Braya longii (Long’s braya), *Braya fernaldii* (Fernald’s braya), and Disturbance on Newfoundland’s Great Northern Peninsula

by
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Abstract: *Braya longii* (Long's braya) and *Braya fernaldii* (Fernald's braya) are small arctic-alpine plants which grow only on the limestone barrens of northern Newfoundland. They thrive in areas which are subjected to small-scale disturbance, such as frost heaving, because it prevents other plants from establishing in preferred *Braya* habitat. *Braya longii* and *B. fernaldii* also grow well in areas that have been disturbed slightly by anthropogenic activity. Unfortunately, extensive limestone quarrying on Newfoundland's Great Northern Peninsula has destroyed a significant amount of *Braya* habitat and, as a result, a very limited number of small populations still exist. In 1997, COSEWIC designated *Braya longii* as endangered and *Braya fernaldii* as threatened.

In this study the temporal change in anthropogenic disturbance at each study site is investigated through the use of a Geographic Information System. The results generated by this method indicate that the amount of man-made disturbance on the Northern Peninsula has increased dramatically over the last 50 years. This information is necessary to emphasize the need to protect *Braya* populations from further large-scale anthropogenic disturbance. This study also uses population density measurements to examine the effect of different levels of disturbance (anthropogenic and natural) on the vitality of *Braya* populations. Such information may provide an understanding of the preferred habitat of *Braya* which may aid in the future management of these populations.

Chapter 1: Introduction

1.1 Background Information

During the summers of 1924 and 1925, Harvard botanist, M.L. Fernald, and his companion, Bayard Long, undertook an extensive survey of the flora of Newfoundland. On the Great Northern Peninsula, in particular, they documented a variety of spectacular plant species. Some of Fernald's and Long's interesting discoveries included two species of *Braya,* an arctic genus which had not previously been found so far south. At the time of their discovery Fernald considered these two species, known as *Braya longii* (Long's braya) and *Braya fernaldii* (Fernald's braya), "common" along the Strait of Belle Isle (Fernald, 1926).

Braya longii and *B. fernaldii* grow only on the limestone barrens found along the Strait of Belle Isle and on the northern portion of Newfoundland's Great Northern Peninsula (Figure 1). They typically occupy areas of limestone gravel that have been disturbed by frost heaving and may also be found in areas of small-scale anthropogenic disturbance. Such disturbances are critical to the survival of these species since they eliminate competition from preferred *Braya* habitat. However, *Braya longii* and *B. fernaldii* cannot tolerate large-scale anthropogenic disturbance, such as quarrying, as it destroys potential *Braya* habitat and removes populations. Extensive limestone quarrying on the Great Northern Peninsula has already destroyed many *Braya* populations and the few remaining populations are at risk of being eliminated. If quarrying is allowed to continue at the sites occupied by *Braya* populations there is a good possibility that these two species will become extinct.

Braya longii and *B. fernaldii* are not protected by legislation in Canada or Newfoundland even though they were designated as endangered and threatened, respectively, by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) in 1997. Recently, a *Braya* Recovery Team was

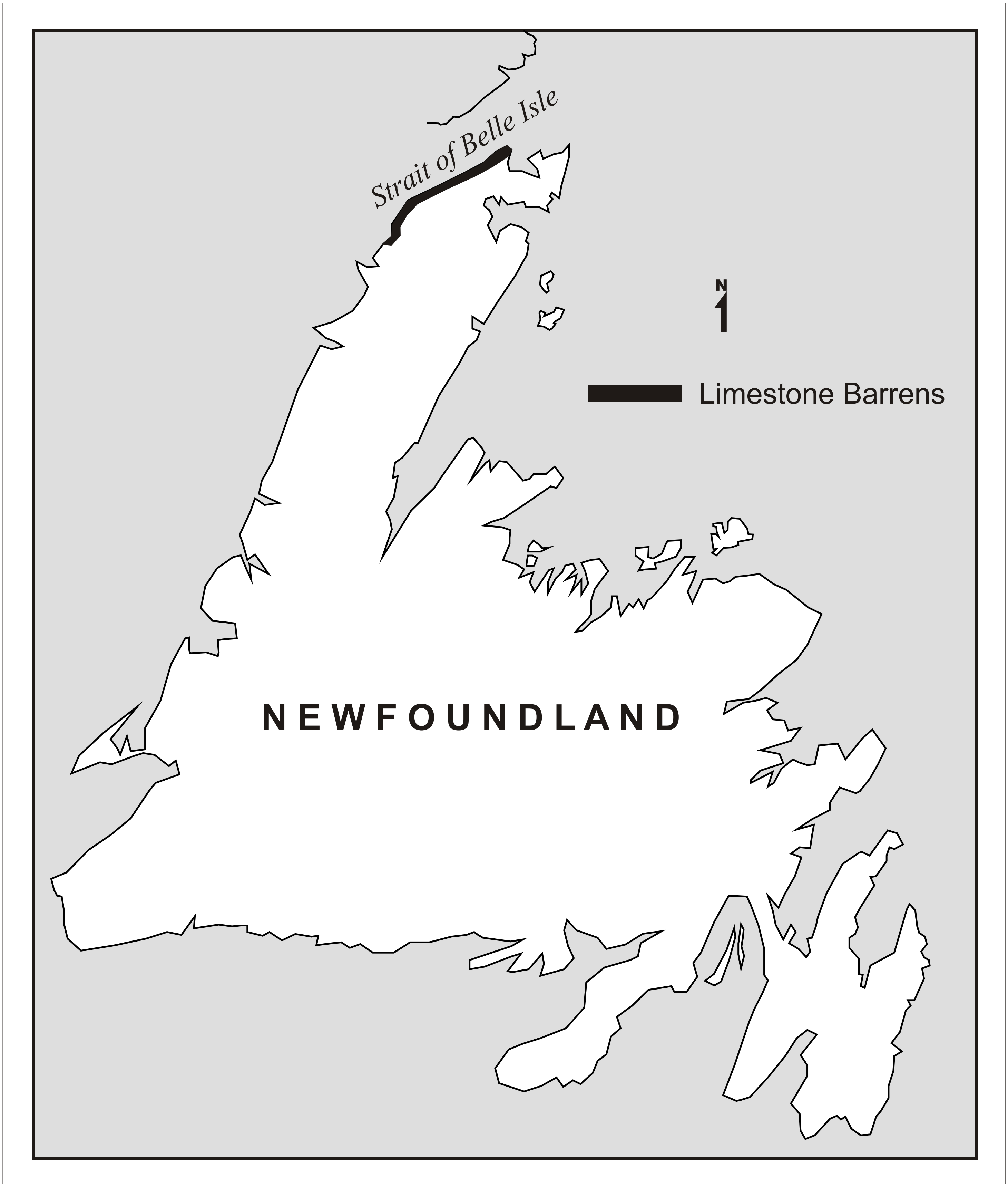

Figure 1: map of Newfoundland showing the location of the limestone barrens (Meades, 1990).

formed to monitor the remaining *Braya* populations and to help find a way to preserve them. This team is seeking habitat protection in the form of reserves, stewardship initiatives, and education programs and is currently undertaking an immediate (provincial) preservation for the seriously "at risk" populations (Hermanutz, 1998). In 1997, Burnt Cape, one of the *Braya fernaldii* sites, was designated as a "Provisional Reserve" by the Newfoundland government and should attain full Reserve status in the near future. Such status will protect this area and the plants inhabiting it from future quarrying.

1.2 Study Objectives

The main objective of this study is to classify disturbance at each of the *Braya* sites as either natural, high anthropogenic, or low anthropogenic based on aerial photo analysis. The amount of each type of disturbance that was created at each site between 1948 and 1995 will then be quantified. Analyses of the different levels of disturbance and of the increase in disturbance on Newfoundland's limestone barrens over the last 50 years should provide an indication of the long-term stability and viability of this type of habitat. Hopefully, this information will aid the *Braya* Recovery Team in obtaining protection for *Braya longii* and *B. fernaldii.*

Another objective of this study is to provide information about the effects of different levels of disturbance (natural and anthropogenic) on the vitality of *Braya* populations through the comparison of population densities. Such information will help provide a better understanding of the dependence of *Braya* on different types of disturbance and of the historical population dynamics of these *Braya* species.

1.3 Overview of Methods

In order to quantify the amount of disturbed habitat at each of the *Braya* sites areas of disturbance, such as gravel pits, were identified on aerial photos that were taken in 1948, 1968, 1979, and 1995. Classification of these disturbed areas as either natural, high anthropogenic, or low anthropogenic was attempted by analysing the aerial photos with a stereoscope. Ground-truthing at each of the study sites was later conducted to determine whether or not disturbed areas had been classified correctly. The aerial photos were then traced onto mylar sheets and the disturbed areas were outlined. Once the outlines had been imported into a Geographic Information System the areas of disturbance were digitized and then queried to determine the total area of disturbance at each site for each of the four years.

The vitality of *Braya* populations growing in naturally and anthropogenically disturbed areas was determined by taking density measurements. At each study site, the type of disturbance was noted and a one meter square quadrat was randomly tossed throughout the *Braya* population five times. After each toss the number of plants within the quadrat was counted. The results of the density measurements were then compared to determine whether populations had the greatest densities in areas of natural, high anthropogenic, or low anthropogenic disturbance.

Chapter 2: Literature Review

2.1 Organization of the Literature Review

The literature review is divided into three components: limestone, disturbance, and *Braya*. Since *Braya longii* and *B. fernaldii* grow in limestone a section describing this type of rock and the characteristics of the limestone barrens, where these species are found, is essential. Information on the role of disturbance in ecosystems and a description of disturbance-tolerant plants have also been included since *Braya longii* and *B. fernaldii* thrive in areas of small-scale disturbance. Finally, a section on the *Braya* species is necessary to provide information about the physical appearance, biology, and geography of these plants, as well as background information about the quarrying problem on the Great Northern Peninsula and its effect on *Braya* populations.

