 4.3). In total these areas account for ~ 15% of the survey area. In addition, there are also instances where human activity has caused minor disturbance of the natural substrate. For example, the use of ATVs and spreading of fish nets did not physically alter the substrate; however, these activities can still impact braya (Fig. 4.7). This type of disturbance was observe in 12% of the non-human modified substrate classes.

Belt transects were also mapped in anthropogenic areas at the edge of the airstrip at Sandy Cove and the gravel lot at Yankee Point. At both sites substrate consisted of a rounded to sub-rounded clast-supported gravel with only minor amounts of sandy matrix. This material has most likely been brought to the site from an adjacent quarry at Yankee Point.

4.1.5 - Braya Occurrence

The percent area of favoured braya substrate was recorded for each land cover/substrate class in the grid survey (Table 4.1). Data on braya densities and population structure within the belt transects are from Noel (2000).

Braya was most concentrated within the diamicton land cover/substrate class and its subdivisions. Substrates favoured by braya were 47% and 43% of cover values for the unsorted and high density sorted diamicton, respectively. Within the high density sorted diamicton there was a distinct braya distribution across the different substrate zones. No braya were found growing in the
central zone, whereas the border zone had low mean number of individuals and a density of \(<10\) per m\(^2\). On the other hand, the intermediate zone had a density of \(~40\) per m\(^2\) at the Anchor Point and Sandy Cove sites.

Within the grid area human-modified substrates had very low numbers of braya and braya supporting substrate. However, the gravels at Yankee Point and the edge of the airstrip at Sandy Cove had mean densities of 180 braya per m\(^2\) and \(~70\) braya per m\(^2\), respectively.

Figure 4.7 This picture shows an example of how human activity may slightly modify the unsorted diamicton substrate class. In this case nets have been spread out over an area of unsorted diamicton at the Airstrip site.
4.2 - Substrate Characteristics

Measurement of specific substrate characteristics was restricted to those substrates with the highest braya densities and highest mean number of individuals as determined by Noel (2000). These substrate classes include: (i) diamicton, and (ii) human-modified substrates at Yankee Point and the gravel airstrip at Sandy Cove.

4.2.1 - Upfreezing

Upfreezing of dowels was monitored during the winters of 1999-2000 and 2000-2001 in the diamicton and human-modified substrate classes (Fig. 4.8). All dowels, regardless of depth of insertion or substrate experienced on average 55% more vertical displacement in 1999-2000 than in 2000-2001. In addition, during the 1999-2000 frost season dowels inserted deeper in the substrate experienced on average ~50% more vertical displacement then those at shallower depths. With the exception of the central zone at Sandy Cove, depth of insertion had no major effect on the amount of upfreezing during the 2000-2001 frost season. The pattern at Sandy Cove shows an initial increase in upfreezing between dowels inserted between 5 and 10 cm, with a decrease at greater depth.

Unfortunately the 1999-2000 data set is limited to sorted diamicton only; however, the 2000-2001 data set shows that, with the exception of the intermediate and central zones of sorted circles, the variation in dowel displacement was relatively consistent between study sites and substrate types (between 0 and 2 cm). The intermediate and central zones both have displacement values generally above 2 cm.

For both Anchor Point and Sandy Cove there was a clear increase of at least 2 cm in dowel displacement from the border to the central zones of sorted circles (Fig 4.9). This trend was present
during the 1999-2000 and 2000-2001 frost seasons with a maximum difference of ~6.5 cm occurring at the Sandy Cove site 2000-2001 frost season (10 cm insertion depth).

Figure 4.8 This graph summarizes all results for dowel monitoring from the 1999-2000 (blue) and 2000-2001 (red) frost seasons. The data are sorted by substrate (designation on x-axis) and study site (designation above data). Displayed are the mean values (central box), +/- 1 standard deviation (range around mean), number of dowels on which the mean is based (number below range), and the insertion depth of dowels (number above range). The y-axis is a measure of the amount of vertical displacement due to upfreezing.
Figure 4.9 Dowel lines 3 and 4 at the Sandy Cove study site before and after the 1999-2000 frost season. The same nail is circled (red) in A and B. A) Dowel position before upfreezing; black marker lines on the dowels are level with the substrate surface. B) Dowel position after upfreezing; black marker lines are well above the substrate surface. The majority of the dowels within the central zones have been completely thrown out of the substrate.

