COSEWIC
Assessment and Status Report

on the

Fernald's Braya
Braya fernaldii

in Canada

ENDANGERED
2012

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC. 2012. COSEWIC assessment and status report on the Fernald's Braya *Braya fernaldii* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 36 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm)

Previous report(s):

COSEWIC. 2000. COSEWIC assessment and status report on the Fernald's braya *Braya fernaldii* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 22 pp.

Meades, S.J. 1997. COSEWIC status report on Fernald's braya *Braya fernaldii* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-22 pp.

Production note:
COSEWIC would like to acknowledge Susan Squires for writing the status report on Fernald's Braya, *Braya fernaldii*, in Canada, prepared under contract with Environment Canada. This report was overseen and edited by Bruce Bennett, Co-chair of the COSEWIC Vascular Plants Specialist Subcommittee.

For additional copies contact:

COSEWIC Secretariat
c/o Canadian Wildlife Service
Environment Canada
Ottawa, ON
K1A 0H3

Tel.: 819-953-3215
Fax: 819-994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le Braya de Fernald (*Braya fernaldii*) au Canada.

Cover illustration/photo:
Fernald's Braya — Photo: S. Squires.

Catalogue No. CW69-14/92-2013E-PDF
ISBN 978-1-100-22221-9

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – November 2012

Common name
Fernald's Braya

Scientific name
Braya fernaldii

Status
Endangered

Reason for designation
This small perennial plant, endemic to the limestone barrens of the Great Northern Peninsula of Newfoundland, is at increased risk over its limited range due to numerous threats. Ongoing habitat loss and degradation, combined with a non-native agricultural moth, result in low rates of survival and reproduction. These threats and the additional impact of climate change lead to the prediction that the species will go extinct in the wild within the next 80 years.

Occurrence
Newfoundland and Labrador

Status history
Designated Threatened in April 1997. Status re–examined and confirmed in May 2000. Status re-examined and designated Endangered in November 2012.

COSEWIC
Executive Summary

Fernald's Braya
Braya fernaldii

Wildlife Species Description and Significance

Fernald's Braya (*Braya fernaldii*) is a small (10 cm tall) herbaceous perennial in the mustard family Brassicaceae. It has fleshy, dark green to purplish, linear spatulate (spoon-shaped) leaves arranged in rosettes and four-petalled white to pinkish or purplish flowers. Fernald's Braya is very similar morphologically to Long's Braya (listed as Endangered under the *Species at Risk Act*) but it is shorter and has narrower petals, smaller and more purplish sepals, and pubescent leaves and fruit. It is one of four vascular plants endemic (only known from) to the island of Newfoundland.

Distribution

Fernald's Braya is endemic to the Limestone Barrens ecosystem on the island of Newfoundland, Canada. It is known from 16 populations that span about 150 km of coastline. It is likely that Fernald's Braya occurs sparsely throughout the almost continuous strip of limestone barrens at the northern (70 km) end of its range.

Habitat

Fernald's Braya is a calciphile (requires calcium-rich soils) that inhabits the Limestone Barrens—a mosaic of patches of shallow nutrient-poor calcium-rich soils in frost-shattered barrens, bedrock outcrops, fine-grained substrate, and tundra-like heaths within 1.5 km of the coast, and situated 13 to 15 m above sea level. Frost action, soil erosion from heavy precipitation, and wind erosion maintain open areas in which Fernald's Braya seedlings germinate. Fernald's Braya is also capable of inhabiting undisturbed limestone barrens where frost action has formed patterned substrate, such as sorted stripes and polygons, or anthropogenically degraded limestone barrens, such as abandoned limestone quarries and roadways, and levelled areas of land around utility lines. These areas consist of homogeneous gravel substrates with no patterned substrate and low species diversity.

Biology

Fernald's Braya is a long-lived (likely 20+ years) perennial whose life cycles can be divided into eight stages: seeds, four seedling stages (year one to four), and three adult stages (vegetative, single rosette flowering, and multiple rosette flowering). Flowering begins in mid-June and plants produce fruit by mid-August. Each flower produces on average 10-16 small (1-1.5 mm), round seeds that need to undergo a period of cold stratification and be scarified before they will germinate. Fernald's Braya growing on anthropogenically degraded habitat move more quickly through their life cycle and have a higher reproductive output than individuals growing on undisturbed habitat, but they also have higher mortality rates. Fernald's Braya are not known to reproduce asexually.

Population Sizes and Trends

A survey between 1996 and 2000 estimated that there were 3,434 flowering Fernald's Braya. The same 15 populations counted 8-12 years later contained only 1,242 mature plants (a 64% decline). An additional population not known during the first survey (Green Island Brook) contained 2,056 mature plants, increasing the current estimate of the global Fernald's Braya population to 3,282 mature plants. However, the Green Island Brook population is an anthropogenically disturbed population and, as a result of its very different life history, may only persist by immigration from outside populations. The population size of Fernald's Braya continues to decline, based on permanent monitoring plots. Population viability models provide additional evidence that the population size is declining. Two historical sites, Savage Cove and Ice Point, named in the *National Recovery Plan for Long's Braya and Fernald's Braya* still do not contain Fernald's Braya and are considered historically extirpated. Rescue effect is not possible because Fernald's Braya is endemic to the island of Newfoundland.

Threats and Limiting Factors

Past habitat loss through quarrying, road construction, and community expansion was the most significant and widespread threat to Fernald's Braya, but currently it is the maintenance of that infrastructure that is a threat. These large-scale disturbances left some areas heavily degraded but still capable of supporting Fernald's Braya (i.e., represent anthropogenically disturbed populations). Populations on such anthropogenically degraded habitat may threaten the viability of undisturbed populations by acting as reservoirs for pests and pathogens. Fernald's Braya populations are negatively affected by an introduced, pesticide-resistant, agricultural insect pest and two pathogens, all of which decrease seed set and increase mortality rates in each population. Summer and winter air temperatures on the limestone barrens increased from 1991 to 2002 and mean annual air temperature is predicted to increase another 4ºC by 2080. These climatic changes could reduce winter snow cover, alter the frost-sorting processes characteristic of the limestone barrens, and affect the population distribution and abundance of pests and pathogens.

Surveys conducted within the distribution of Fernald's Braya found that 59-76% of respondents thought off-road vehicles were causing more damage than any other human activity. Dumping garbage, piling and cutting wood, and drying fishing nets can cause Fernald's Braya mortality and decrease habitat quality, but these activities are more localized and less frequent. Hybridization with the closely related Long's Braya is possible but considered rare. Until roads degraded the landscape, these species did not co-occur and there was no indication of hybridization; however, recent research suggests hybridization is possible in populations on anthropogenically degraded habitat where these species co-occur.

Protection, Status, and Ranks

Fernald's Braya is listed as Threatened in the federal *Species at Risk Act* and the Newfoundland and Labrador *Endangered Species Act.* Fernald's Braya is ranked by NatureServe as critically imperilled globally (G1), nationally (N1), and provincially (S1). Fernald's Braya is protected within the Port au Choix National Historic Site, the Watts Point Ecological Reserve, and the Burnt Cape Ecological Reserve—the latter of which was established shortly after the last COSEWIC assessment of Fernald's Braya.

TECHNICAL SUMMARY

Braya fernaldii
Fernald's Braya Braya de Fernald
Range of occurrence in Canada: Newfoundland and Labrador (island of Newfoundland only)

Demographic Information

Generation time. (*Seedlings planted* in situ *in 2002 had not flowered by 2011 nor were they the size of flowering plants, suggesting generation time is at least 10 years, and likely 20+ years. The age of the youngest and oldest breeding individual has not yet been determined*.)	10+ years
Is there an observed continuing decline in number of mature individuals?	Yes
Estimated percent of continuing decline in total number of mature individuals within 5 years. (*Determined from PVA which projects declines of 90% within 10 years*)	45%
Observed percent reduction in total number of mature individuals over the last 10 years, or 3 generations. (*Determined from population surveys in 1996-2000 and 2008-2011. Data for 3 generations are not available*)	64%
Projected percent increase in total number of mature individuals over the next 10 years.	N/A
Estimated percent reduction in total number of mature individuals over any 10 years period, over a time period including both the past and the future. (*Determined from PVA*)	90%
Are the causes of the decline clearly reversible and understood and ceased?	Some reversible and understood, but not ceased
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	~1000 km²
Index of area of occupancy (IAO) (*The species' IAO has increased by 12 km^2 based on a 2 x 2 km UTM grid*.)	120 km²
Is the total population severely fragmented?	No
Number of locations∗ (*Based on the threats of an invasive insect pest and a pathogen, which annually infest/infect populations, and the effects of climate change, which are predicted to increasingly affect all individuals*)	1
Is there an observed continuing decline in extent of occurrence?	No
Is there an observed continuing decline in index of area of occupancy?	No
Is there an observed continuing decline in number of populations?	No
Is there an observed continuing decline in number of locations*?	No
Is there an observed continuing decline in quality of habitat? (*Habitat continues to decline due to maintenance of existing infrastructure, off-road vehicle use, wood piling and cutting, dumping of garbage, and fishing net drying*.)	Yes

∗ See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term

Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations∗?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Populations	**Number of Mature Individuals in 2008-2011 Survey**
Port au Choix National Historic Site	54*
Anchor Point East	121
Anchor Point West (St. Barbe)	12
Ice Point	Historically extirpated
Savage Cove	Historically extirpated
Shoal Cove	1
Green Island Brook	2056
Watts Point South	12
Watts Point Ecological Reserve	7
Four Mile Cove	2
Big Brook	3
Lower Cove	28
Watt's Bight	62
Boat Harbour	6
Cape Norman	46
Cook's Point	17
Cook's Harbour	14
Burnt Cape Ecological Reserve	857
Total *All the limestone outcrops that may contain Fernald's Braya have not yet been surveyed so the population size is an underestimate of the total global population size; however, the areas counted encompass the entire range of the species, and the largest limestone outcrops, and hence are very likely the largest concentrations of the species.*	**>3298**

* additional plants were counted at the Port au Choix National Historic Site by Parks Canada, but due to a different counting technique are not presented here.