2.2 Limestone

Limestone is formed by the compaction of coral plant and animal remains on the bottoms of the world's oceans. It is composed predominantly of calcium carbonate and is the most common form of carbonate rock (Trudgill, 1985). Limestone often has a calcium carbonate content between 95% and 99% which makes it a rock of very high purity. Apart from calcium carbonate, limestone may also be composed of dolomite and very small amounts of other minerals, such as aluminum and sulphur.

The chemical and physical properties of a rock determine the effectiveness of weathering and erosion processes. The high content of calcium carbonate in limestone means that it may be easily weathered and is highly soluble in acidic waters. Also, the frequency and number of penetrable joints and bedding planes within the rocks provide lines of access to percolating water, facilitate freeze-thaw action, and form focal points for the action of abrasion. As a result of the susceptibility of limestone areas to weathering and abrasion very distinctive landscape features are produced such as caves, emerging streams, and bare rock surfaces (Trudgill, 1985).

Heathlands are vast non-forested areas characterized by broad-leaved, evergreen shrubs which are adapted to exposure and nutrient-poor soils. Heathlands underlain by limestone are called limestone heaths and are restricted to a narrow belt along the northwest coast of Newfoundland where it is referred to as "limestone barrens" (figure 2). These barrens consist of numerous calcicolous plant species forming a sparse vegetation cover over calcareous boulder pavement (Meades, 1983).

Figure 2: a portion of Newfoundland's limestone barrens at Watt's Point

Unfortunately, the vegetation of the limestone barrens and plants occupying other limestone habitats are being threatened worldwide due to the commercial significance of limestone. Limestone quarrying is an activity that is of great economic benefit since it provides materials for road construction, building stone, and industrial uses such as steel manufacture (Wigglesworth, 1991).

However, this excavation and removal of large limestone deposits is destroying potential habitat for many plant species whose survival depends on the availability of this type of environment.

Many plant species throughout the world have become extinct as a result of extensive limestone quarrying. On the island of Malta, for instance, the quarrying of limestone has had an enormous impact on the landscape and on the wildlife which inhabit it. Much of the vegetation on the South coast of Malta, including the national plant, is being threatened and one species of the Maltese orchid has already disappeared (Balm, 1996). In Australia measures are being taken to prevent the extinction of one species, the limestone caladenia (*Caladenia calcicola)*. This plant is now considered endangered due to the loss of its habitat by limestone quarrying. Only three populations of this limestone native are thought to exist and are believed to be very small. Between 1980 and 1984 the previously largest known population was almost entirely destroyed by quarrying (Action Statement, 1998).

2.3 Disturbance

Plant communities in nature are constantly changing. Over time, there are fluctuations in the density, age-structure, and species composition of a population as old plants die and new ones are established. Natural communities also vary across the landscape as differences in the physical characteristics, resource availability, and microclimatological conditions of a region create spatial discontinuities in the distributions of populations. One major cause of this temporal and spatial heterogeneity in plant communities is disturbance (Sousa, 1984).

For the first half of the 20th century, ecologists generally believed that ecosystems progressed steadily and predictably along well-defined successional pathways until they reached a stable, selfsustaining state. This “climax” condition was considered to be the “normal” state for communities in a particular geographical region (Sprugel, 1991). In the 1970s that attitude began to change due to a number of studies which proved that natural disturbance plays an important role in natural ecosystems (White, 1979; Sousa, 1979). It was then understood that climax is not necessarily the “normal” condition for an ecosystem since natural disturbance is so common that a system rarely ever reaches a stable state.

Natural disturbance is defined by Pickett and White (1985) as “any discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment”. According to White (1979), the main types of disturbance that affect North American vegetation include wind, fire, ice storms, temperature fluctuations, cryogenic movement of soil, precipitation variability, and natural catastrophes such as landslides and hurricanes. Such agents of change, which are external to the plant community, are described as exogenous disturbances. Other types of disturbance are created within the community as a result of plant processes, such as predation and outbreaks of disease, and are classified as endogenous disturbances.

Disturbances caused by the forces of nature can obviously have a great impact on plant communities but so can disturbances caused by humans. Through the development of technology humans have had an increasingly profound effect on the earth’s landscapes. The impact of humans on vegetation has been accelerating rapidly due to activities such as mining, draining of wetlands for agricultural and fuel usage, and clearing extensive areas of natural vegetation for agricultural and other purposes (Bazazz, 1983).

Seagrass populations throughout the world, for example, are diminishing rapidly due to human disturbance. Over the last ten years 90 000 hectares of seagrass loss has been documented. This is mainly a result of a reduction in water quality caused by human activities, such as nutrient and sediment loading from runoff and sewage disposal, dredging and filling, pollution, upland development, and certain fishing practices. Since seagrasses are aquatic plants which grow completely submerged, pollinating via the water, any reduction in water clarity leads to a decline in their productivity and, therefore, to a decline in population numbers (Short and Wyllie- Echeverria, 1996).

In some cases, anthropogenic disturbance may actually benefit plant communities. Bazazz (1983) suggests that there are similarities between some natural and man-made disturbances. Fire that is started by lightning, for instance, may have the same positive impact on a plant community as a fire that is started by a human. More often, however, anthropogenic disturbance is detrimental to an ecosystem. Most human activities produce large-scale disturbances which elicit negative responses similar to those produced by large-scale natural catastrophes, such as hurricanes and landslides (Mooney and Godron, 1983). As a result, humans are causing the disappearance of many plant species and, consequently, are contributing to a steady decline in the world's biotic diversity.

Whether vegetation benefits from, or is harmed by, a disturbance depends largely on the magnitude and frequency of the disturbance (White, 1979; Bazazz, 1983). Disturbances show continuous gradients with respect to magnitude. The effects of wind on a forest, for instance, can vary from simple pruning of branches to extensive blowdowns caused by hurricanes. The frequency of disturbance also varies widely in natural systems. Areas that are in the path of tropical storms, for instance, experience disturbance that occurs at regular intervals, while fires in the forests of the American midwest normally only occur every 100 to 200 years. Disturbances should not occur so often or so infrequently that many species are eliminated but at a rate sufficient to allow continued recruitment and persistence of species (Sousa, 1984).

The "intermediate disturbance hypothesis" (Connell, 1978) suggests that optimum species richness can only be obtained in a community if it is exposed to some intermediate level of disturbance. Intermediate disturbance can maintain the species diversity of a site by removing some individuals and making more resources, such as space and nutrients, available for new plants and the surviving individuals. In one study, Sousa (1979) shows how disturbance increases the species diversity of a rocky intertidal community in southern California. As a result of wave action, boulders which had originally only been colonized by a species of green algae became covered by a mixture of green and several types of red algae within a few months. The boulders that were not exposed to this disturbance, however, remained covered mainly by one type of red algae after a period of two to three years.

Plant species that have become adapted to disturbance are called r-strategists. These species are generally good colonizers because they have high reproductive potential and are tolerant of environmental extremes. Disturbance-adapted species also have fast initial growth rates but are intolerant of competition and, because they exist in disturbed habitats, have short life spans (Bazzaz, 1996; White, 1979). Trees that grow in flood plains, for example, are r-strategists because they exhibit certain characteristics which have allowed them to survive in such a highly disturbed habitat. These include fast growth rates, large yearly seed crops, light wind and water dispersed seeds, ability to sprout when damaged, and high flood tolerance (Koevenig, 1976).

While some plant species develop adaptations which allow them to exploit disturbed areas, other plants depend on some form of disturbance to create conditions that are suitable for growth and reproduction of offspring (Sousa, 1984). Grasses, for example, only flourish where they are pruned by grazers. Once they have been cropped, grass leaves continue to form because the meristem is located very close to the ground where it cannot be eaten. Since the leaf tip is the oldest part of the grass plant and the base is the youngest, frequent grazing ensures that new leaves are constantly being produced and that grass populations are always young and healthy (Owen, 1980). The lodgepole pine (*Pinus contorta)* is another species whose success is dependent on disturbance. The seeds of this coniferous tree are held in serotinous cones whose scales are sealed by resin bonds and are released only if these bonds are broken by the heat from a fire (Muir and Lotan, 1985).

2.4 ***Braya***

Braya longii and *B. fernaldii* (Figure3) are members of the mustard family, or family Brassicaceae. They are Newfoundland endemics and grow only on the limestone barrens found along the Strait of Belle Isle and on the northern half of the Great Northern Peninsula. The two species of *Braya* and other tundra-like vegetation characteristic of these regions are specifically adapted to the extreme exposure and low winter temperatures to which they are subjected. *Braya longii* and *Braya fernaldii* have stout taproots which allow them to reach adequate moisture and keep them anchored in the shallow well-drained soils of the limestone heath.

These two species of *Braya* are caespitose perennials, approximately 1 to 10 centimeters tall, with linear-spatulate leaves and a cluster of small white flowers arranged singly along a stalk (Figure 2). Both species are very similar in appearance and it is often difficult to distinguish one from the other, however, some small physical differences exist between the two. *Braya longii*, for example, is generally somewhat larger than *B. fernaldii* in terms of height, petal size, and sepal length. Also, the siliques of *Braya fernaldii* have soft hairs while *B. longii* has smooth, hairless siliques (Meades, 1996a, 1996b).

Figure 3: a specimen of *Braya fernaldii* in fruit at Burt Cape

Braya longii and *B. fernaldii* also differ with respect to geographical range. In 1924, Bayard Long and M.L. Fernald located four populations of *Braya longii* along the Strait of Belle Isle which ranged in size from 3 to more than 200 individuals. Two of these populations were found at Sandy Cove and the others were discovered further south at Savage Cove and Yankee Point. The locations of these original populations, which still exist today, are seen on Figure 4.