4.2.2 - Sediment Texture

A total of 33 samples from Sandy Cove, Anchor Point and Yankee Point were analysed for sediment texture. Analysis of these samples show variations of 25%, 7% and 6% for the gravel, sand, and silt/clay fractions respectively. Gravel fractions had larger variations because sample size was relatively small (~150g) compared with the weight of a single pebble. Therefore small variations in the number of pebbles meant large variations in weight of the gravel fraction.

Unsorted diamicton at both the Anchor Point and Sandy Cove sites have a similar texture; means were between 60% and 67% for silt/clay and 16% and 20% for gravel. This sediment texture is similar to that described by Grant (1994) for glaciomarine drift on the Northern Peninsula.
With one exception, texture becomes increasingly finer towards the centre of the sorted circles sampled (n=5) with an average decrease of 19% in the gravel fraction and an average increase of 25% in the silt/clay fraction (Fig. 4.10). This pattern is also observed for the data means (Fig. 4.11). There was almost no change in the sand fraction across sorted circles (not shown on Fig. 4.10 or 4.11, Appendix 1).

The large textural variation observed in the unsorted diamicton is similar to the total variation observed in all zones of the sorted diamicton. However, if only the mean values are considered, it appears that the texture of the unsorted diamicton most closely resembles the intermediate zone.

Human-modified substrates at Sandy Cove and Yankee Point are predominantly composed of gravel, with mean values of 65% and 86% respectively. Both sites generally have less than 10% silt and clay. The human-modified substrate at Yankee Point is slightly coarser than at Sandy Cove. All human-modified substrates are substantially coarser than natural diamictic substrates.

Figure 4.10 Textural variations of the gravel (blue) and silt/clay fractions (red) across the sorted circles at Sandy Cove (SC) and Anchor Point (AP). Each line represents an individual sorted circle that was sampled (5 in total).
textural variations between substrates and study sites

Figure 4.11 Texture variations expressed in weight percent of gravel (blue) and silt/clay (red) fractions for each substrate sampled at Sandy Cove (SC), Yankee Point (YP) and Anchor Point (AP). Mean values (box), data range, and number of samples used (number below range) are presented.

4.2.3 - Nutrient Regime

Thirty-three substrate samples collected in the summers of 1999 and 2000 were analysed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Three additional samples were submitted as blind duplicates to assess the variation in nutrient regime of individual substrates. These samples showed that there was error associated with the nutrient analysis. This
error was significant enough in the nitrogen and phosphorus analysis to cause considerable overlap in values from different substrates which negated results for these two variables. There is also broad overlap in the K, Ca, and Mg values; however some trends are apparent in the data (figure 4.12).

Human-modified substrates have the largest variation in calcium, magnesium and potassium with ranges between 1812 and 3115 ppm, 243 and 478 ppm, and 40 and 135ppm, respectively. Not surprisingly, there was considerable overlap in nutrient concentration sampled from Yankee Point and Sandy Cove because both sites likely share a common quarry source.

The central zones of sorted circles at both Anchor Point and Sandy Cove had lower calcium and potassium and higher magnesium values compared to their border zones. Nutrient concentrations are generally higher in sorted diamicton at Sandy Cove than at Anchor Point.

Nutrient concentrations in the samples from unsorted diamicton at Sandy Cove and Anchor Point are similar. These values most closely resemble the intermediate and central zones of sorted diamicton from these sites. Calcium and potassium values were similar from human-modified and natural substrates, whereas magnesium was generally higher in natural substrates.
Figure 4.12 Nutrient concentrations for various substrates at Yankee Point (YP), Sandy Cove (SC) and Anchor Point (AP). The vertical bars show the range of values for substrates at each site.
4.3 - Identifying Potential Locations

The airphoto survey covered an area of ~260 km² from New Ferolle to Cape Norman (Fig. 4.13). In total, 300 locations were identified as potential areas that might contain suitable braya substrate as determined from the substrate characteristics and mapping. Sites ranged in size from ~2500 m² up to 3 km². Potential sites were identified using the following criteria (Fig. 4.14):

a) non-vegetated areas (visible expanses of heathland)

b) non-wetland areas

c) above the high tide water level

d) exposed substrate (bright tone suggesting low vegetation cover).