Quantitative Analysis

Probability of extinction in the wild is at least 10% within 100 years. *PVA suggests that there will be a continued decline (90%) over a 10-year period (2008-2018) and a 100% probability the species will go extinct within 80 years* (*approximately 5-8 generations*).	Yes

See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term

Threats (actual or imminent, to populations or habitats)

Threats of 1) invasive insect herbivory, 2) pathogen infection, 3) habitat loss and degradation through gravel extraction, off-road vehicle use, road maintenance, maintenance and construction of utility corridors, local use of the limestone barrens, community expansion, and road construction, 4) change in habitat quality as a result of climate change altering frost-sorting processes, air temperature, precipitation patterns and amounts, and pest and pathogen frequency, and 5) hybridization with Long's Braya. The threats of insect herbivory, pathogen infection, maintenance of utility corridors, and off-road vehicle use have been the most significant in the last 10 years and research suggests the impacts of climate change will worsen over the next 70 years (i.e. temperature increase of 4°C by 2080). Population viability analysis (PVA) suggests that under current conditions Fernald's Braya could go extinct in 80 years (approximately 5-8 generations). Population viability modelling with the mortality impacts of herbivore and pathogen threats removed improves the population growth rate but not to the point of its being stable or increasing.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Endemic to the island of Newfoundland.	
Is immigration known or possible?	Impossible
Would immigrants be adapted to survive in Canada?	n/a
Is there sufficient habitat for immigrants in Canada?	n/a
Is rescue from outside populations likely?	No

Status History

Status History: Designated Threatened in April 1997. Status re-examined and confirmed in May 2000. Status re-examined and designated Endangered in November 2012.

Status and Reasons for Designation

Status:	**Alpha-numeric code:**
Endangered	**A3bce; B1ab(iii,v)+2ab(iii,v); E**

Reasons for designation: This small perennial plant, endemic to the limestone barrens of the Great Northern Peninsula of Newfoundland, is at increased risk over its limited range due to numerous threats. Ongoing habitat loss and degradation, combined with a non-native agricultural moth, result in low rates of survival and reproduction. These threats and the additional impact of climate change lead to the prediction that the species will go extinct in the wild within the next 80 years.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A3 with a future inferred reduction in the total number of individuals by >50% (b) an index of abundance appropriate to the taxon (c) a decline in index of area of occupancy, extent of occurrence and/or quality of habitat, and (e) the effects of introduced taxa, hybridization, and pathogens.

Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Endangered B1 EO < 5000 km² (~1000 km²) + B2 IAO <500 km² (120 km²), there is only one location based on the threat of the invasive insect, there is a continuing decline in the extent and quality of habitat and in the number of individuals.

Criterion C (Small and Declining Number of Mature Individuals): Meets Threatened C1, as the total population is <10,000 mature individuals that continue to decline at a rate of >10% over the next ten years, and may meet Threatened C2 a(i) as the one population that contains >1000 mature individuals is thought to be a population sink.

Criterion D (Very Small or Restricted Total Population): Meets Threatened D2 as there is only one location, and the populations could decline quickly in the face of the pathogen and insect threats.

Criterion E (Quantitative Analysis): Meets Endangered as the number of plants is predicted to continue to decline (90%) over a 10-year period (2008-2018) and there is a 100% probability the species will go extinct within 80 years (approximately 5-8 generations).

PREFACE

Fernald's Braya (*Braya fernaldii*) is endemic to the Limestone Barrens ecosystem on the island of Newfoundland. It was assessed in 2000 as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). It was listed under the Canadian *Species at Risk Act* and the Newfoundland and Labrador *Endangered Species Act* in 2002. Within Newfoundland and Labrador, recovery planning for Fernald's Braya is the responsibility of the Limestone Barrens Species-at-Risk Recovery Team. A federal recovery strategy for the species has been completed and a provincial recovery plan for the Limestone Barrens is being prepared.

Since the last assessment, three additional populations (Anchor Point East, Green Island Brook, and Shoal Cove) have been found; therefore Fernald's Braya is now currently known from 16 geographically separate, extant populations. Detailed population surveys from 1996-2000 and again from 2008-2011, data from four years of permanent monitoring plots, and population viability models all provide evidence that the population size of Fernald's Braya is continuing to decline as a result of anthropogenic threats (e.g. off-road vehicles, maintenance of utility corridors), an invasive insect pest, two unidentified pathogens, and change in habitat quality as a result of climate change altering the pattern and amount of snow and ice cover, air temperature, precipitation amounts, and over the longer term, frost-sorting processes. Off-road vehicles, maintenance of utility corridors, hybridization, the effects of climate change, and pathogens were not listed as threats in the previous status report (Meades 1997). As a result of Fernald's Braya being legally listed under the Canadian *Species at Risk Act* and the Newfoundland and Labrador *Endangered Species Act* the threat of habitat loss as a result of limestone quarrying has decreased because quarry permits can only be obtained in areas where Fernald's Braya have not been found and areas of potential occurrence are checked prior to permit approval.

Fernald's Braya are found within the federally protected Port au Choix National Historic Site, and the provincially protected Watts Point Ecological Reserve and Burnt Cape Ecological Reserve. The latter was established shortly after the last COSEWIC assessment of Fernald's Braya.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2012)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada | Environnement Canada
Canadian Wildlife Service | Service canadien de la faune
Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

Fernald's Braya
Braya fernaldii

in Canada

2012

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Scientific name: *Braya fernaldii* Abbe

Synonyms: *Braya americana* (Hook.) Fernald
Braya purpurascens (R. Br.) Bunge var. *fernaldii* (Abbe) Boivin

English common name: Fernald's Braya; Fernald's Rockcress

French common name: Braya de Fernald

Family: Brassicaceae (mustard)

Major plant group: Dicot flowering plant

Morphological Description

Fernald's Braya is a small (1-7 (10) cm tall) herbaceous perennial with a contractile taproot that anchors the plant against frost heave (Meades 1997). It has fleshy, dark green to purplish, linear spatulate basal leaves that average 1-4 cm in length and 1-3 mm in width (Figure 1a) (Harris 1985). Leaves are arranged in rosettes and while most individuals have one to five rosettes, some larger individuals have 10-20 rosettes. Inflorescences are elongated, unbranched flowering stalks with a dense arrangement of four-petalled, white to pinkish or purplish flowers at the top (Figure 1b) (Harris 1985). The fruit pods are pubescent (covered with short hairs) and each elongated fruit holds on average 10-16 seeds (Figure 1c) (Meades 1997).

A)

B)

C)

Figure 1. Fernald's Braya (*Braya fernaldii*) A) not flowering (i.e., vegetative growth stage), B) in flower, and C) in fruit (Photos: S. Squires).

Fernald's Braya is very similar morphologically to Long's Braya (*Braya longii*), which is listed under Schedule 1 of the *Species At Risk Act* (SARA) as endangered, and is also endemic to the Limestone Barrens on the island of Newfoundland (Figure 2). Fernald's Braya is shorter than Long's Braya and has narrower petals, smaller and more purplish sepals, and pubescent leaves and fruit (Harris 1985).

Figure 2. Global distribution of Fernald's Braya (*Braya fernaldii*), which is endemic to Canada.

Population Spatial Structure and Variability

Fernald's Braya is now known from 16 geographically separate, extant populations (Table 1) between the Port au Choix National Historic Site and the Burnt Cape Ecological Reserve, a distance of about 150 km (Hermanutz *et al*. 2009) (Figure 3). It is likely that Fernald's Braya can be found throughout its range in sparse and scattered patches within areas of suitable habitat. However, all populations are geographically, and genetically separated by areas of unsuitable habitat, such as water, forests, communities, or paved roadways, through which seed dispersal is highly unlikely (Tilley 2003).

Table 1. A comparison of the change in the total number of flowering Fernald's Braya (*Braya fernaldii*) plants counted in undisturbed (N) and anthropogenically degraded (D) habitat between 1996-2000 and 2008-2011 surveys. (* = a long-term study population).

	Population	Disturbance	1996-2000 Count	2008-2011 Count	Percent Change (%)	Years Surveyed	No. of Years Between Surveys
1	Port au Choix National Historic Site*	N	150	54	64 ↓	1999; 2008	9
2	Anchor Point East*	N	250	121	52 ↓	1999; 2008	9
3	Anchor Point West (St. Barbe)*	N	650	12	98 ↓	1999; 2008	9
4	Shoal Cove*	N	50	1	98 ↓	2000; 2008	8
5	Green Island Brook*	D	-	2056	-	- ; 2008	-
6	Watts Point South*	D	800	12	99 ↓	1998; 2008	10
7	Watts Point Ecological Reserve*	N	75	5	93 ↓	1999; 2008	9
		D	50	2	96 ↓	1999; 2008	9
8	Four Mile Cove	N	40	2	95 ↓	1999; 2011	12
9	Big Brook	N	3	3	0	2000; 2008	8
10	Lower Cove	N	200	21	90 ↓	1999; 2008	9
		D	100	7	93 ↓	1999; 2011	12
11	Watt's Bight	D	20	62	210 ↑	2000; 2008	8
12	Boat Harbour	N	20	6	70 ↓	2000; 2011	11
13	Cape Norman*	N	150	46	69 ↓	2000; 2008	8
14	Cook's Point	D	25	17	32 ↓	1999; 2008	9
15	Cook's Harbour	N	-	14	-	- ; 2008	-
		D	1	0	100 ↓	1996; 2008	12
16	Burnt Cape Ecological Reserve*	D	850	857	1 ↑	1998; 2008	10
	TOTAL		3434	3298			