Braya fernaldii was first discovered in 1925 by M.L. Fernald who, at that time, considered it to be a very common plant along the Straits region. Fernald originally located *Braya fernaldii* at eight sites including Ice Point, Big Brook, Boat Harbour, Watt's Bight, Four-Mile Cove, Cape Norman, Burnt Cape, and one mile inland of Savage Cove. These populations ranged in size from 1 plant to more than 200 individuals. Recently, only two of the original *Braya fernaldii* sites were relocated at

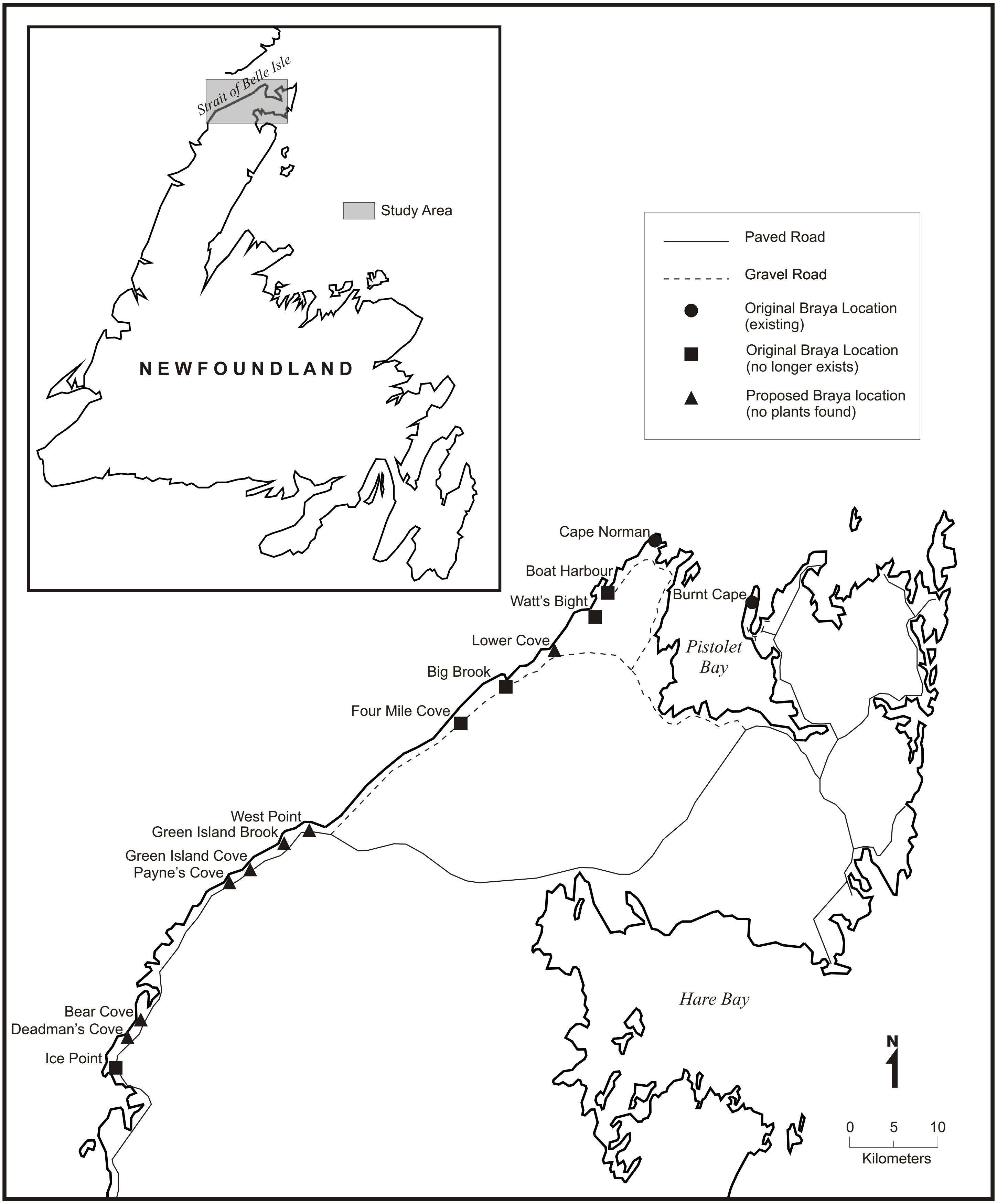

Figure 4: Map of the study area showing the locations of Fernald's original *Braya* populations which still exist, those which have disappeared, and potential sites investigated by the *Braya* Recovery Team.

Cape Norman and Burnt Cape. Figure 4 also shows the locations of the existing populations of *Braya fernaldii* and the original sites at which populations have not recently been relocated.

Braya longii and *B. fernaldii*, like all North American brayas, are calciphiles. This means that they will only inhabit calcareous substrates such as the limestone barrens of Newfoundland. These two species are most robust and grow in greatest numbers in recently disturbed areas. On the limestone barrens where *Braya* is found, large sorted polygons are formed as a result of intense frost activity in the soil. This type of disturbance is essential for the survival of *Braya* populations because it prevents other species from establishing in its preferred habitat. If a seed source is nearby, *Braya* will colonize such disturbed areas very quickly and will become the dominant plant. Over time, however, as the site stabilizes, the number of *Braya* plants decreases as competition from other species causes them to be displaced. In areas of minimal disturbance, *Braya* occurs only as scattered individuals (Meades, 1996a, 1996b).

Braya longii and *B. fernaldii* have also been known to colonize areas of the limestone barrens that have been anthropogenically disturbed, such as abandoned roadbeds and quarry sites. Over the last 20 years, however, anthropogenic disturbance on Newfoundland's limestone barrens has been so extensive that it is threatening the survival of these two plant species in their natural habitat (Figure 5). A large percentage of the coastal barrens has been destroyed due to the quarrying of limestone for road construction. As a result, much of the natural *Braya* habitat has been lost and the short-distance dispersal mechanism of these species prevents them from colonizing new areas once a site is destroyed. Man-made locations have provided some suitable habitat for *B. longii* and *B. fernaldii* but they are at risk of being completely removed from these sites if quarrying is allowed to continue.

Figure 5: quarrying at Sandy Cove

On the COSEWIC list of plants designated at risk in Canada, *Braya longii* is considered endangered, meaning that it is facing imminent extinction, and *Braya fernaldii* is considered threatened, or likely to become endangered if limiting factors are not reversed (COSEWIC, 1997). Regardless of these classifications neither one of these species is protected by legislation in Canada or Newfoundland.

Some steps are being taken to protect several of the *Braya* populations. A proposal has been made to make Sandy Cove, where one of the main *Braya longii* populations are found, exempt from quarrying but no protection has yet been granted. One *Braya fernaldii* site exists near Watt's Point Ecological Reserve and it has been suggested that the reserve boundary be extended to include this population (Meades, 1996a, 1996b). This move would protect it from future quarrying, however, it would still be threatened by the ATV users which frequently drive across the Reserve. Quarrying is no longer allowed on Burnt Cape, the site of another *Braya fernaldii* population, which was designated as a "Provisional" Reserve in 1997 and will attain full Reserve status soon.

Chapter 3: Study Area

Research for this project was conducted at six locations along the Strait of Belle Isle Barrens: Yankee Point, Savage Point, Sandy Cove, Watt's Point, Cape Norman, and Burnt Cape (Figure 6). This ecoregion occupies the northwest and northernmost portions of Newfoundland's Great Northern Peninsula. The terrain of this region is primarily flat and undulating and does not exceed an elevation of 60 meters. The soil covering the limestone barrens is very shallow and extensive areas of bedrock lie exposed (Meades, 1990).

Extreme cold characterizes the climate of this region. The average daily temperature for the month of February is -9 degrees celsius and may go as low as -16 degrees celsius. In July, the mean daily temperature is approximately 13 degrees celsius but may reach 17 degrees celsius. Pack ice, which can be seen off the coast from December to June, retards the arrival of spring to the Straits region more severely than anywhere else in Newfoundland (South, 1983).

The Strait of Belle Isle ecoregion receives approximately 760 mm. to 900 mm. of precipitation which is considered to be relatively low. Regardless, this region experiences an average of 186 days per year with measurable snow, the greatest number recorded for the island. Snow cover is continuous from January to the end of March and frost can occur at any time throughout the year. Fog frequency along the Straits is also high.

The vegetative season for this ecoregion is less than 110 days, the shortest of any of Newfoundland's ecoregions. The type of vegetation which grows along the Strait of Belle Isle clearly reflects its cold climate as it has the most tundra-like vegetation on the island. This landscape is completely without tall trees but tuckamore of white spruce (*Picea glauca),* black spruce (*P. mariana),* and balsam fir (*Abies balsamea)* are common. The rocky coastal barrens support a unique mixture of arctic-alpine species, Gulf of St. Lawrence endemics and, due to the presence of limestone, calciphiles.

The six study sites are the *Braya* sites which were located by the *Braya* Recovery Team in July of 1998. The study areas are discussed below starting with Yankee Point and moving northward.

3.1 Yankee Point

The first study site is located on the headland northeast of Mistaken Cove, known to local residents as Yankee Point. The population of *Braya longii* found at this site is located on a parking lot of limestone gravel which was quarried from the site. Unfortunately, the parking area sits adjacent to a dirt road which is traveled frequently by large trucks carrying gravel. Much of the land between the *Braya* habitat and the coast has been disturbed by extensive quarrying. The absence of vegetation in the gravel pits and the presence of quarrying machinery indicate that this is an active quarry site.

3.2 Savage Point

The piece of land between Savage Cove and Sandy Cove is the second study site and will be referred to as Savage Point. Two populations of *Braya longii* are located at this site. One group (Savage Point A) is found on a flat area of limestone gravel which is an old airstrip. The second population (Savage Point B) is located west of the airstrip. The limestone at this site is in large chunks and appears to be disturbed to some degree by frost heaving. However, several large piles of rock seen throughout the area may be evidence of anthropogenic disturbance.