Human disturbance was also noted in cases where:

a) roads were present through a potential site

b) sites had geometrical boundaries

c) buildings and non-natural objects lying on top of the exposure (eg. wood piles, machinery, car wrecks).

d) an obvious excavation into the natural surface cover (eg. quarry)

Of the 300 potential sites, 72 were field-checked by the author or other braya recovery team members (Appendix 2). Of these 72 sites, suitable braya substrate was observed in 35 (~50%), while braya plants were observed growing at 26 (~35%). If these percentages are extrapolated to the remaining unchecked sites identified from the airphoto analysis (228), then it might be expected that 110 sites contain suitable substrate and 82 may contain braya.
Figure 4.13 The airphoto survey covered an area of ~260 km$^2$ (purple area)
Figure 4.14 Potential braya sites (outlined in red) near the community of Green Island Brook. A ground shot of the hatched site is shown in Figure 4.14.
Chapter 5 - Discussion

The following chapter summarizes the results but also attempts to provide possible reasons why they were obtained. In addition, this chapter attempts to provide insight as to what the results mean in terms of effects on braya population and distribution. More importantly, the chapter includes a discussion of how the results affect conservation and protection strategies, as well as future research direction.

5.1 - Braya Substrates

Substrate mapping showed that braya mainly grow in areas that are open, free of vegetation and contain an unconsolidated fine grained sediment as noted by Bell (Hermanutz, 2001). On the limestone barrens diamicton of either glaciomarine or glacial origin is the most common substrate containing this type of material. At Sandy Cove, diamicton contains 94% of the braya growing on natural substrates but only accounts for 16% of the survey area.

Population studies by Noel (2000) noted that the intermediate zone of sorted circles contained higher densities and a higher mean number of individuals than any other natural substrate. Detailed maps of the sorted diamicton at Sandy Cove and Anchor Point from this study indicate that the intermediate zone only accounts for about 10% of this substrate. Together then, the grid and transect survey maps suggest that braya are highly adapted to a distinctive but very limited substrate type, which represents only 1.6% of the study area.

5.2 Substrate Characteristics and Braya

Cryogenic disturbance is the single greatest natural factor affecting braya growth on the limestone barrens. Frost heave, specifically upfreezing, of sediment acts to keep areas open and
vegetation-free which is important to a pioneering plant like braya (Hermanutz, 2001). Within sorted circles it was found that the amount of upfreezing increases between 30 and 99% from the border to the central zones. The high level of upfreezing in the central zone inhibits the growth of plant life, including braya. Relatively moderate levels of upfreezing within the intermediate zone provide enough disturbance to keep vegetation cover low; however, braya are able to succeed in this environment because of their stress-tolerating adaptions, such as long contractile taproots (Mann pers. comm., 2002). Lower braya numbers within the border zone of sorted circles and in unsorted diamicton are associated with lower values of upfreezing, which may raise competitive stress.

Cryogenic processes are responsible for the textural sorting documented in sorted circles of the limestone barrens. As predicted, there was a marked increase in the silt/clay fraction accompanied by a decrease in the gravel fraction from border to central zones (Washburn 1956; Henderson 1968; Hallet & Prestrud 1985; Hallet et al 1988).

Despite the clear zonation in grain size, braya growth does not appear to be limited by substrate texture. For example, the human-modified gravel substrates at Yankee Point and Sandy Cove are texturally very different than the natural substrates yet they support large braya populations. On the other hand, substrate texture likely influences the amount of upfreezing and therefore has an indirect influence on braya growth. For example, the fine grained central zones of sorted circles at Sandy Cove and Anchor Point experienced more upfreezing compared to the coarse grained border zones. It is important to stress, however, that substrate texture may influence the population structure and long term viability of braya, this will be discussed in further detail in the next section.

The spatial patterns in nutrient concentration across sorted circles suggests that some nutrient distribution may also be affected by cryogenic processes. Decreases in calcium and potassium concentrations from border to central zones of sorted circles follow the model predicted by the
convectional movement of material within these features (Hallet, 1985; French, 1987; Washburn, 1988; Ballantyne and Harris, 199). In contrast, magnesium values increase toward the central zones as predicted by Jonasson and Sköld (1983). The weak zonation of nutrients within sorted circles suggests some cryogenic influence; however, the low correspondence with spatial patterns of upfreezing suggest that factors like soil chemistry, soil moisture or nutrient mobility may also be affecting the observed pattern.