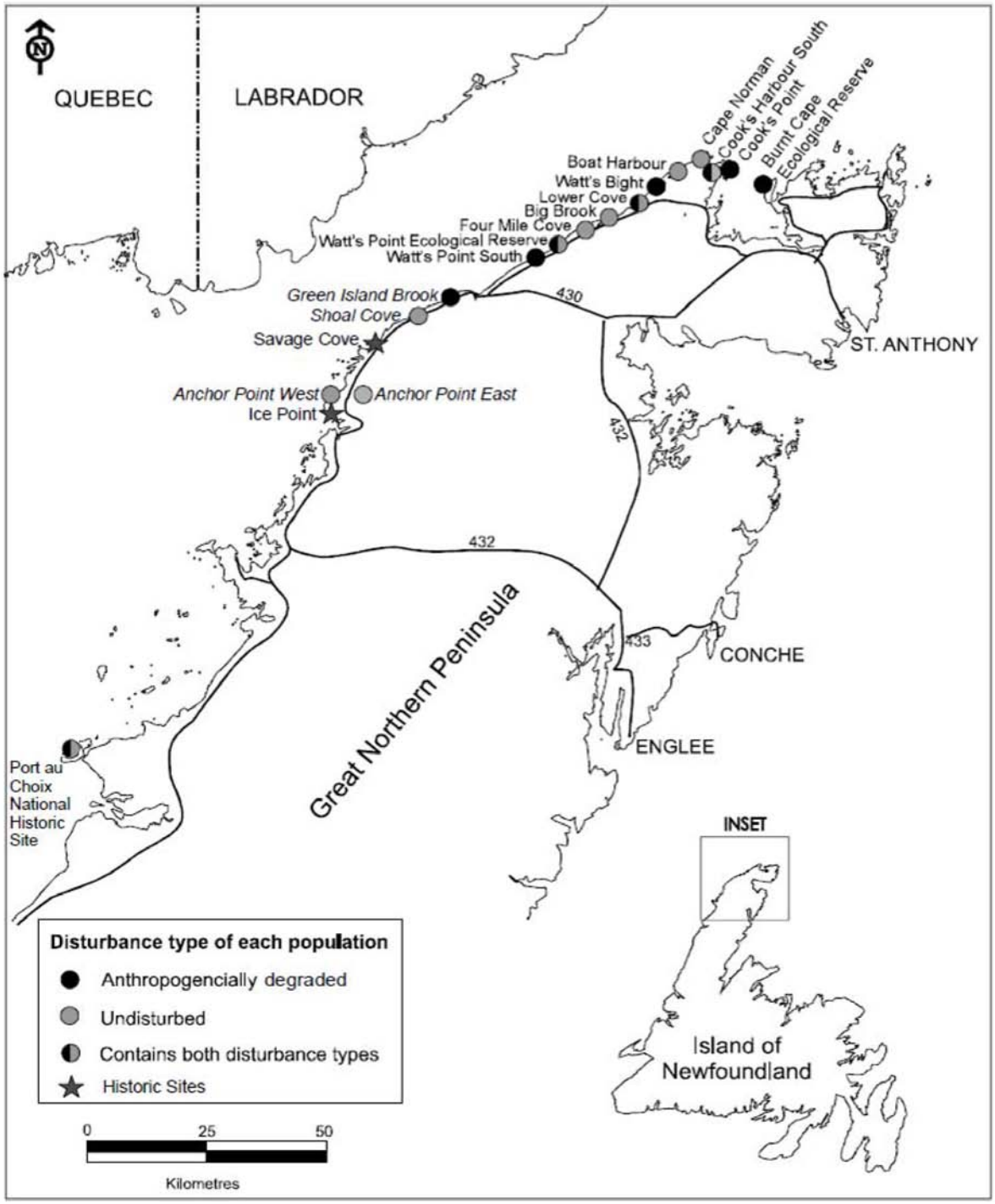


Figure 3. Distribution of Fernald's Braya (*Braya fernaldii*) populations and their level of disturbance. Populations found since the last COSEWIC assessment are written in italics (used and modified with permission from Squires 2010).

Parsons (2002) found that there were significant morphological differences ($p \leq 0.001$) among the Burnt Cape Ecological Reserve, Watts Point Ecological Reserve, Anchor Point, St. Barbe, and Cape Norman populations in eight of the 17 floral characters measured (i.e. petal, sepal, style, and stamen lengths). Parsons' (2002) reproductive studies noted that Fernald's Braya fitness is higher when individuals are crossed with individuals from the same population than when crossed with individuals from different populations, which also suggests that populations are differentiated from one another and suffer from outbreeding depression. Preliminary genetics work supports minimal population differentiation, although it suggests that the polyploid Fernald's Braya (Warwick *et al*. 2004) is a young species and that insufficient time has passed for the differentiation to be significant (Good-Avila 2008). A 1400 base-pair sequence from the chloroplast genome, an area known to have a high rate of evolution in species of family Brassicaceae, was sequenced for 15 individuals from seven populations. All populations showed minimal differentiation from one another and individuals from two populations, the Port au Choix National Historic Site and the Burnt Cape Ecological Reserve shared a mutation (a five base pair insertion) suggesting that there may be a relationship between these Fernald's Braya populations (Good-Avila 2008), although no logical connection has been determined.

Designatable Units

A single designatable unit is recognized for Fernald's Braya in Canada. The entire species is composed of 16 populations on the island of Newfoundland that all occur within a single national ecozone, the Boreal National Ecological Area. All Fernald's Braya populations occur within a single ecoregion, the Strait of Belle Isle Barrens (Parks and Natural Areas Division 2007). Preliminary genetics work supports minimal population differentiation (Good-Avila 2008). As such a single status designation is thought to reflect the probability of extinction of the species.

Special Significance

Fernald's Braya is one of four vascular plants endemic to the island of Newfoundland. Two other endemic species, Long's Braya and Barrens Willow (*Salix jejuna*), have also been assessed by COSEWIC and are listed under the Canadian *Species at Risk Act* and Newfoundland and Labrador *Endangered Species Act* as Endangered.

No Aboriginal traditional ecological knowledge (TEK) is known for this species although the limestone barrens are valued for their ecological importance as a hotspot for rare plant diversity. Increasingly, the limestone barrens are being valued by local communities for the economic contribution to ecotourism in Newfoundland and Labrador (Limestone Barrens Habitat Stewardship Program 2007).

DISTRIBUTION

Global Range and Canadian Range

Fernald's Braya is endemic to the island of Newfoundland, Canada (Meades 1997) (Figure 2) where it is restricted to the Limestone Barrens ecosystem on the Great Northern Peninsula of Newfoundland. At the time of the 2000 COSEWIC assessment, 13 geographically separate Fernald's Braya populations were known to exist, in addition to two populations (Savage Cove and Ice Point) which were considered then and are still considered to be historically extirpated (Meades 1997). Since the last assessment, three additional populations (Anchor Point East, Green Island Brook, and Shoal Cove) have been found and Fernald's Braya is now known from 16 geographically separate, extant populations (Table 1; Figure 3) (Hermanutz *et al.* 2009). The southernmost population at the Port au Choix National Historic Site is separated from the next population to the north, Anchor Point, by about 80 km (Hermanutz *et al*. 2002). It is likely that Fernald's Braya can be found sparsely distributed throughout the almost continuous strip of the northern limestone barrens found between the Watts Point Ecological Reserve and Cape Norman (Figure 3). While the populations are separated from each other by unsuitable habitat, this fragmentation is not considered "severely fragmented" as per the IUCN definition as greater than 50 percent of the plants occur in patches that are large enough to support a viable population (Table 1). The habitat is naturally fragmented.

Extent of Occurrence and Index of Area of Occupancy

The species' extent of occurrence (EO) in Canada is about 1,000 km^2. The index of area of occupancy (IAO) for Fernald's Braya is 120 km^2 based on a 2 x 2 km UTM grid. Since the previous status report (Meades 1997) additional populations have been located and therefore the species' IAO has increased by 12 km^2 based on a 2 x 2 km UTM grid.

Search Effort

Fernald's Braya was first described in 1924 by Bayard Long and Merritt Lyndon Fernald (Hermanutz *et al.* 2002). Fernald found eight Fernald's Braya populations in 1925 (Big Brook, Boat Harbour, Watt's Bight, Four Mile Cove, Cape Norman, Burnt Cape, Savage Cove (now extirpated), and Ice Point (now extirpated)) (Meades 1997). Between 1963 and 1987, botanists from the Université de Montréal found an additional four Fernald's Braya populations (Cook's Harbour, Port au Choix, St. Barbe (now Anchor Point West), and Watts Point) and in 1995, Meades (1997) found three more populations (Watts Point South, North Cook's Harbour (now Cook's Point), and South Cook's Harbour (now Cook's Harbour)).

Subsequent to the last assessment, the Limestone Barrens Species-at-Risk Recovery Team (2004) resurveyed the 13 extant populations, the two historical populations, and many previously unsurveyed limestone barrens and found three additional populations at Anchor Point East, Green Island Brook, and Shoal Cove. Currently, 16 extant Fernald's Braya populations are known.

Potential Fernald's Braya habitat was identified by the Limestone Barrens Species-at-Risk Recovery Team in 2004 from aerial photos (Greene 2002; Limestone Barrens Species-at-Risk Recovery Team 2004). Areas of potential habitat surveyed and found to contain Fernald's Braya are now considered critical habitat (Limestone Barrens Species-at-Risk Recovery Team 2004; Environment Canada 2012*;* Limestone Barrens Species-at-Risk Recovery Team *In Prep*). There are still areas of potential habitat within the known distribution of Fernald's Braya that remain to be surveyed. It is thus possible that the number of known occurrences will increase with increasing survey coverage but it is highly unlikely the overall distribution of the species will expand.

Limestone barrens habitat within Newfoundland and Labrador but outside the known distribution of Fernald's Braya, such as the limestone barrens on the Port au Port Peninsula and Table Mountain have been well surveyed numerous times in recent years (Djan-Chékar and Hanel 2004; SSAC 2004, 2006). Although they are known to contain other species rare to Newfoundland and Labrador, including the Low Northern Rockcress (*Braya humilis*) and Mackenzie's Sweetvetch (*Hedysarum boreale* subsp. *mackenziei*), they do not contain Fernald's Braya.

HABITAT

Habitat Requirements

Fernald's Braya is a calciphile that inhabits the limestone barrens (Meades 1997; Noel 2000), a mosaic of patches of shallow nutrient-poor, calcium-rich soils in frost-shattered limestone of varying sizes, limestone bedrock outcrops, fine-grained limestone substrate, and tundra-like heaths (Figure 4) (Banfield 1983; Donato 2005). Frost action, wind and soil erosion, and heavy precipitation shape the soluble limestone maintaining open areas and creating suitable microsites for germination of Fernald's Braya seedlings along zones of intermediate frost action (Noel 2000; Greene 2002). In undisturbed limestone barrens, frost action has formed patterned substrate, such as sorted stripes and polygons. Vegetation is typically less than 10 cm tall and covers less than 50% of the substrate (Meades 1997). The majority of the limestone barrens are found within 1.5 km of the coast and are situated 13 to 15 m above sea level (Greene 2002). These physical characteristics coupled with the arctic-like weather, make this habitat unique on the island of Newfoundland and in Canada.

A)

B)

Figure 4. Undisturbed limestone barrens habitat at A) Port au Choix National Historic Site and B) Anchor Point (Photos: S. Squires).

Fernald's Braya is capable of inhabiting limestone barrens that have been severely anthropogenically degraded. Anthropogenically degraded habitat has suffered large-scale disturbance to both the vegetation and the substrate, and now contains homogenous gravel substrates with no patterned or sorted substrate and has low plant species diversity (Greene 2002; Rafuse 2005). These areas include limestone-based roadways (Figure 5), abandoned limestone quarries, and levelled areas of land around power and phone line poles. Fernald's Braya are capable of inhabiting these degraded patches by either colonizing the area from nearby undisturbed habitat or growing from seed present in the limestone gravel that was disturbed or moved during construction (Squires 2010).