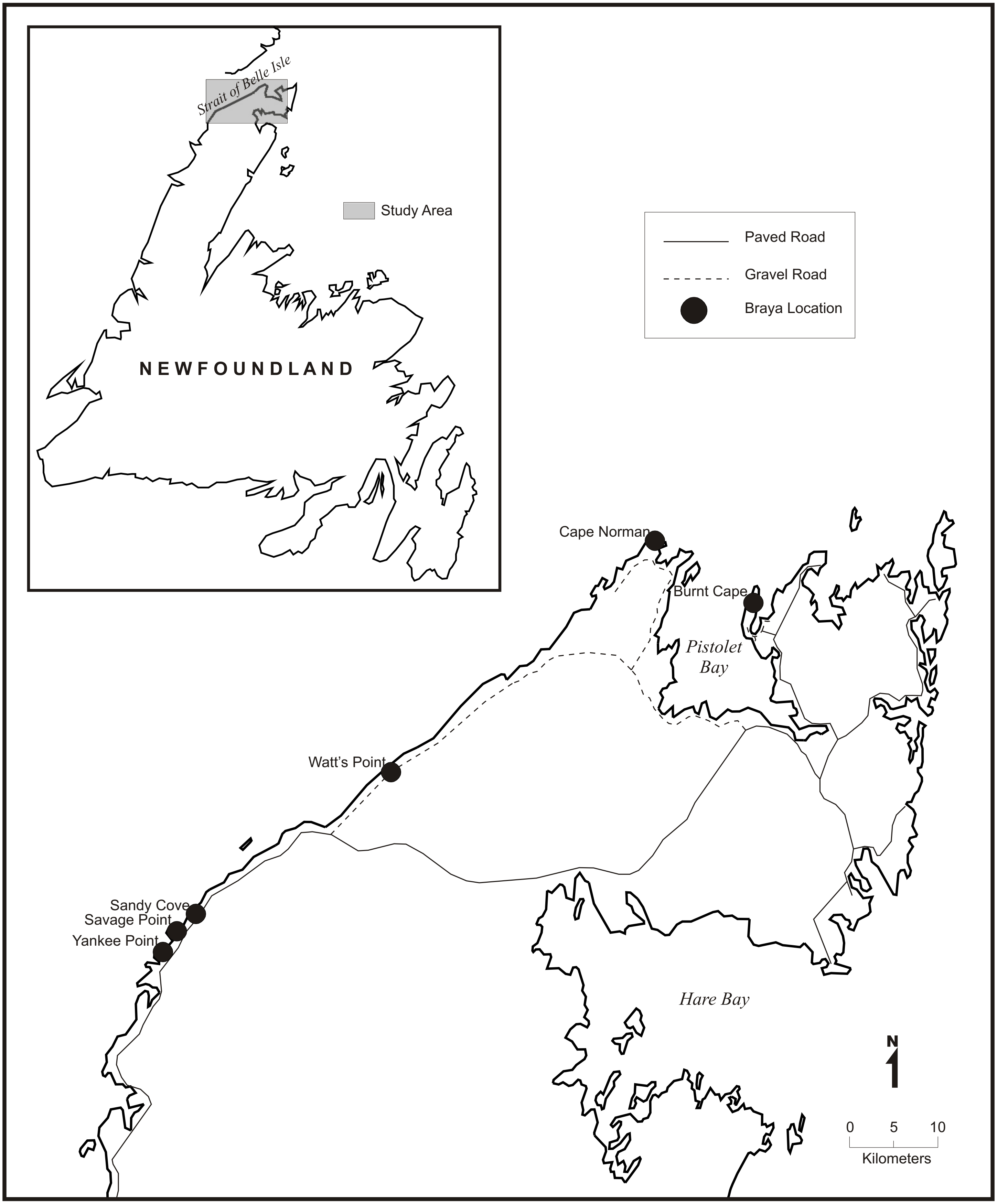

Figure 6: Map of study area showing *Braya* locations.

3.3 Sandy Cove

Two populations of *Braya longii* are also found on the point of land opposite Savage Point, northeast of Sandy Cove. One population (Sandy Cove A) is located on an area where the earth appears to have been scraped by a plough and the material was pushed up to form a small bank. A very large gravel pit is located between this population and the ocean. The other population (Sandy Cove B) is found northeast of the first group beside a dirt road coming off the highway. Individual plants can be seen growing amongst large chunks of limestone which may have been disturbed by freeze-thaw action.

3.4 Watt's Point

A large population of *Braya fernaldii* is located near this Reserve which was established to preserve a variety of species which characterize the limestone barrens. The *Braya* inhabit an old road of limestone gravel which runs through the Reserve and was once the coastal highway.

3.5 Cape Norman

Large slabs of exposed limestone dominate the barren landscape at this location on the very tip of the Northern Peninsula. A line of utility poles begins just north of the Cape Norman lighthouse near the ocean and extends southward across the landscape. A small population of *Braya fernaldii* can be found scattered around the fourth pole from the lighthouse. These plants are growing amongst gravel-sized limestone rocks which appear, in some areas, to be sorted into polygons as a result of frost activity.

3.6 Burnt Cape

A population of *Braya fernaldii* is located at this site in an area of limestone gravel which used to be a limestone quarry. These plants are growing beside a dirt road that winds through the cape. Burnt Cape has been quarried extensively but in 1997 this area was designated as a “Provisional” Reserve by the Newfoundland government and quarrying was banned from the area. During the summer of 1998, local residents began filling in many of the gravel pits on Burnt Cape, while being careful not to disturb the *Braya* site, as part of a program to rehabilitate the area.

Chapter 4: Methods

In order to study disturbance over time on the Great Northern Peninsula aerial photos of each of the study sites that were taken between 1948 and 1995 were obtained. The numbers of these aerial photos and a description of each are provided in Table 1. Disturbance areas are visible on the photos because they are much lighter than the surrounding undisturbed areas as much of the vegetation has been removed and the limestone is now exposed. An attempt was made to classify each area of disturbance into one of three categories: natural (frost heaving), high anthropogenic (surficial material had been removed, such as gravel pits), or low anthropogenic (gravel surface had been scraped). A stereoscope, which revealed the depth of the disturbance, aided in the identification and classification of disturbed areas. Each of the photos were then traced onto a mylar sheet and the disturbed areas were outlined. Aerial photos of most of the Northern Peninsula were taken in 1948, 1968, 1979, and 1995. Study sites were traced four times if photos for each of these years were available, however, those sites for which a set of photos was missing were only traced three times.

Field work at each of the study areas took place during the first week of July, 1998 when the *Braya* Recovery Team made its first trip to the Northern Peninsula. The team located populations of *Braya* at Yankee Point, Savage Point, Sandy Cove, Watt's Point, Cape Norman, and Burnt Cape (Figure 6). The team also visited other sites where *Braya* populations had been previously discovered by Fernald, but was unable to find them. An attempt was made to locate new populations at potential sites which were identified on the aerial photos by their similar appearance to known *Braya* locations. However, no new populations were found. Potential sites investigated by the *Braya* Recovery Team are shown in Figure 4 and include Deadman's Cove, Bear Cove, Payne's Cove, Green Island Cove, Green Island Brook, West Point, and Lower Cove.

The *Braya* Recovery Team counted the number of *Braya* individuals at each site and some individuals were tagged so that populations can be monitored. Samples of these tagged plants were taken for electrophoresis and possible transplantation at Memorial University's Botanical Garden. The author also did some ground-truthing to determine the level of habitat disturbance at each study site. Areas of low anthropogenic disturbance generally had only the top layer of gravel removed, such as gravel roads. Sites at which large amounts of material had been removed to create a pit were considered areas of high anthropogenic disturbance. Areas which appeared to be disturbed by frost action were considered to have been naturally disturbed. Natural disturbance was identified by the presence of frost polygons. These are circles or polygonal shapes which are formed by the sorting of soil material according to size in areas of shallow frost activity (Hallett, 1990).

Another trip to the Northern Peninsula was taken during the first week of August, 1998. At each of the six study sites the size of the area occupied by *Braya* populations was measured. Several measurements of the tagged plants were also taken to provide baseline data for future monitoring of these populations, including leaf size, stalk length, and number of flowers per stem. Density measurements of the *Braya* populations were taken by the author at each site by randomly tossing a meter square quadrat throughout the population and counting the number of *Braya* plants it contained (figure 7). Five random samples were taken at each site. These measurements were then used to determine whether *Braya* populations grow more vigorously in areas of natural, high anthropogenic, or low anthropogenic disturbance.

Table 1: Description of aerial photos of study sites

Location	Year	Photo #	Black and White or Colour	Scale
Yankee Point	1948	NFL 2 - 22	B/W	1: 39,600
Yankee Point	1968	20532 - 4	B/W	1:15,840
Yankee Point	1979	79021 - 174	Colour	1:12,500
Yankee Point	1995	95014 - 65	Colour	1:12,500
Savage Point & Sandy Cove	1968	205321 - 179	B/W	1:15,840
Savage Point & Sandy Cove	1979	79021 - 170	Colour	1:12,500
Savage Point & Sandy Cove	1995	95012 - 72	Colour	1:12,500
Watt's Point	1948	NFL 2 - 91	B/W	1:39,600
Watt's Point	1968	20523 - 155	B/W	1:15,840
Watt's Point	1995	95008 - 140	Colour	1:12,500
Cape Norman	1948	NFL 2 - 165	B/W	1:39,600
Cape Norman	1968	20529 - 80	B/W	1:15,840
Cape Norman	1995	95004 - 4	Colour	1:12,500
Burnt Cape	1948	NFL 2 - 157	B/W	1:39,600
Burnt Cape	1968	20528 - 135	B/W	1:15,840
Burnt Cape	1979	79015 - 70	Colour	1:12,500
Burnt Cape	1995	95009 - 56	Colour	1:12,500


Figure 7: measuring population density at Burnt Cape using a 1 m square quadrat

When the field work was completed the outlines of each of the aerial photos were imported into a Geographic Information System to calculate the total area of disturbance over time at each site. The outlines were scanned in .tiff format and imported into MAPINFO 4.5. All scanned images were then geo-referenced to North American Datum 27, zone 21. Each image was then geometrically corrected and the disturbance areas were digitized as polygons. The polygons were then queried to determine the actual area of disturbance. For each study site the polygon areas were added together to produce the total area of disturbance. In order to show the temporal change in disturbance at each study area an overlay was performed.