Nutrient concentrations in unsorted diamicton and human-modified gravels overlap with those from sorted diamicton. Nutrient concentrations therefore, do not appear to be limiting braya growth.

5.3 - Comparing Substrates

Noel (2000) noted that there were substantial differences in braya population structure between human-modified and natural substrates. Specifically, it was noted that populations on human-modified substrates were characterised by high recruitment and low persistence, whereas populations on natural substrates had low recruitment and high persistence.

The most obvious difference between natural and human-modified substrates is texture. Human-modified substrates at Yankee Point and Sandy Cove are composed of well-sorted gravel, with little or no fine grained matrix. The absence of a matrix, particularly silt and clay, affects the timing of heat, moisture and nutrient retention of a substrate. It is possible that these factors combine to produce a more favourable germinating environment for braya seeds in the spring and early summer (earlier thawing, warmer temperatures, increased light in void spaces between gravel). However, these conditions may be unable to sustain seedlings through the remaining growing season because of poor moisture retention and high competition between braya seedlings.
Furthermore, the cohesive nature of fine grained sediment acts to protect root structures from wind abrasion. The coarse gravels of human-modified substrates would offer substantially less protection from wind compared to natural substrates. It is possible that these factors account for the high recruitment and low persistence seen in human-modified substrates compared with natural conditions and suggests that texture may affect braya population structure.

There was also a significant variation in the amount of upfreezing experienced by human-modified substrates compared with the intermediate and central zones of sorted circles. The most obvious explanation for this difference is the absence of fine material within the human-modified substrates. Substrates containing a large amount of silt/clay particles trap water more readily and keep it from draining or evaporating giving these substrates a greater potential for frost heave. In addition, variations in severity of the frost season (compare the 1999-2000 and 2000-2001 frost seasons) would have a greater affect on substrates with a large silt and clay fraction. Brink (1964) links needle ice formation with mortality of seedlings. As a result, seedlings in human-modified substrates may have a greater chance of survival due to less needle ice formation. However, because these substrates lack a fine grained matrix mature plants do not have much to anchor themselves in and may be more susceptible to ejection from substrate during a more severe frost season (eg. 1999-2000 season). These factors may also account for the relatively high recruitment and low persistence observed in human-modified substrates.

5.4 - Implications for Conservation and Protection

Results from this study help to better understand the substrates that braya grow on, but more importantly they offer insight into how braya can be better protected and conserved.
5.4.1 - Transplantation

It has been suggested that braya seedlings and/or seeds be transplanted from identified braya locations or greenhouses to new locations with suitable substrate to help reduce the risk of extinction. The transplantation of braya into new areas now has an even greater chance of success because of the results from this research. Using the results from the airphoto analysis and substrate studies, new areas containing suitable substrate/habitat may be located. Braya seedlings and/or seeds can then be transplanted in specific locations within the substrate where the greatest chance of success exists. For example, braya transplanted to the sorted diamicton class would be placed in the intermediate zones of sorted circles as these areas have the greatest densities of braya as identified by Noel (2000).

In addition, Dr. Wilf Nicols, Director of the Memorial University's Botanical Gardens, has been successfully growing braya in a greenhouse setting for possible transplantation. Information on substrate texture and nutrient concentration may be used to produce a substrate that more closely resembles the diamicton class composition. This may in turn ensure a higher success rate of plants transplanted in natural substrates.

5.4.2 - Remediation

In the past, remediation work has focussed on raking of human-modified gravel and transplanting braya into these areas. For example, between 1996 and 1998 this type of remediation work was supervised by Sue Meades at Burnt Cape. Here the procedure was successful in maintaining the braya population but did not create what would be deemed a natural substrate. Noel (2000) has shown that these human-modified gravels produce populations that have low persistence compared to natural substrates and are therefore less stable. Therefore remediation may be more
successful if a larger component of fine material, namely glaciomarine drift or glacial till, is added to the gravel. This would better simulate the unsorted diamicton substrate class and possibly mean longer persistence of braya in these substrates.