Figure 5. Anthropogenically degraded limestone barrens on and along an abandoned roadbed in the Watts Point Ecological Reserve (Photo: S. Squires).

Habitat Trends

Approximately 30% of limestone barrens habitat has been anthropogenically degraded (Hermanutz *et al.* 2009). Of the 16 known Fernald's Braya populations, eight are growing in undisturbed habitat, five are growing in anthropogenically degraded habitat, and three contain areas of both habitat types (Figure 3) (Hermanutz *et al.* 2009). The majority of habitat degradation occurred from 1968 to 1990 when quarrying removed limestone rock and gravel for the construction of the Route 430 (Janes 1999) and communities developed (Hermanutz *et al.* 2002). In some areas, utility operators and municipalities have used limestone gravel to level areas of land, support power/phone lines, or build roads creating patches of anthropogenically degraded habitat (Figure 5). Continued degradation of limestone barrens habitat is a result of gravel extraction, off-road vehicle use, maintenance of utility corridors and power/phone lines, garbage dumping, and use as a staging area to cut wood and dry fishing nets. According to the current recovery strategy these threats remain of medium to high concern and occur throughout the distribution of the limestone barrens (Environment Canada 2012). Of a lower concern is loss and degradation of limestone barrens due to community expansion and/or the construction of new roads.

BIOLOGY

Life Cycle and Reproduction

Fernald's Braya is a long-lived (10+ years) perennial with a life cycle consisting of eight stages: seeds, four seedling stages (year one to four), and three adult stages (vegetative, single rosette flowering, and multiple rosette flower) (Appendix 1).

Fernald's Braya is not known to reproduce asexually and therefore relies on sexual reproduction to maintain populations (Parsons and Hermanutz 2006). Flowering begins in mid-June and plants produce fruit by mid-August (Parsons 2002). Fernald's Braya at the most southerly known site, Port au Choix National Historic Site, flower first and plants at the most northerly site, Cape Norman, are last to flower (Donato 2005). Flower and subsequent fruit production is relatively successful. On average from 1998 to 2011, the difference between the number of flowers per stalk and the number of fruit produced on the same stalk was 2.2 for Fernald's Braya growing on undisturbed habitat and 1.6 for Fernald's Braya growing on anthropogenically degraded habitat (Squires and Hermanutz unpubl. data).

Each fruit holds 10-16 small (1-1.5 mm) round seeds (Meades 1997). Seeds require a period of cold stratification and scarification before they will germinate. Pollination studies found that fruit set was highest (70-85%) under self-pollination and open-pollination controls, and lowest (15-55%) when outcrossed with plants from other populations or after hybrid pollination with Long's Braya (Parsons and Hermanutz 2006). Seed set was highest (70%) in open-pollination controls and lowest (0%) after hybrid pollination with Long's Braya (Parsons and Hermanutz 2006).

Seed burial experiments indicate that Fernald's Braya seeds can remain stored in the seed bank for a minimum of three years with viability of seeds ranging from 15-81% (Squires 2010). Studies to determine the quantity of seeds within the seed bank and seed longevity suggest that Fernald's Braya populations do not rely heavily on the seed bank to maintain viability over the short-term (Tilley 2003; Squires 2010). Seeds planted back into the wild in 2002 had not flowered by 2011 were still quite small (one rosette of leaves), suggesting generation time is at least 10 years (Tilley 2003; Squires and Hermanutz unpubl. data). The ages of the youngest and oldest breeding individuals have not yet been determined.

The probability of survival is higher for adult stages growing on undisturbed habitats compared to those on anthropogenically degraded habitat (Squires 2010; Appendix 1). Fernald's Braya growing on anthropogenically degraded habitat progress through their lifecycle more quickly than individuals growing on undisturbed habitat (Squires 2010; Appendix 1). The reproductive output (number of seeds per plant) of a multiple rosette plant on undisturbed habitat is on average five times higher than a single-rosette, flowering Fernald's Braya and this difference increases to 17 times higher for a Fernald's Braya growing on anthropogenically degraded habitat (Squires 2010).

Physiology and Adaptability

Fernald's Braya have a contractile taproot that anchors the plant against frost heave (Meades 1997). They are pioneers of both naturally frost-disturbed areas and anthropogenically degraded areas, and are intolerant to shade and competition. Fernald's Braya can colonize anthropogenically degraded areas quickly, but will be outcompeted due to shade intolerance by other vegetation such as grass if natural frost action is not present to maintain regular soil disturbance.

The Memorial University Botanical Garden has successfully maintained Fernald's Braya in their seed bank and live plant *ex situ* program since 1998 (Driscoll 2006). Fernald's Braya has been propagated from both seed and tissue culture (Driscoll 2006). Adult plants grown *ex situ* do not survive when transplanted back into the wild but seeds stored *ex situ* and scarified prior to transplant readily germinate on the limestone barrens (Driscoll 2006). Seedlings that emerged from seeds planted on the barrens in 2002 are still alive but have not yet flowered (Tilley 2003; Squires and Hermanutz unpubl. data). Fernald's Braya seeds planted *ex situ* can flower within a few years as it is challenging to mimic the climatic characteristics of the limestone barrens that produce conditions such as frost sorting that slow the growth of Fernald's Braya in the wild (Driscoll 2006).

Dispersal and Migration

Fernald's Braya has no specialized insect, vertebrate, or wind dispersal mechanisms. It is self-pollinating and it is unlikely that pollen travels between or among populations due to distance and natural geological and biological boundaries. Seeds disperse passively from an open seed capsule using wind and have no adaptations for increasing dispersal (Meades 1997). Fernald's Braya seeds rarely disperse more than 50 cm from the parent plant (Tilley 2003). It may be possible that some longer-distance dispersal occurs by water or on snow.

Interspecific Interactions

Fernald's Braya survival and reproductive output is negatively affected by two pathogens and an invasive insect pest (see *THREATS AND LIMITING FACTORS*). The first pathogen was recorded on Fernald's Braya in 1925 by Fernald at Boat Harbour (Fernald 1950). This pathogen causes leaf and flower stalk deformities and increased leaf pubescence (Figure 6a) (Hermanutz *et al*. 2002). In 2004, Fernald's Braya flowering stalks were found to be infected by an unidentified pathogen that caused the flowering stalks to become mouldy (Figure 6) (Squires 2010) (see *THREATS AND LIMITING FACTORS*). Diamondback Moth (*Plutella xylostella*; Lepidoptera: Plutellidae) is an invasive, pesticide resistant, global agricultural pest of the mustard family (Figure 6c) (Talekar and Shelton 1993) (see *THREATS AND LIMITING FACTORS*). It travels into Canada annually on high-altitude air currents from overwintering sites in the United States (Talekar and Shelton 1993). It was first found on Fernald's Braya in 1995 (Meades 1997) and annually infests Fernald's Braya, particularly flowering plants (Hermanutz *et al.* 2002; Parsons 2002; Squires *et al.* 2009; Squires 2010).

A)  B) 

C) 

Figure 6. The pests and pathogens of Fernald's Braya (*Braya fernaldii*). A) Fernald's Braya infected with an unknown pathogen causing flowering stalk deformities and increased pubescence; B) Long's Braya (*Braya longii*) flowering stalk infected with an unidentified pathogen (far left stalk that is pale pink) amongst uninfected stalks (same symptoms occur on Fernald's Braya); and C) Diamondback Moth (*Plutella xylostella*) adult on braya (Photo credits: S. Squires).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

1996-2000 Survey:

In preparation for the *National Recovery Plan for Long's Braya and Fernald's Braya* (Hermanutz *et al.* 2002), each known population of Fernald's Braya was surveyed and counted by the Limestone Barrens Species-at-Risk Recovery Team (then the Braya Recovery Team). Observers walked arm's-length apart counting flowering Fernald's Braya. These counts constitute the 1996-2000 survey (Table 1).

2008-2011 Survey:

To determine changes in population size, a second survey began in 2008. The total number of flowering plants in 12 of the 15 Fernald's Braya populations identified in the *National Recovery Plan for Long's Braya and Fernald's Braya* (note Anchor Point East and West and now considered two populations) (Hermanutz *et al.* 2002), including all the Fernald's Braya populations identified in the previous status report (Meades 1997) plus the Green Island Brook population, were counted in 2008 (Table 1) (Hermanutz *et al.* 2009). In July 2011, the remaining three populations (Four Mile Cove, Lower Cove, and Boat Harbour) were surveyed (Table 1). At each population, the area counted was georeferenced and, using measuring tapes, a grid was created to ensure that plants were not missed or counted twice.

It was not possible to count at all the limestone outcrops that may contain Fernald's Braya because Fernald's Braya can likely be found throughout its range in sparse and scattered patches. The draft *Long's braya and Fernald's braya Recovery Strategy* (Environment Canada 2012) recommends surveying all potential sites over a five-year period to finalize critical habitat maps and population counts. To date 47% of potential Fernald`s Braya habitat has been surveyed; 34% is considered critical habitat (Environment Canada 2012), 13% is suitable habitat but currently unoccupied, and the remaining 53% is potential, unsurveyed habitat (Durocher pers. comm. 2012), but represents smaller, more isolated patches of limestone substrate.

1998-2011 Permanent Monitoring Plants and Plots:

Data on growth and reproductive output have been recorded annually from permanently tagged plants in each Fernald's Braya study population since 1998 (Table 1). These study populations cover the entire distribution of the species and include populations on undisturbed and anthropogenically degraded habitat, and populations outside and inside protected areas. Within each study population, the basal diameter, longest leaf, longest flowering stalk, number of flowering stalks, number of flowers per stalk, and number of fruit per stalk were recorded from 15-30 permanently tagged plants. Plants of all ages, reproductive stages, and sizes were monitored and individually tagged using a nail, flagging tape, and a uniquely numbered aluminum tag (Figure 1a).

In 2008, 1m x 2m permanent plots were established in all study populations to assess changes in population size and composition from the 2008-2011 survey (Hermanutz *et al.* 2009). A minimum of two permanent plots were established per population, but more were established in each population until 10% of the known 2008 population size was represented by plots throughout the species' range. Plots were clearly defined using nails and string and tagged with a nail, orange flagging tape and a uniquely numbered aluminum tag. In 2008, 2010, and 2011, the number of Fernald's Braya in each plant stage were counted within each of the 39 permanent monitoring plots.