Chapter 5: Results

Levels of disturbance at each *Braya* site could be clearly identified in the field, however, even with the use of a stereoscope it was not possible to distinguish between areas of low anthropogenic and natural disturbance on the aerial photos. Also, since no global positioning system was used in the field it was difficult to determine the exact location and size of each area of disturbance on the aerial photos. As a result, the area of each type of disturbance could not be calculated. Instead, the total area of disturbance at each site between 1948 and 1995 was determined. These results are provided in Table 2 and in Figure 8 which shows the increase in disturbance at each site over the last fifty years.

Figures 9 to 13 are outlines of each study site showing the areas that were disturbed between 1948 and 1995. The approximate locations of the *Braya* populations found at each site are also displayed in these figures. Since Yankee Point, Savage Point, and Sandy Cove are the only areas that experienced disturbance in more than one year, overlays were done for these three areas only. The overlaid areas of disturbance at these sites are seen in Figures 9 and 10. The results of the density measurements and the level of disturbance observed at each site during field investigations are provided in Table 3.

5.1 Yankee Point

The approximate location of the population found at this site can be seen in Figure 9. This population occupies an abandoned parking lot of limestone gravel. The foundation of a building that has recently been knocked down remains in one corner of the lot. The parking lot is an area of low anthropogenic disturbance because the surface of the earth has only been scraped, however, large quarry pits surround this *Braya* population. Much of the land between the parking lot and the ocean has been disturbed by quarrying and even more will be disturbed as this is an active quarry site.

The *Braya* Recovery Team counted more than 1600 individuals of *Braya longii* at this site. This population covers basically the whole extent of the parking lot which is approximately 120 m long and 10 m wide. Five random samples were taken by the author at this site using the 1m x 1m quadrat. There were 6 individuals of Long's braya in the first sample, 48 in the second, 35 in the third, 1 in the fourth, and none in the fifth sample.

Figure 8 shows that disturbance at this site increased greatly between 1948 and 1995. Table 2 indicates that there was no disturbance at this site before 1968, however, in 1979, approximately 221, 743 m^2 of land had been disturbed, mainly by quarry activity. In 1995, that number increased to 256, 136 m^2. Figure 8 shows the extent of disturbance in 1979 and 1995. The bulk of the disturbance appears to have been completed by 1979 as some of the disturbed areas remained virtually unchanged in 1995. However, some of the disturbed areas have increased since 1979, including the quarry site south of the lot. This area has grown significantly and markers placed by the quarry company, which were observed during fieldwork, indicate that it will extend almost to the coastline.

5.2 Savage Point

The *Braya longii* population occupying the airstrip at this location (Savage Point A) is identified in Figure 10. The airstrip is a flat area of limestone gravel which has had its surface scraped and is, therefore, an area of low anthropogenic disturbance. Evidence of larger-scale disturbance surrounds this population, however. A gravel pit, which appears to have been abandoned due to the presence of

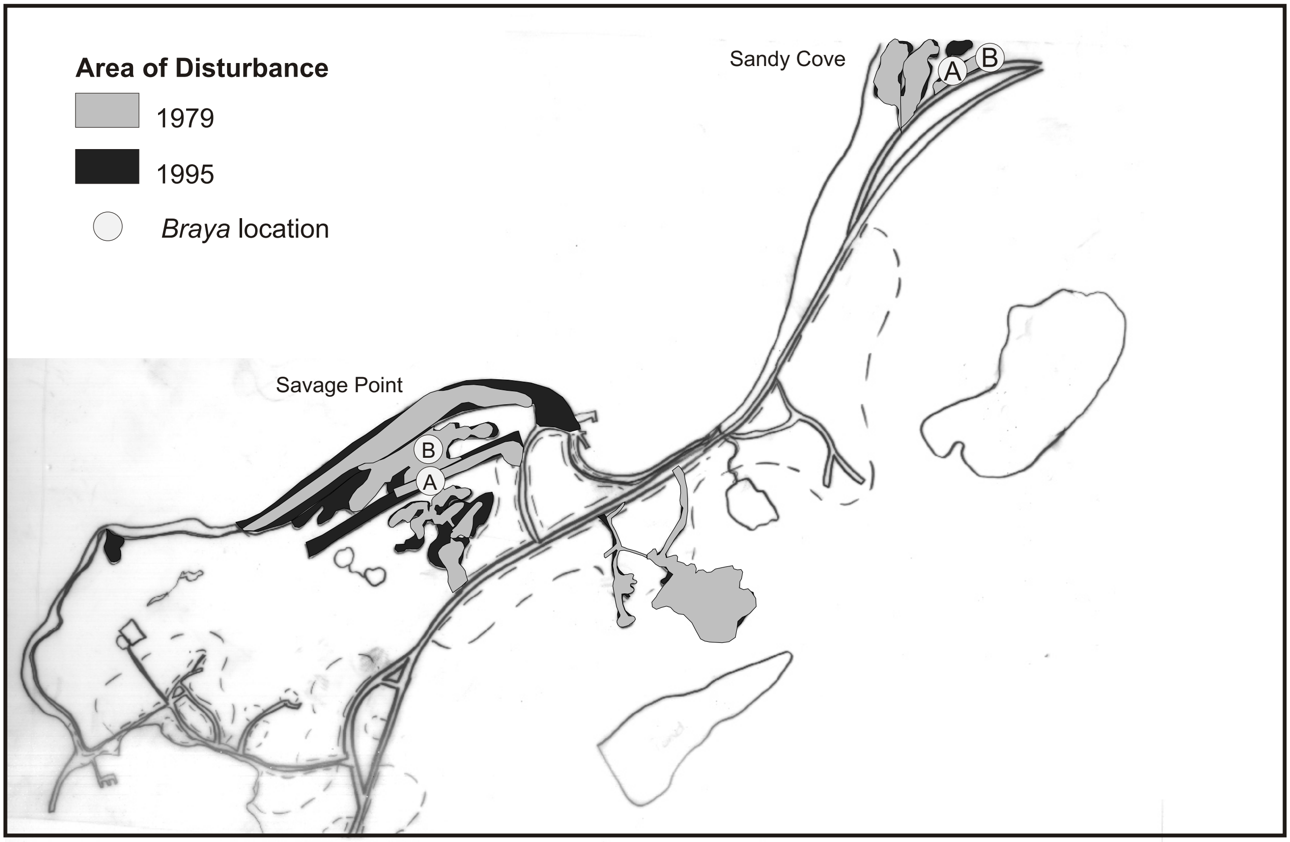

Figure 8::Location of *Braya* Populations and area of disturbance at Savage Point and Sandy cove