5.4.3 - Locating New Populations

Previous efforts of locating braya populations by Meades (1995 and 1996) and the Braya Recovery Team (1998-2001) have been limited by time and accessibility. Every year the Braya Recovery Team conducts roadside surveys of the limestone barrens to locate new braya populations and these surveys have proven to be successful. However, the airphoto survey from this study offers a more systematic approach to ensure all potential locations are checked. The strength of the approach is shown by the field checked data: almost 50% of sites checked contained suitable substrate for braya occupation and 70% of these supported braya populations. In total, 18 previously unknown braya populations were located.

Assuming that the results of the airphoto survey can be meaningfully extrapolated to the remaining unchecked locations (228), it is suggested that there may be an additional 82 braya populations to be located in the mapped area. Furthermore, only 7% of the limestone barrens mapped in this study contains suitable habitat for braya. This supports Hermanutz’s (2001) rough estimate that less than 10% of the entire limestone barrens represents suitable habitat for braya.

In recognition of the effectiveness and efficiency of this approach, the Braya Recovery Team has decided to expand the initial study area to include the entire limestone barrens. In addition they have decided to apply the same methodology in the identification of critical habitat for another rare plant species, *Salix jejuna* (Bell pers. comm., 2002).
5.5 - Future Research

The research presented in this study is essentially a preliminary look at braya substrates and the role that substrate may play in determining braya growth and population structure. More detailed studies of upfreezing, texture and nutrient regime are needed to draw stronger correlations between substrate and braya.

5.5.1 - Frost Heave Monitoring

The importance of frost heave, particularly upfreezing, in limiting or promoting the growth of braya has been suggested, however the data is far from complete. A long term monitoring project of frost heave from year to year is necessary to better understand the specifics of this process. Such a project would provide further justification of the patterns described here. There is also some ambiguity in the question of whether depth of insertion affects the amount of upfreezing of dowels. Washburn (1988) and French (1996) suggest that magnitude of upfreezing decreases with increasing depth however this study did not clearly provide evidence to either disprove or reinforce that idea. A more detailed study of frost heave could lead to clarification of this question and a better understanding of how braya root structures are affected by their depth of penetration in substrate. Presently there are plans in place to install devices to monitor temperatures in the air and substrates of braya populations (Bell pers. comm., 2002).

5.5.2 - Substrate Sampling

All the results presented here are from substrates in the central area of these limestone barrens. Further investigation into conditions at the northern (eg. Cape Norman, Burnt Cape) and
southern (eg. Port au Choix) extremities of the limestone barrens is also necessary. Although qualitative observations and preliminary substrate sampling suggest that the substrates at these locations are significantly different detailed substrate sampling is needed to verify this. Continued sampling within the diamicton class would provide a larger data set and more statistically sound results than are extractable from the results of this study. An extension of sampling into substrates that appear suitable but do not contain braya would also provide valuable information on what can be deemed suitable braya substrate.

5.5.3 - Airphoto Survey Completion

A strategy for the completion of the airphoto survey for all of the limestone barrens is currently underway. Additional airphotos have been obtained and arrangements have been made for the author to field check remaining sites in the 2002 summer field season. Not only will this identify critical areas for braya conservation but it will also be one of the first stages in a detailed mapping and cataloguing of the limestone barrens habitat (Bell, personal communication). Furthermore, identification of all braya locations on the limestone barrens can allow the base layer for focussed study of assessing the true total area of the limestone barrens containing braya supporting substrate.

In conclusion, the results from this research help provide a promising future for the long term persistence of both *Braya longii* and *Braya fernaldii* on the limestone barrens of Newfoundland's Great Northern Peninsula. The research has expanded the knowledge base on suitable braya substrate as well as general substrates of the limestone barrens. There are many other rare species that grow on the limestone barrens and it is possible that this type of approach could be employed for those species to aid in their survival and protection as well.


Janes, H., (1999). *Braya longii* (Long's Braya), *Braya fernaldii* (Fernald's Braya), and
disturbance on Newfoundland's Great Northern Peninsula. Honors Thesis, Dept. of Geography, Memorial University of Newfoundland.


## Appendix 1

Grain size for all substrate samples taken from Yankee Point (YP), Sandy Cove (SC), and Anchor Point (AP). (expressed in weight percent)

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## Field checked sites from airphoto survey

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