Abundance

The total population of Fernald's Braya was estimated to contain 3,434 mature individuals (flowering plants) in the 1996-2000 survey (Table 1; Hermanutz *et al*. 2009). Approximately 3,298 mature individuals were counted in the 2008-2011 survey, 91% of which were in populations on anthropogenically degraded habitat (Table 1). An additional 1241 plants (778 of which were mature) were counted by Parks Canada at the Port au Choix National Historic Site in 2011 (Burzynski pers. comm. 2011). The 2008-2011 survey included one population, Green Island Brook, which was not counted in the earlier survey (Table 1; Hermanutz *et al*. 2009). All the limestone barrens that may contain Fernald's Braya have not yet been surveyed so the population size is an underestimate of the total global population size; however, the areas counted encompass the entire range of the species and are very likely the largest concentrations of the species as most of the sites with a high likelihood of finding Fernald's Braya have been surveyed.

Fluctuations and Trends

Survey Data:

The Green Island Brook population was not counted in the 1996-2000 survey and contains nearly two-thirds of the flowering plants counted (Table 1). However the Green Island Brook population is an anthropogenically disturbed population and is considered a population sink. A comparison of survey data for the 15 populations counted in both the 1996-2000 survey and 2008-2011 survey recorded a decline of 64% from 3,434 mature individuals to 1,242 mature individuals (Table 1). All populations decreased in size (ranging from a 32% to a 99% decline) except for the Burnt Cape Ecological Reserve population which remained stable (1% increase) and the Watts Bight population which increased by 2.1 times (Table 1). The two historical populations, Savage Cove and Ice Point, named in the *National Recovery Plan for Long's Braya and Fernald's Braya* (Hermanutz *et al.* 2002) were checked and still no *Braya* were located, and therefore they are thought to be either extirpated or based on misidentified place names (Hermanutz *et al.* 2002).

In addition to the Fernald's Braya counted in areas of the Port au Choix National Historic Site during the 1996-2000 survey and 2008-2011 survey (Table 1), Parks Canada recounted additional sites. The two surveys for Port au Choix National Historic Site represent a partial population count, and indicate a 64% decline (Table 1). A 2011 count, in the Port au Choix National Historic Site, of 29 sites found 409 flowering and non-flowering plants (Burzynski pers. comm. 2011; Environment Canada 2012). This is less than the 1241 flowering and non-flowering plants counted between 2005 and 2009 at those same sites and represents a decline of 67% (Burzynski pers. comm. 2011; Environment Canada 2012).

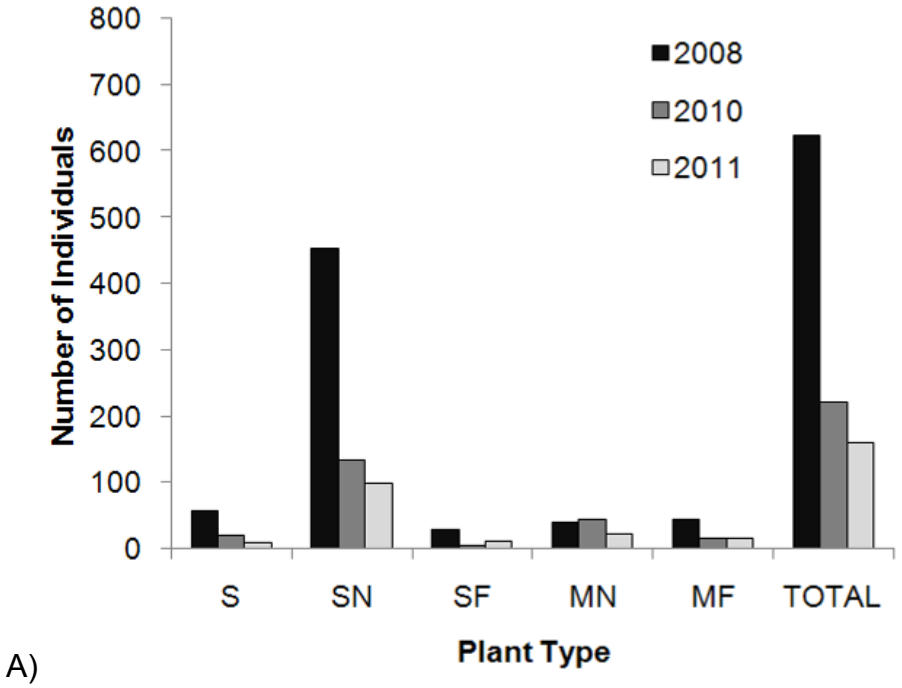
Permanent Monitoring Plots:

The results from the permanent monitoring plots support the population decline noted in the 2008-2011 survey (Table 1; Figure 7), and the decline Parks Canada recorded in 2011 (Burzynski pers. comm. 2011; Environment Canada 2012). The number of Fernald's Braya found within plots on undisturbed habitat have declined by 74% and the number within plots on anthropogenically degraded habitat have declined by 77%. Additionally, six of the 39 plots now contain no Fernald's Braya. These declines have occurred in every plant stage (Figure 7).

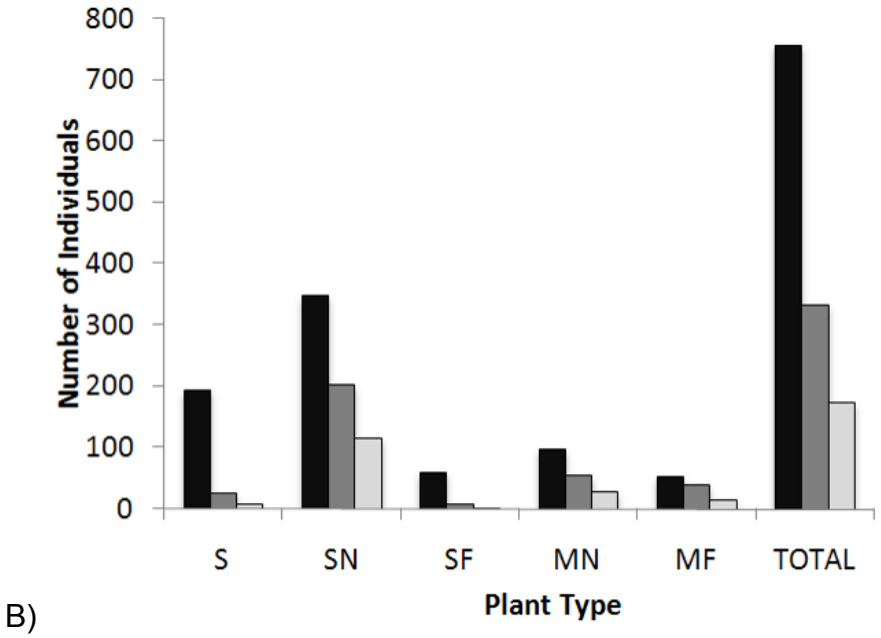
Fernald's Braya populations do not undergo extreme fluctuations.

Population Viability Analysis (PVA):

Stage-based transition matrices were created from demographic data collected from the permanently tagged plants between 1998 and 2006 and summarized into deterministic projections (i.e. model performs the same way for a given set of initial conditions and does not vary as a result of stochastic variables; Squires 2010). These projections suggest current and future (2008-2018) declines of 90% in both undisturbed and anthropogenically degraded populations (Figure 8) and that Fernald's Braya has 100% probability of going extinct in 80 years (Squires 2010). Management scenarios were explored by adjusting the survival rates to reflect removing the insect pest and pathogens threats. Removal of any one of these threats improved the population viability but did not increase the growth rate to or above one (i.e. a stable or increasing growth rate) (Appendix 1; Figure 8) (Squires 2010).



A)



B)

Figure 7. Number of Fernald's Braya (*Braya fernaldii*) individuals in each plant stage on A) undisturbed habitat and B) anthropogenically degraded habitat in 2008, 2010, and 2011. (Note: S = Seedling, SN = single rosette, non-flowering, SF = single rosette, flowering, MN = multiple rosette, non-flowering, and MF = multiple rosette, flowering).