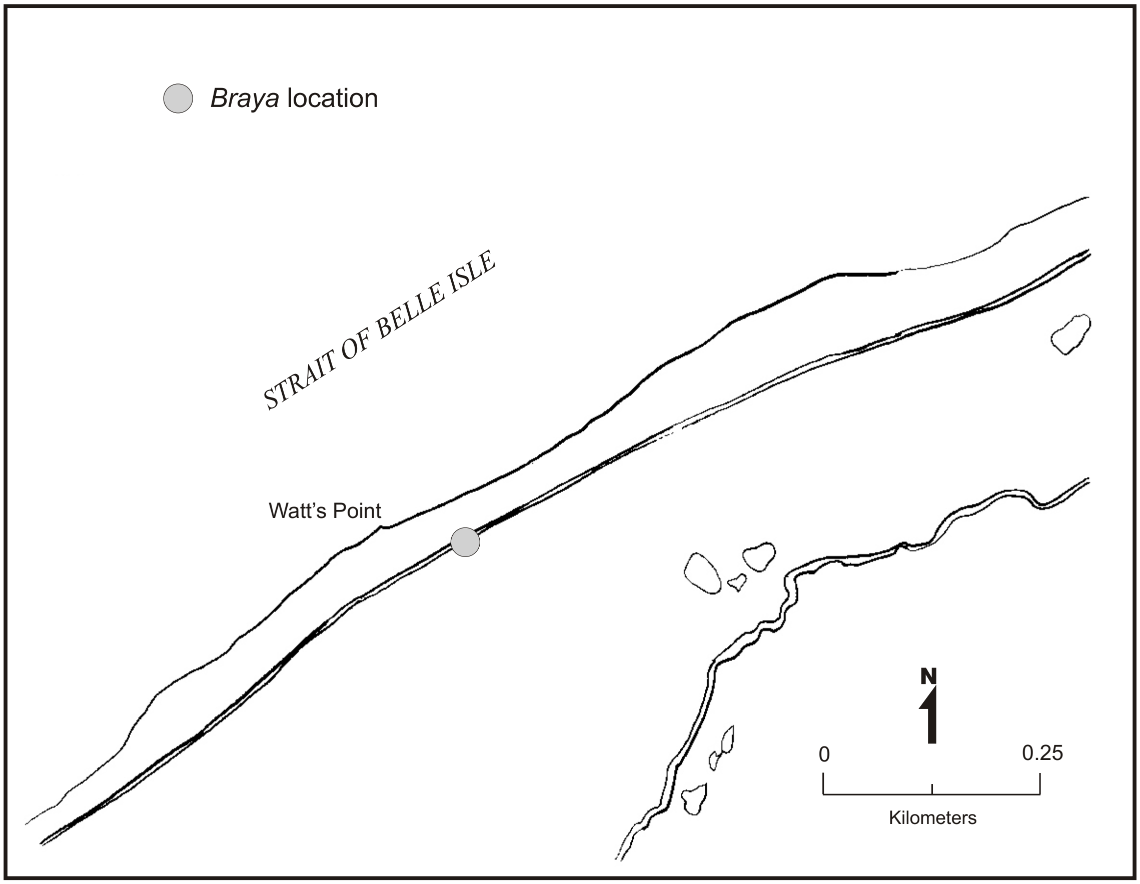

Figure 11: Location of *Braya* population at Watt's Point

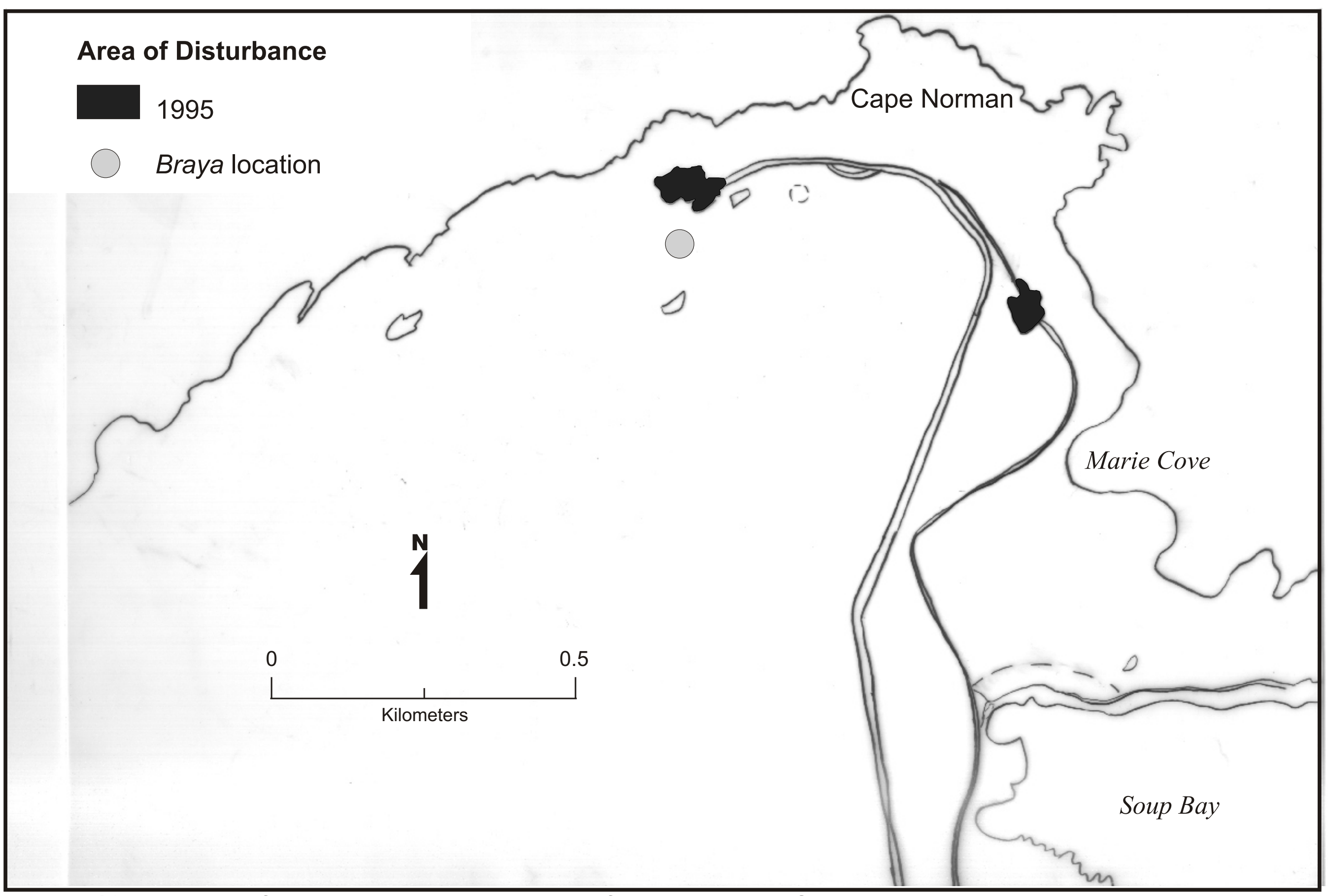

Figure 12: Location of *Braya* population and area of disturbance at Cape Norman

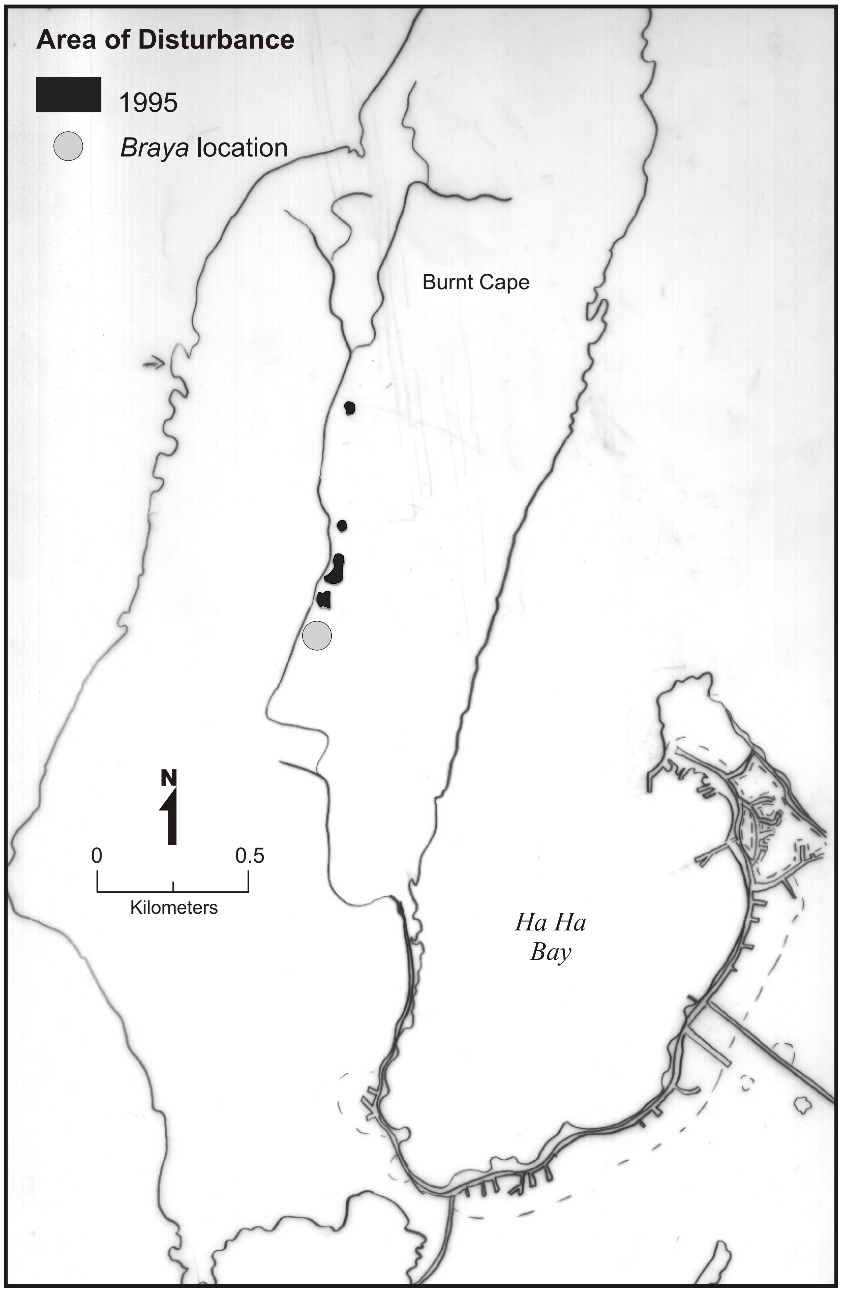

Figure 13: Location of *Braya* population and area of disturbance at Burnt Cape

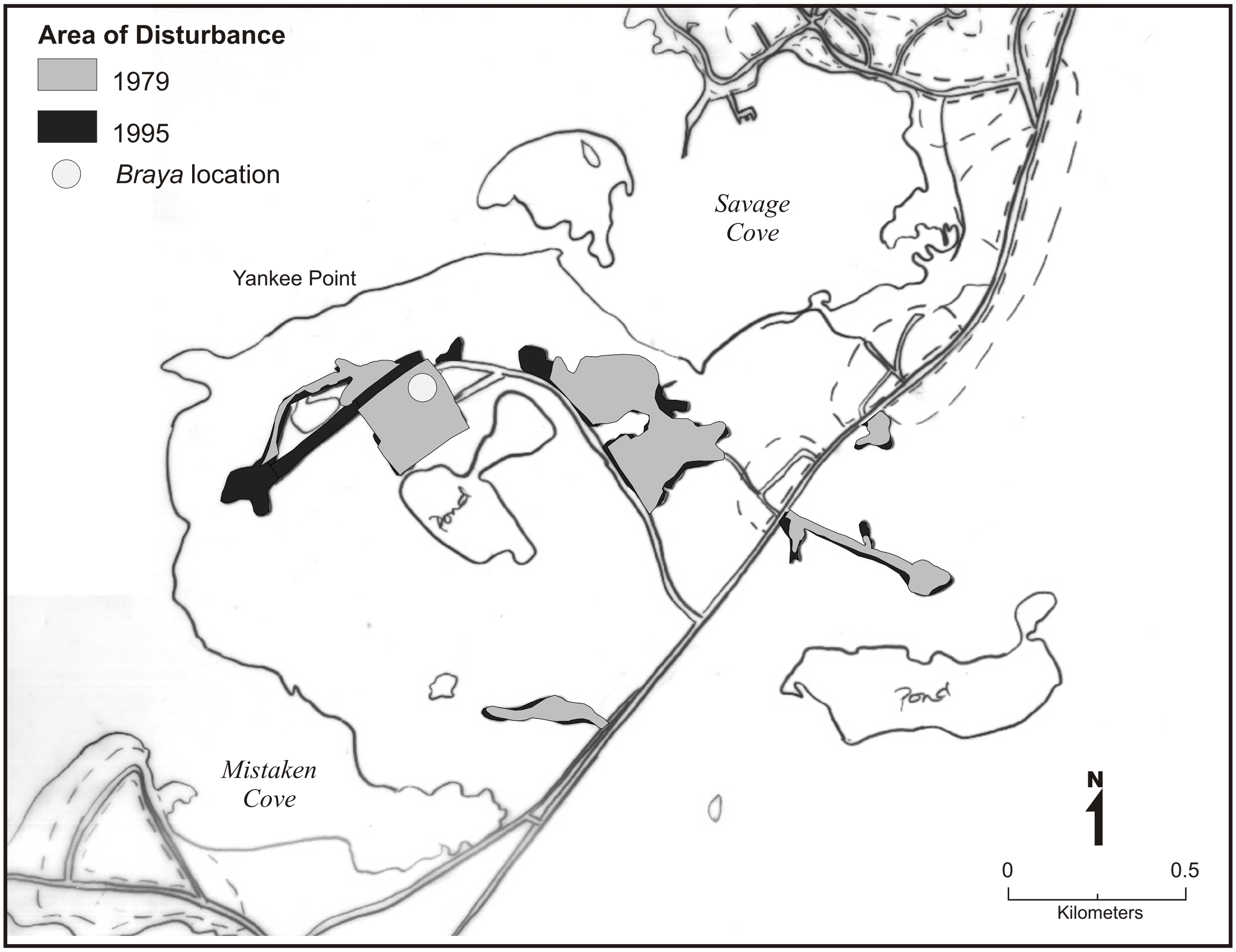

Figure 9: Location of *Braya* population and area of disturbance at Yankee Point

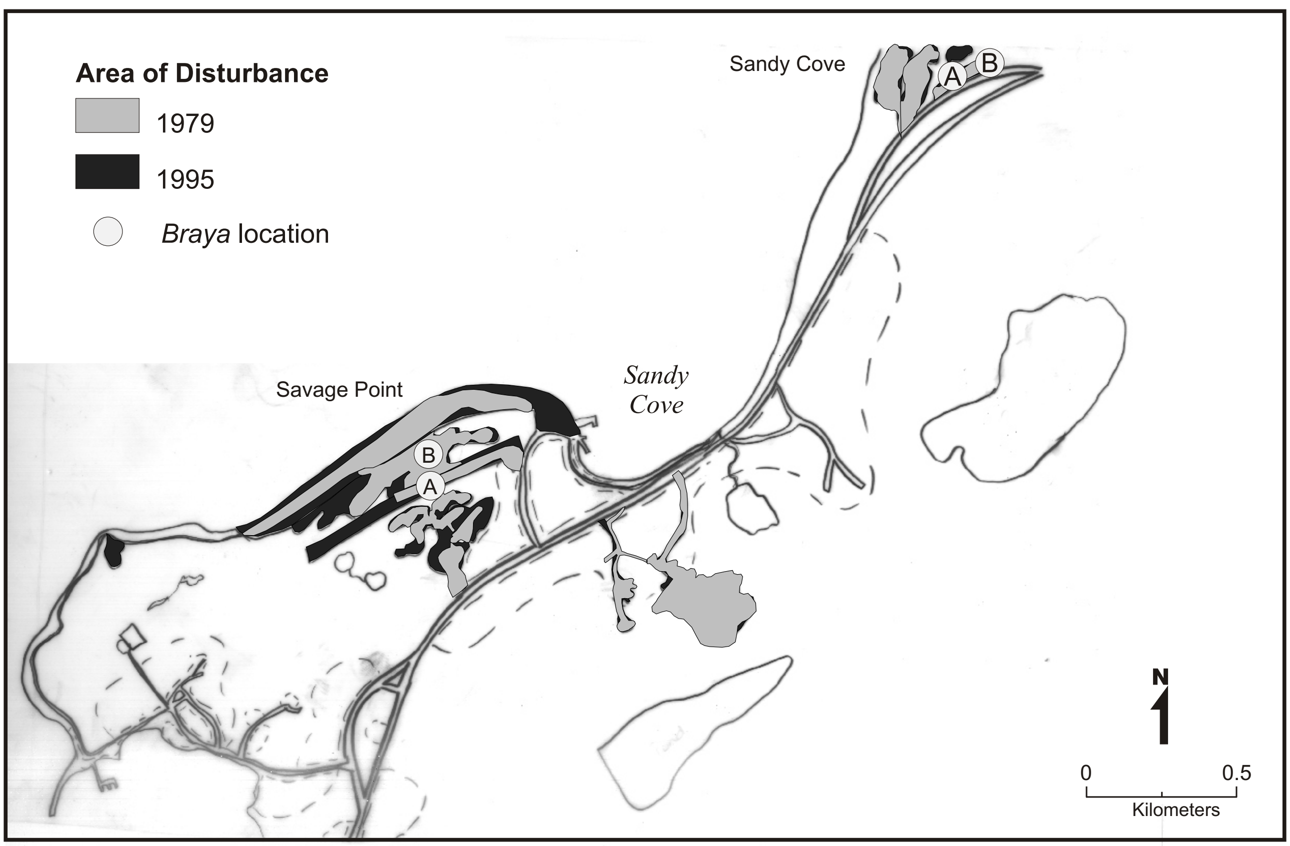

Figure 10: Location of *Braya* populations and area of disturbance at Savage Point and Sandy Cove

Table 3: Habitat disturbance level and density measurements (per m^2) for each *Braya* population

Population	Disturbance Level	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Yankee Point	Low Anthropogenic	6	48	35	1	0
Savage Point A	Low Anthropogenic	0	3	1	1	1
Savage Point B	Natural	0	0	2	3	0
Sandy Cove A	Low Anthropogenic	0	13	0	1	6
Sandy Cove B	Natural	0	4	3	3	4
Watt’s Point	Low Anthropogenic	1	0	6	6	14
Cape Norman	Natural	1	1	1	2	0
Burnt Cape	High Anthropogenic	15	>50	35	14	41

vegetation on it, is located between the airstrip and a nearby community. Another large quarry pit, which may or may not be active, is found near the coastline west of the airstrip.

The *Braya* Recovery Team counted more than 2000 individuals in this population of *Braya longii*. The area of the airstrip that they inhabit is approximately 600 m long and 5 m wide. No *Braya* plants were found in the first sample taken by the author. The second sample revealed a density of three *B. longii* specimens per m^2. Only one *Braya* plant was found in each of the next three samples.

The second population of *Braya longii* at this site (Savage Point B), which is also identified in Figure 10, is located closer to the ocean in an area that appears to have been disturbed to some degree by natural processes. This area is not flat like the airstrip and the limestone is in large chunks. In some places, the limestone rocks have been sorted into circles by frost action. There is some evidence of anthropogenic disturbance at this site since the limestone has been bulldozed into piles in some spots. The *Braya* population which inhabits this area is not far from the quarry site near the coastline

Roughly 900 individuals of *Braya longii* were counted by the *Braya* Recovery Team at this site which measures approximately 250 m long and 125 m wide. The first two random samples taken by the author contained no *Braya* plants. Two plants were found in the third sample, three in the fourth sample, and no plants were counted in the fifth sample.

According to Figure 8 and Table 2, this area was not disturbed by limestone quarrying before 1968. By 1979, however, a total area of 230, 353 m^2 had been disturbed at this site. The amount of disturbance at Savage Point reached 268, 439 m^2 in 1995 making it the most disturbed of all of the study sites. Figure10 indicates that the airstrip doubled in size between 1979 and 1995 and that the disturbed areas east and west of the airstrip have also grown since 1979. One new quarry site has developed in this area since 1979 while the disturbed areas west of the highway have remained approximately the same size.

5.3 Sandy Cove