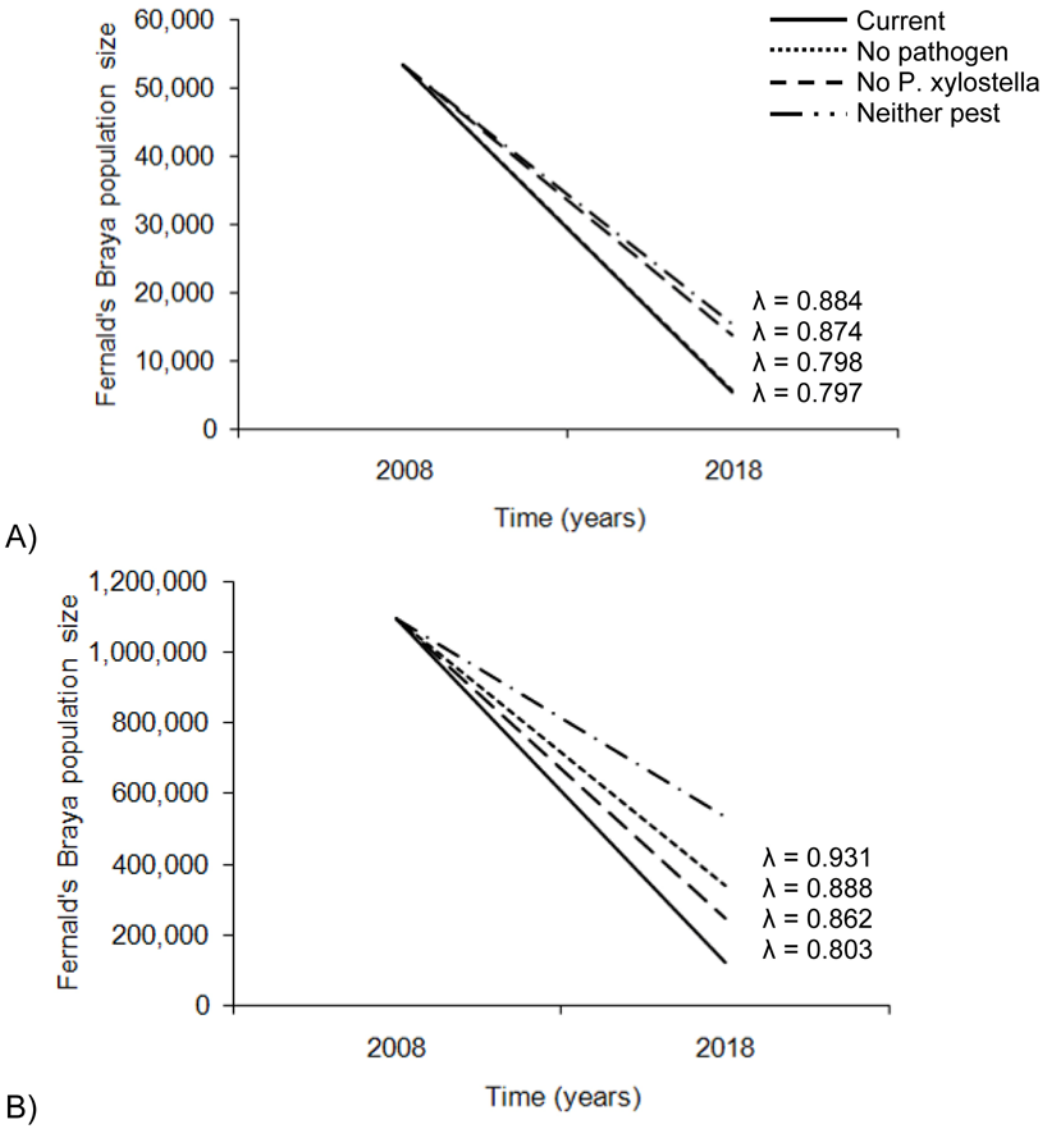


Figure 8. Deterministic growth rates (λ) and projected A) Fernald's Braya (*Braya fernaldii*) undisturbed and B) Fernald's Braya (*Braya fernaldii*) anthropogenically degraded population sizes for current and management models over a 10-year period. (Note: The population size includes all plant stages in the life cycle including seeds and seedlings) (used with permission from Squires 2010).

Rescue Effect

Rescue effect is not possible because Fernald's Braya is endemic to the island of Newfoundland.

THREATS AND LIMITING FACTORS

The draft recovery strategy for Fernald's Braya (Environment Canada 2012) and the provincial recovery plan for Fernald's Braya (Limestone Barrens Species-at-Risk Recovery Team *In Prep*) list 1) invasive insect herbivory, 2) pathogens, 3) habitat loss and degradation through gravel extraction, off-road vehicle use, road maintenance, maintenance and construction of utility corridors, local use of the limestone barrens, community expansion, and road construction, 4) change in habitat quality as a result of climate change altering frost-sorting processes, air temperature, and precipitation amounts, and 5) hybridization as threats to the viability of Fernald's Braya populations. Fernald's Braya is considered to occur at a single location. This is based on the combined threats of the invasive Diamondback Moth and a pathogen which annually infest/infect populations. In addition the effects of climate change are predicted to increasingly affect all individuals.

Invasive Insect Herbivory

The viability of Fernald's Braya populations is negatively affected by herbivory from an invasive, pesticide resistant, global agricultural pest, the Diamondback Moth (Figure 6c). Between 2003 and 2005, 16% of surveyed Fernald's Braya were damaged by the Diamondback Moth, causing seed set to decline by 29% and mortality rates to increase (Squires *et al.* 2009). On the closely related Long's Braya, larval feeding reduced mean seed output by up to 60%, from 10.8 - 4.3 seeds/fruit, and damaged 26% of leaves (Squires *et al*. 2009). For both Fernald's Braya and Long's Braya, plant mortality was related to the amount of leaf and fruit damage the year prior to death, as well as two or three years before the plant died (Squires *et al*. 2009). The impact of this insect on Fernald's Braya and Long's Braya represents one of the first documented impacts of an agricultural insect pest on a rare plant (Squires *et al.* 2009; Blitzer *et al*. 2012).

In 2011, only one flowering plant at the Burnt Cape Ecological Reserve was found infested with a Diamondback Moth egg and only one flowering plant in the Port au Choix National Historic Site was found infested with a Diamondback Moth larva. While the intensity of the annual Diamondback Moth infestation appears to fluctuate, all populations of Fernald's Braya are similarly affected within a given year, meaning that if the threat worsens it will worsen in all populations. Management scenarios explored with population viability models showed that a change in survival rates to mimic those not infested by this insect pest improved viability but did not increase the growth rate above 1 (i.e. a positive growth rate) (Figure 8) (Squires 2010).

Pathogens

The viability of Fernald's Braya populations is negatively affected by two pathogens. The first pathogen was recorded on Fernald's Braya in 1925 at Boat Harbour (Fernald 1950) and causes leaf and flower stalk deformities and increased pubescence (Figure 6a) (Hermanutz *et al*. 2002). The same characteristics were recorded in the Watts Point Ecological Reserve in 1995 (Meades 1997) and in the Burnt

Cape Ecological Reserve, Anchor Point, and Cape Norman populations in 2003 (Squires 2010). In 2011, symptoms of this pathogen were recorded on nine plants (two at Watts Point South, one at Cape Norman, and five at the Burnt Cape Ecological Reserve, and one at Boat Harbour). This represents 9% of the tagged plants surveyed, a decline from the average 27% of tagged plants infected each year between 2003 and 2005 in the same populations (Squires 2010). While the intensity of the annual infection rates appears to fluctuate, all populations of Fernald's Braya are influenced similarly within a given year, meaning that if the threat worsens it will worsen in all populations.

Mortality is significantly higher in infected plants, with 35% of infected plants dying the year following an infection, compared to only 18% of non-infected plants (Squires 2010). Infected plants do not contribute to annual seed production as flowering stalks are too deformed (Squires 2010). Management scenarios explored with population viability models showed that a change in survival rates to mimic those not infected by this pathogen improved viability but did not increase the growth rate above 1 (i.e. a positive growth rate) (Figure 8) (Squires 2010).

The second pathogen was recorded on Fernald's Braya in 2004 and causes the flowering stalks to become mouldy (Figure 6b) (Squires 2010). The symptoms always begin on a single fruit, turning the fruit from green to pink to white, and move up and down the flowering stalk until the entire stalk is white (Figure 6b). The flowering stalk subsequently develops mould, causing the seeds within the fruits to die (Squires 2010). This pathogen was first recorded infecting one Long's Braya population in 2003 and spread within one year to nearly all Fernald's Braya populations. Between 2003 and 2005, 2% of tagged Fernald's Braya were infected (Squires 2010), whereas in 2011 this pathogen was not observed on any tagged plant. The low infection rates of this pathogen (2% between 2003 and 2005) resulted in little reduction of survival and seed production (Squires 2010). The majority (66-100%) of both pathogen infections occurred in populations on anthropogenically degraded habitat. Because the dispersal mechanisms and factors (e.g. climate) controlling both these pathogens within or among populations is unknown, it is not clear whether or not the current infection rates can be expected to worsen or improve.

Habitat Loss and Degradation

Large-scale habitat loss has occurred on the limestone barrens as a result of quarrying for limestone, community expansion, road construction, and creation of utility corridors. Quarrying results in habitat destruction or severe habitat degradation. As a result of Fernald's Braya being legally listed under the Canadian *Species at Risk Act* and the Newfoundland and Labrador *Endangered Species Act*, quarry permits can only be obtained in areas where Fernald's Braya have not been found and areas of potential occurrence are checked prior to permit approval.

Road construction and community expansion within the distribution of Fernald's Braya began in the late 1960s and increased between 1975 and 1990 when Highway 430 and its side roads were paved and utility corridors installed (Janes 1999). The highway bisected some Fernald's Braya populations (e.g. Anchor Point). Since then, the Fernald's Braya population has been minimally impacted by the construction of new roads, communities, or utility corridors and maintenance of existing infrastructure is an ongoing threat. Operators of road maintenance equipment use the limestone barrens on either side of the roads to turn around or park vehicles (Environment Canada 2012). In 2006, 53% of Fernald's Braya in the long-term monitoring program (17/32 tagged plants) at Cape Norman were killed as a result of heavy machinery accessing a pole line (Hermanutz *et al*. 2006). In addition to direct mortality, this activity caused irreversible changes in natural hydrologic patterns within the site (Hermanutz *et al*. 2006). In 2011, NALCOR energy, a utility operator, chose Shoal Cove as a landing site for a cable that will extend under and across the Strait of Belle Isle to bring electricity from a Central Labrador Hydroelectric project to the Avalon Peninsula of Newfoundland. A pilot project, including testing horizontal drilling technology and the construction of a weather tower has occurred without impact to the Fernald's Braya population. Potential impacts of the full-scale project and mitigation options are being discussed as part of the ongoing environmental assessment.

These large-scale habitat disturbances left some areas of limestone barrens incapable of supporting Fernald's Braya while others were heavily degraded but still capable of supporting Fernald's Braya [see *Habitat Requirements].* Populations of Fernald's Braya on anthropogenically degraded habitat typically have higher reproductive output and grow in densities at least ten times those found in undisturbed habitat (Hermanutz *et al*. 2002). However, populations on degraded habitat are subject to higher rates of herbivory and pathogen pressure and experience altered population dynamics, including moving more quickly through their life cycle, having increased mortality rates, and relying more heavily on seed production and seedling survival to maintain long-term viability (Squires 2010; Appendix 1). There is concern that populations on anthropogenically degraded habitat may actually threaten the viability of populations on undisturbed habitat by acting as reservoirs from which pathogens can actively colonize them (Squires 2010).

Smaller scale disturbances, such as off-road vehicles, primarily dirt bikes, snowmobiles, trucks, and all terrain vehicles (ATV), as well as piling and cutting wood, continue to degrade habitat and destroy individual plants. Off-road vehicle damage is a threat throughout the limestone barrens but is especially severe within Port au Choix National Historic Site and at Cape Norman (Rafuse 2005). Populations on anthropogenically degraded habitat suffer fewer impacts because the substrate is already compacted, whereas populations on undisturbed habitat are very vulnerable to off-road vehicle damage, including trampling of individual plants, changes in hydrology due to water pooling in vehicle tracks, and substrate compaction (Rafuse 2005). The Newfoundland and Labrador Snowmobile Federation operates a snowmobile trail that runs through the Fernald's Braya population at Anchor Point. The creation of this trail in the late 1990s did degrade habitat but regular maintenance of the trail has resulted in

minimal problems because the federation has agreed to groom the trail only when there is two or more feet of snow. Land use surveys conducted from 2001-2007 in nine communities within the distribution of the limestone barrens (n = 845 surveys) found that 59-76% of respondents thought the use of off-road vehicles, particularly ATVs and dirt bikes, was causing the most damage to the limestone barrens, more than both limestone quarrying and community construction (House 2008).

Communities regularly dump garbage, pile and cut wood, and dry fishing nets on the limestone barrens. These activities can result in direct mortality of Fernald's Braya or decrease the quality of the habitat by leaving litter and a heavy sawdust layer. Stewardship initiatives have resulted in a decline in the drying of fish nets. However, wood piling and cutting still occur at the Green Island Brook population and resulted in the destruction and subsequent loss of Fernald's Braya within one permanent monitoring plot in 2010.

Climate Change

Summer and winter air temperatures on the limestone barrens increased from 1991 to 2002 (Donato 2005) and mean annual air temperature is predicted to increase 4ºC by 2080 across the entire distribution of Fernald's Braya (Slater 2005). Cumulative rainfall from May to August at the Sandy Cove Airstrip weather station (between the Anchor Point and Shoal Cove populations; Figure 3) in 2003 and 2004 was approximately 50% below the 30-year normal (1971-2000) (Squires 2010).

These climatic changes could alter the frost-sorting processes characteristic of the limestone barrens and thus decrease the amount of suitable substrate for Fernald's Braya. The porous soils of the limestone barrens increase the impact of desiccation during dry summers or winters with particularly sparse snow cover (Burzynski 2011). Climate change may also affect the distribution and abundance of pathogens and the Diamondback Moth. The survival rate of Diamondback Moth increases and generation time decreases with an increase in air temperature (Talekar and Shelton 1993). Warming temperatures and reduced precipitation in 2004 and 2005 allowed the Diamondback Moth to produce multiple generations thus reducing seed productivity and, consequently, population viability (Squires *et al*. 2009).

Hybridization

Fernald's Braya is closely related to Long's Braya and to Smooth Northern Rockcress (*Braya glabella*) and it appears to have a hybrid origin (Warwick *et al*. 2004). Pollination studies found that Fernald's Braya fruit set was low (25%) and seed set was 0% after pollination with Long's Braya (Parsons and Hermanutz 2006). However, the same pollination studies found that Long's Braya fertilized with Fernald's Braya pollen was capable of producing fruit and viable seed (Parsons and Hermanutz 2006). Parsons (2002) noted that outliers in her morphological and reproductive studies were in anthropogenically degraded populations where the two species were in closest proximity to each other (i.e. Shoal Cove and Anchor Point). Until road construction

created degraded habitat these species were not known to co-occur and there was no indication of hybridization (Parsons and Hermanutz 2006). In order for natural hybridization to occur, both species must be in close proximity to one another as pollen is dispersed by wind. Because both species persist by self-pollination, hybrids would likely persist (Parsons and Hermanutz 2006).

PROTECTION, STATUS, AND RANKS

Legal Protection and Status

Fernald's Braya is listed as Threatened on Schedule 1 of the Canadian *Species at Risk Act*, and is found within the federally protected Port au Choix National Historic Site (Environment Canada 2011). Fernald's Braya is also listed as Threatened under Newfoundland and Labrador's *Endangered Species Act* and is found within the provincially protected Watt's Point Ecological Reserve and Burnt Cape Ecological Reserve.

In 2002, the *National Recovery Plan for Long's Braya and Fernald's Braya* was written (Hermanutz *et al.* 2002). Since then, many recovery actions for Fernald's Braya have been implemented including creation of the Burnt Cape Ecological Reserve, evaluation of the seed bank, a population viability analysis, establishment of an *ex situ* conservation program, and establishment of a local stewardship and education program (Limestone Barrens Species-at-Risk Recovery Team *In Prep*). Updates to this recovery document have recently been released or will soon be; *Long's Braya and Fernald's Braya Recovery Strategy* (Environment Canada 2012), the *Long's Braya and Fernald's Braya Action Plan,* and the *Limestone Barrens Ecosystem Recovery Plan* (Limestone Barrens Species-at-Risk Recovery Team *In Prep*) will be available.

Non-Legal Status and Ranks

Fernald's Braya is ranked by NatureServe as globally Critically Imperilled (G1), nationally Critically Imperilled (N1), and Critically Imperilled (S1) on the island of Newfoundland (NatureServe 2010; Anions pers. comm. 2011). Fernald's Braya has also been ranked provincially At Risk (CESCC 2011).

Habitat Protection and Ownership

Fernald's Braya is not known to occur on private land. All known occurrences are on provincial crown land, federal crown land, or within municipal limits and are identified as critical habitat within the draft *Long's Braya and Fernald's Braya Recovery Strategy* (Environment Canada 2012) and the draft *Limestone Barrens Ecosystem Recovery Plan* (Limestone Barrens Species-at-Risk Recovery Team *In Prep*). Critical habitat within Port au Choix National Historic Site is legally protected by the *Historic Sites and Monuments Act* and the *Species at Risk Act* (Parks Canada 2007). Fernald's Braya on provincial crown land adjacent to the Port au Choix National Historic Site is protected

through a habitat stewardship agreement signed in 2009 by the Government of Newfoundland and Labrador and the Town of Port au Choix. Efforts are currently underway to protect the Cape Norman Department of Fisheries and Oceans critical habitat by a ministerial order. It is possible to legally protect critical habitat under the Newfoundland and Labrador *Endangered Species Act,* although this has not yet been done for any Fernald's Braya population.

Fernald's Braya populations are legally protected within the Burnt Cape Ecological Reserve and the Watts Point Ecological Reserve under the Newfoundland and Labrador *Wilderness and Ecological Reserves Act,* specifically the *Burnt Cape Ecological Reserve Order* and the *Watts Point Ecological Reserve Order.* Destruction of critical habitat within these provincial protected areas is prohibited through regulations that prevent the use of motorized vehicles or equipment, the removal or disturbance of substrate, development of infrastructure, disposal of garbage, etc.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

The author wishes to offer a sincere thanks to S.J. Meades who wrote the original Fernald's Braya status report, as it provided the base on which so much Fernald's Braya and limestone barrens research has been completed. Guidance and support was provided by members of the Limestone Barrens Species-at-Risk Recovery Team and volunteer field assistance was provided by L. Squires. Special thanks to the K. Timm (COSEWIC Secretariat), J. Wu (COSEWIC Secretariat), and B. Bennett (Vascular Plant SSC) who provided managerial and technical support to the project. Funding for this report and associated fieldwork was provided by Environment Canada.

Authorities Contacted

Amirault-Langlais, D. Senior Social Science Analyst, Canadian Wildlife Service, Environment Canada and COSEWIC Contact. Sackville, New Brunswick, Canada.

Anions, M. Director of Science, NatureServe Canada. Ottawa, Ontario.

Blaney, S. Botanist/ Assistant Director, Atlantic Canada Conservation DataCentre (regional office). Sackville, New Brunswick,Canada.

Burzynski, M. Vegetation Biologist, Parks Canada Agency. Rocky Harbour, Newfoundland and Labrador, Canada.

Djan-Chékar, N. Curator of Natural History, Provincial Museum Division (The Rooms). St. John's, Newfoundland and Labrador, Canada.

Durocher, A. Data Manager, Atlantic Canada Conservation Data Centre (NL office). Corner Brook, Newfoundland and Labrador, Canada.

Eaton, S. Wildlife Biologist, Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick, Canada.

Hanel, C. Botanist, Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada.

Hermanutz, L. Professor, Memorial University of Newfoundland and Co-Chair of the Limestone Barrens Species-at-Risk Recovery Team. St. John's, Newfoundland and Labrador, Canada.

House, D. Project Manager, Limestone Barrens Habitat Stewardship Program. River of Ponds, Newfoundland and Labrador, Canada.

Jones, N. Aboriginal Traditional Knowledge Coordinator, COSEWIC. Gatineau, Québec, Canada.

Limestone Barrens Species-at-Risk Recovery Team. 2011 Recovery Team Meeting. Cape St. George, Newfoundland and Labrador, Canada.

Moores, S. Senior Manager, Department of Environment and Conservation, Government of Newfoundland and Labrador and COSEWIC Contact. Corner Brook, Newfoundland and Labrador, Canada.

Nantel, P. Conservation Biologist, Parks Canada and COSEWIC Contact. Gatineau, Québec, Canada.

Raillard, M. Manager, Population Conservation, Canadian Wildlife Service. Environment Canada. Sackville, New Brunswick, Canada.

Skinner, R. Data Manager, Atlantic Canada Conservation Data Centre (NL office). Corner Brook, Newfoundland and Labrador, Canada.

Spence, M. Manager, Port au Choix National Historic Site, Parks Canada Agency. Port au Choix, Newfoundland and Labrador, Canada.

Thomas, P. Biologist, Canadian Wildlife Service, Environment Canada. St. John's, Newfoundland and Labrador, Canada.

INFORMATION SOURCES

Banfield, C.E., and J.D. Jacobs. 1983. Regional patterns of temperature and precipitation for Newfoundland and Labrador during the past century. The Canadian Geographer 42: 353-364.

Blitzer, E.J., C.F. Dormann, , A. Holzschuh, A.M. Klein, T.A. Rand, and T. Tscharntke. 2012. Spillover of functionally important organisms between managed and natural habitats. Agriculture, Ecosystems and Environment 146: 34-43.

Burzynski, M. 2011. Results of the 2011 *Braya fernaldii* survey at Port au Choix National Historic Site. Field Report for Parks Canada. Rocky Harbour, Newfoundland and Labrador, Canada. 3 pp.

Canadian Endangered Species Conservation Council (CESCC). 2011. Wild Species 2010: The General Status of Species in Canada. National General Status Working Group. Ottawa, Ontario, Canada. 302 pp.

Djan-Chékar, N., and C. Hanel. 2004. The Newfoundland rare plant project: Including an update to the rare vascular plants of the Island of Newfoundland. Department of Environment and Conservation, Government of Newfoundland and Labrador. Web site: www.env.gov.nl.ca/env/publications/wildlife/index.html#rpp [accessed August 2011].

Donato, E. 2005. Climatology of the limestone barrens, Northern Peninsula, Newfoundland: Implications for rare plant phenology and distribution. M.Sc. Dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 88 pp.

Driscoll, J. 2006. *Ex situ* conservation protocols for the persistence of *Braya longii* (endangered), *Braya fernaldii* (threatened) and *Salix jejuna* (endangered) endemic to the limestone barrens of Newfoundland. M.Sc. dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 126 pp.