The approximate location of the population of *Braya longii* which occupies the scraped area at this site (Sandy Cove A) can be seen on Figure 10. A bank of pushed up earth near this population indicates that this area has been scraped by the blade of a bulldozer so it is classified as an area of low anthropogenic disturbance. In fact, an abandoned blade is sitting on top of this bank. This site is not quite as rocky as the other *Braya* locations and has several patches of exposed peat. Several large gravel pits are located east of this population and extend almost to the coastline. Quarrying machinery can be seen in one of the gravel pits which may be an indication that it is still active.

Five hundred individuals of *Braya longii* were counted at this site by the *Braya* Recovery Team. The area that they inhabit is small, measuring approximately 25 m long and 12 m wide. The first random sample taken by the author contained no individuals of *Braya longii* but the second sample contained 13 plants. No *Braya* plants were counted in the third sample, only one was found in the fourth sample, and 6 *Braya* specimens were counted in the fifth sample.

The other population of *Braya longii* found at Sandy Cove (Sandy Cove B) is located just east of the Sandy Cove A population and is also identified on Figure 10. This site sits adjacent to a gravel road which comes off the highway and is classified as an area of natural disturbance as it appears to have been disturbed to some degree by frost activity. The limestone in this small area has been shattered into large chunks but there is no sign of frost sorting.

This site is approximately 38 m long and 18 m wide and is occupied by 600 plants which were counted by the *Braya* Recovery Team. No *Braya* individuals were found in the author's first random sample. Four plants were found in the next sample, 3 plants were found in the second and third samples, and the last sample contained 4 plants.

Figure 8 shows that the total area of disturbance created at this site between 1948 and 1995 is much smaller than that created at Yankee Point and Savage Point. Similar to the two previous study sites, however, disturbance is not evident at Sandy Cove in 1948 and 1968. In 1979 and 1995, the total area of disturbance was 41, 457 m^2 and 42, 339 m^2, respectively. Only a small portion of Sandy Cove is visible on the outline and a great deal of this area has been destroyed by quarrying. The majority of the disturbance had been created by 1979 with minimal growth occurring between 1979 and 1995.

5.4 Watt's Point

The population of *Braya fernaldii* found at Watt's Point inhabits a portion of the old coastal highway. To the west of this limestone gravel road is the ocean and areas of exposed limestone can be seen east of the road. The *Braya* population is located approximately 9 km in from the start of the gravel road near the modern highway. Driving along the road up to the site disturbance can be seen on the sides of the road in the form of large ditches caused by the bulldozing of material to create the old highway. This disturbance, however, cannot be seen on the aerial photos and was, therefore, not included in the calculation of the amount of disturbance at this site. Figure 11 is an outline of the Watt's Point area which indicates the approximate location of the *Braya* site. According to Figure 8 and Table 2, disturbance as a result of quarrying could not be seen on any of the aerial photos of Watt's Point.

More than 800 individuals of *Braya fernaldii* were counted by the *Braya* Recovery Team at this site. This population inhabits an area of the gravel road which is roughly 300 m long and 2 m wide. Only one *Braya* specimen was found in the first random sample taken by the author and no plants could be seen in the second sample. The next two samples each produced six plants and fourteen individuals were counted in the fifth sample.

5.5 Cape Norman

At this site a small population of *Braya fernaldii* are hidden amongst a great landscape of exposed limestone. The approximate location of this population is given in Figure 12. This population is located on a north-facing slope south of the Cape Norman lighthouse in an area of limestone gravel. In places, these rocks are arranged in polygons as a result of frost heaving, therefore, it is classified as an area of natural disturbance. There is no evidence of quarrying in the immediate vicinity.

Vegetation in this area is sparse and the population of approximately 75 individuals of *Braya fernaldii* were counted by the *Braya* Recovery Team within a 60 m radius. Four *Braya* plants were counted in the author's first sample, one in the second sample, and three plants were found in the third sample. The fourth sample contained 10 plants and the fifth sample contained no *Braya* individuals.

According to Figure 8, the amount of disturbed area at Cape Norman has not increased much over the last fifty years. This area appears to have been unaffected by limestone quarrying until 1979, at least, and only 8710 m^2 of disturbance had been created anthropogenically by 1995. An overlay of this area could not be done since disturbance is only visible in the 1995 aerial photo.

5.6 Burnt Cape

The approximate location of the population of *Braya fernaldii* located at this site is identified in Figure 13. This population is found in an abandoned quarry pit amongst limestone gravel adjacent to an unpaved road. Since it appears that a considerable amount of material has been removed from this site it is classified as an area of high anthropogenic disturbance. The area occupied by the plants is relatively flat, though some are growing on the gentle slopes of the pit.

The *Braya* Recovery Team counted approximately 900 plants at this site. They occupy an area that is roughly 100 m long and 15 m wide. Fifteen individuals were counted in the first random sample taken by the author and more than 50 plants were found in the second sample. The third sample contained 35 plants, the fourth had 14 plants, and 41 plants were counted in the fifth sample.

Figure 8 indicates that the line of increasing disturbance for Burnt Cape is similar to that of Cape Norman. Table 2 shows that, in 1995, the total area of disturbance at Burnt Cape was 6872 m^2. The photos of this area that were taken prior to 1995 reveal no quarry-related disturbance. An overlay of disturbance areas could not be done for this site because disturbance was only visible on the 1995 aerial photo.

Chapter 6: Discussion and Conclusions

6.1 Density

Five of the eight populations of *Braya* which were studied occur in areas that have been anthropogenically disturbed, four of which are areas of low disturbance and one of which is an area of high disturbance. The other three populations are located in areas that appear to have been disturbed by natural forces. The results of the density measurements indicate that *Braya* populations generally have the greatest densities in areas of anthropogenic disturbance and the lowest densities in naturally disturbed areas. The population with the highest population density is found in the area of high anthropogenic disturbance and the populations which grow in naturally disturbed areas have very low densities. In areas of low anthropogenic disturbance *Braya* population densities range from very low to fairly high.

The population at Burnt Cape, which has the greatest number of plants per square meter, occurs on the only study site that has a high level of anthropogenic disturbance. The population with the second greatest density is found at Yankee Point, which is an area of low anthropogenic disturbance. The densities of the remaining *Braya* populations are considerably lower than those of the Burnt Cape and Yankee Point populations. The Sandy Cove A and Watt's Point populations had similar plant densities as at least one of the samples taken at each site contained between ten and fifteen *Braya* individuals. Both of these sites are areas of low anthropogenic disturbance. The populations of *Braya* that are found at Savage Point and Cape Norman and the Sandy Cove B population had the lowest densities with less than five plants in each sample. The Sandy Cove B, Savage Point B, and Cape Norman populations are located in areas of natural disturbance but the Savage Point A population is found in an area of low anthropogenic disturbance.

The explanation for high *Braya* population densities in the areas of high anthropogenic disturbance and low population densities in the naturally disturbed areas may be related to the age of the disturbance at each site. As mentioned previously, *Braya* grows most vigorously in recently disturbed areas. Over time, as the area becomes more stable, other plants will become dominant and the number of *Braya* individuals will decrease. Since the ages of the naturally disturbed areas are unknown it is possible that they are much older than the anthropogenically disturbed areas and, therefore, have become dominated by species other than *Braya longii* and *B. fernaldii*. The vitality of *Braya* populations growing in anthropogenically disturbed may also be explained by the fact that nutrient availability is greater in areas of large-scale anthropogenic disturbance than in areas of natural disturbance (Hermanutz, 1998).

When discussing these results it should be considered that the conditions of the *Braya* sites and the size and density of the populations prior to their documentation in the 1990s are unknown. Before the study sites were disturbed by human activity the *Braya* populations must have grown in areas of natural disturbance. It is possible that, at that time, the populations were larger and healthier than they are today. It is also possible that the "naturally" disturbed areas in which some of the populations are found were not created exclusively by natural forces. They may have been disturbed previously by human activity which could have caused frost heaving to occur. Patterned ground only occurs in exposed areas which are subjected to low temperatures, such as the limestone barrens of northern Newfoundland (Wilson, 1952). In areas such as these, it also requires low plant cover. The first stage of quarrying involves the scraping of the top layer of earth at a site and, consequently, the removal of any vegetation growing in it. Quarrying may, therefore, be beneficial to *Braya* populations as it promotes frost heaving and creates areas of potential habitat.

The results of this study may indicate that *Braya* populations have the greatest densities when growing in an area of high anthropogenic disturbance, however, these populations are not representative of historically accurate populations (Hermanutz, 1998). Populations of *Braya* that existed prior to the generation of anthropogenic disturbance on the Great Northern Peninsula were probably more like the populations that are growing in naturally disturbed areas today. In order to produce more historically accurate populations further research on the mechanism of disturbance on the limestone barrens is essential.

Although a certain degree of anthropogenic disturbance may help to increase *Braya* numbers extensive quarrying may lead to the extirpation of the remaining populations. One incident has been documented by a visitor to Burnt Cape in which a bulldozer was burying a population of *Braya fernaldii* with peat as it created a new quarry (Meades, 1996). This type of disturbance cannot be beneficial to any plant. Obviously, the number of *Braya* populations has decreased since quarrying began on the Great Northern Peninsula because many of the populations located by Fernald have disappeared. Figure 4 indicates that, of the seven original *Braya fernaldii* populations discovered by Fernald, only two remain at Cape Norman and Burnt Cape. The populations at Ice Point, Four-Mile Cove, Big Brook, Watt's Bight, and Boat Harbour no longer exist, probably as a result of human activity.

Presently, quarrying is ongoing at Yankee Point, Savage Point, and Sandy Cove which means that the *Braya* populations located at these sites are at a high risk of suffering the same fate as the majority of Fernald's original populations. The protection of the *Braya* populations discussed in this study is of great importance since the results of intensive surveying of the Northern Peninsula for more populations by the *Braya* Recovery Team indicate that they are the last.

6.2 Quantifying Area of Disturbance

The results of the disturbance area calculations indicate that anthropogenic disturbance on the Great Northern Peninsula has increased greatly between 1948 and 1995. Until at least 1968 quarrying did not occur at any of the study sites. In fact, as of 1974, quarrying had not begun on the Great Northern Peninsula even though extensive deposits of commercially promising limestone had been located at Burnt Cape and near Cape Norman (DeGrace, 1974).

Between 1974 and 1979, Yankee Point, Savage Point, and Sandy Cove had been greatly disturbed and field observations prove that the majority of this disturbance was created by quarrying. Watt's Point, Cape Norman, and Burnt Cape remained undisturbed in 1979. Between 1979 and 1995, disturbance increased slightly at Yankee Point, Savage Point, and Sandy Cove and relatively small areas of land at Cape Norman and Burnt Cape had been anthropogenically disturbed. As of 1995, no disturbance as a result of quarrying had occurred at Watt's Point.

At some sites, including Burnt Cape and Watt's Point, the total area of disturbance which was calculated from the air photos is smaller than the actual area of disturbance at each of these sites. During the field trips to these locations during the summer of 1998 a considerable amount of disturbance could be seen which is not visible on the air photos. At Burnt Cape, which was once a central quarrying location, gravel pits could not be distinguished on the aerial photos from areas of naturally exposed limestone which are prominent throughout the area. In other cases, areas of disturbance may have been too small to decipher at the 1 : 12,500 scale of the most recent aerial photos. This was a problem at Watt's Point where areas of disturbance observed during fieldwork were not visible on the aerial photos. Also, disturbance may have existed prior to 1979 at some sites but because the older aerial photos were taken in black and white and at such small scales disturbed areas could not be seen.

6.3 Conclusions

Disturbance, either naturally or anthropogenically generated, is essential to the survival of *Braya longii* and *Braya fernaldii*. The results of this study indicate that the density of *Braya* populations is greater in areas of high anthropogenic than in low anthropogenic or naturally disturbed areas. However, this may be due to the fact that the naturally disturbed areas are older and more stable than the areas that have been disturbed by human activities, such as quarrying. The fact that the past conditions of the *Braya* sites are unknown should also be considered since *Braya* populations may have been healthier prior to the creation of anthropogenically disturbed areas on the Great Northern Peninsula in the late 1970s.

The study results also indicate that disturbance has increased significantly at most of the *Braya* sites between 1948 and 1995. Due to the disappearance of several of Fernald's original *Braya* populations and the inability of the *Braya* Recovery Team to locate new populations, the importance of protecting the existing populations must be emphasized. In particular, the *Braya* populations at Yankee Point, Savage Point, and Sandy Cove should be considered for immediate preservation since ongoing quarrying at these sites is a threat to their survival.

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