Environment Canada. 2012. Recovery Strategy for Long's Braya (*Braya longii*) and Fernald's Braya (*Braya fernaldii*) in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada. Ottawa, v + 38 p. http://publications.gc.ca/collections/collection_2012/ec/En3-4-119-2012-eng.pdf

Good-Avila, S., pers. comm. 2008. *Email correspondence to S. Squires* and draft report titled "Population Genetic Structure of Long's and Fernald's Braya in Newfoundland". March 2008. University of Winnipeg. Winnipeg, Manitoba, Canada.

Greene, S. 2002. Substrate characteristics of *Braya* habitat on the limestone barrens, Great Northern Peninsula, Newfoundland. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 71 pp.

Harris, J.G. 1985. A revision of the genus *Braya* (Cruciferae) in North America. Ph.D. dissertation. University of Alberta. Edmonton, Alberta, Canada. 250 pp.

Hermanutz, L.A., H. Mann, M.F.E. Anions, D. Ballam, T. Bell, J. Brazil, N. Djan- Chékar, G. Gibbons, J. Maunder, S.J. Meades, W. Nicholls, N. Smith, and G. Yetman. 2002. National Recovery Plan for *Braya longii* and *Braya fernaldii*. National Recovery Plan No. 23. Recovery of Nationally Endangered Wildlife. Ottawa, Ontario, Canada. 38 pp.

Hermanutz, L., S. Squires, and D. Pelley. 2009. 2008 Limestone barrens research report. Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada. 67 pp.

Hermanutz, L., S. Tilley, J. Kemp, J. Robinson, T. Bell, P. Dixon, and W. Nicholls. 2006. Threat assessment and science-based management options for rare plants of the limestone barrens. Endangered Species Recovery Fund. Toronto, Ontario, Canada. 17 pp.

Janes, H. 1999. *Braya longii* (Long's Braya), *Braya fernaldii* (Fernald's Braya) and disturbance on Newfoundland's Great Northern Peninsula. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 44 pp.

House, D. 2008. Limestone Barrens land and community use awareness surveys. Limestone Barrens Habitat Stewardship Program. River of Ponds, Newfoundland and Labrador, Canada. 25 pp.

Limestone Barrens Habitat Stewardship Program. 2007. Limestone Barrens Conservation and Sustainable Ecotourism Workshop Summary. River of Ponds, Newfoundland and Labrador, Canada. 12 pp.

Limestone Barrens Species-at-Risk Recovery Team. 2004. Procedure for determining critical habitat for Long's braya, Fernald's braya and Barrens willow. Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada. 3 pp.

Limestone Barrens Species-at-Risk Recovery Team. *In prep.* Recovery Plan for the Limestone Barrens Ecosystem in Newfoundland and Labrador. Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada.

Meades, S.J. 1997. Status report on Fernald's Braya (*Braya fernaldii*) in Canada. Report for the Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario, Canada. 24 pp.

NatureServe. 2010. NatureServe Explorer: An online encyclopedia of life [web application]. Version 6.2. NatureServe, Arlington, Virginia, United States. Web site: www.natureserve.org/explorer [accessed August 2011].

Noel, L. 2000. The effect of disturbance on the seedling recruitment and persistence of *Braya longii* and *Braya fernaldii*. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 94 pp.

Parks and Natural Areas Division. 1990. Watts Point Ecological Reserve Management Plan. Department of Environment and Conservation, Government of Newfoundland and Labrador. St. John's, Newfoundland and Labrador, Canada. 25 pp.

Parks and Natural Areas Division. 2000. Burnt Cape Ecological Reserve Management Plan. Department of Environment and Conservation, Government of Newfoundland and Labrador. St. John's, Newfoundland and Labrador, Canada. 60 pp.

Parks and Natural Areas Division. 2007. Ecoregions of Newfoundland and Labrador. Department of Environment and Conservation, Government of Newfoundland and Labrador. Web site: www.env.gov.nl.ca/env/parks/maps/ecoregions_nf_lab.pdf [accessed August 2011].

Parks Canada. 2007. Port au Choix National Historic Site of Canada: Management Plan. Parks Canada Agency. Ottawa, Ontario, Canada. 47pp.

Parsons, K. 2002. Using reproductive characters to distinguish between the closely related, rare endemics, *Braya longii* and *B. fernaldii.* Masters dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 127 pp.

Parsons, K., and L. Hermanutz. 2006. Conservation of rare, endemic *Braya* species (Brassicaceae): Breeding system variation, potential hybridization, and human disturbance. Biological Conservation 128: 201-214.

Rafuse, G. 2005. The impact of off-road vehicles on the limestone barrens habitat and resident plants endemic to the Great Northern Peninsula, Newfoundland, Canada. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada.

Slater, J. 2005. Statistical downscaling of temperature and precipitation for climate change impact assessment of rare plants on the limestone barrens of Northwestern Newfoundland. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 72 pp.

Squires, S.E. 2010. Insect pests and pathogens compromise the persistence of two endemic and rare *Braya* (Brassicaceae). Ph.D. dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 184 pp.

Squires, S.E., L. Hermanutz, and P.L. Dixon. 2009. Agricultural insect pest compromises survival of two endemic *Braya* (Brassicaceae). Biological Conservation 142: 203 -211.

SSAC. 2004. The Status of Low Northern Rockcress (*Neotorularia humilis)* in Newfoundland and Labrador. Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada. 8 pp.

SSAC. 2006. The Status of Mackenzie's Sweetvetch (*Hedysarum boreale* subsp. *mackenzii)* in Newfoundland and Labrador. Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, Newfoundland and Labrador, Canada. 15 pp.

Talekar, N.S., and A.M. Shelton.1993. Biology, ecology, and management of the diamondback moth. Annual Reviews of Entomology 38: 275-301.

Tilley, S. [Squires] 2003. The factors governing the distribution of the rare plants *Braya longii* and *Braya fernaldii* (Brassicaceae) in natural habitats. B.Sc. Honours dissertation. Memorial University of Newfoundland. St. John's, Newfoundland and Labrador, Canada. 42 pp.

Warwick, S.I., I.A. Al-Shehbaz, C. Sauder, J.G. Harris, and M. Koch. 2004. Phylogeny of *Braya* and *Neotorularia* (Brassicaceae) based on nuclear ribosomal internal transcribed spacer and chloroplast *trn* intron sequences. Canadian Journal of Botany 82: 376-392.

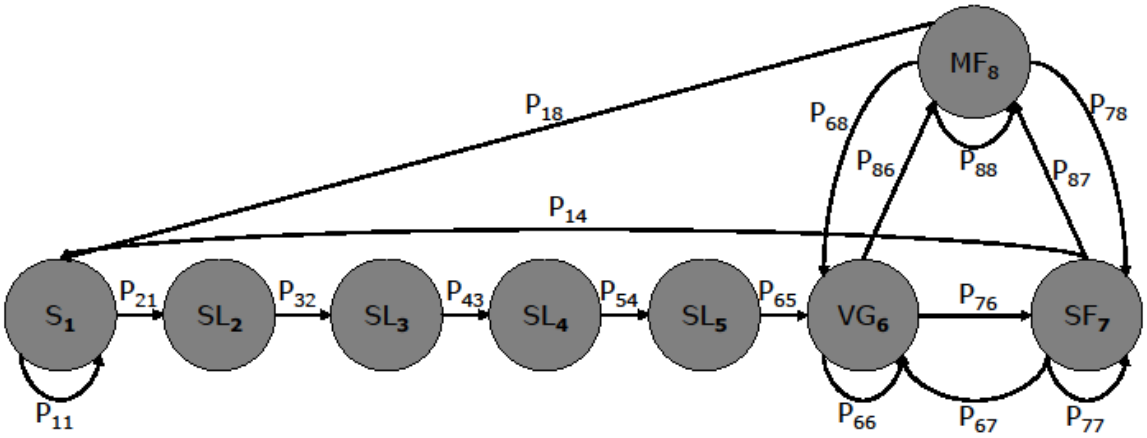
BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Susan (Tilley) Squires, B.Sc., Ph.D., has worked on Fernald's Braya since 2002. She completed her undergraduate and graduate research on Long's Braya and Fernald's Braya and the Limestone Barrens ecosystem. She is now Senior Manager, Stewardship & Education with the Department of Environment and Conservation, Government of Newfoundland and Labrador. She is the author of several scientific papers regarding Fernald's Braya and is co-chair of the Limestone Barrens Species-at-Risk Recovery Team and chair of the Wild Cove Fen Recovery Team.

COLLECTIONS EXAMINED

No collections were examined by the current report writer. Vouchers from Fernald's Braya populations were verified in preparation for the previous status report by S.J. Meades (1997).

Appendix 1. Stage specific transition coefficients for all life stages of *Braya fernaldii* (Squires 2010)



Generalized lifecycle diagram of *Braya fernaldii*. The coefficients **P_{ij} correspond to the probability that an individual in stage j at time t will transition to the stage i at time t+1.** For example P_{21} = the probability that an individual at stage 1 (seed) would germinate and transition to stage 2 (seedling). Note that some stages can persist (P11 = seed will stay as a seed, which represents a seed bank), and that plants can retrogress (i.e. flowering individuals (SF or MF) can become vegetative (VG)). Stages: S- seed, SL- seedling, VG- vegetative growth, SF- single rosette, flowering plant, and MF- multiple rosettes, flowering plant. See transition table below for the actual stage-specific transition coefficients. (Used with permission from Squires 2010).

The stage based, transition matrices for A) *Braya fernaldii* undisturbed and B) *B. fernaldii* anthropogenically disturbed outlining **the probabilities that an individual at stage x, time t will move to stage y, time t+1 and the stage fecundity.** Stages: S- seed, SL- seedling, VG- vegetative growth, SF- single rosette, flowering plant, and MF- multiple rosettes, flowering plant.

A)

Stage	S	SL 1	SL 2	SL 3	SL 4	VG	SF	MF
S	0.001	-	-	-	-	-	51.74	259.04
SL 1	0.005	-	-	-	-	-	-	-
SL 2	-	0.67	-	-	-	-	-	-
SL 3	-	-	0.67	-	-	-	-	-
SL 4	-	-	-	0.83	-	-	-	-
VG	-	-	-	-	0.79	0.53	0.39	0.14
SF	-	-	-	-	-	0.11	0.18	0.08
MF	-	-	-	-	-	0.03	0.11	0.39

B)

Stage	S	SL 1	SL 2	SL 3	SL 4	VG	SF	MF
S	0.001	-	-	-	-	-	107.10	1393.18
SL 1	0.004	-	-	-	-	-	-	-
SL 2	-	0.67	-	-	-	-	-	-
SL 3	-	-	0.67	-	-	-	-	-
SL 4	-	-	-	0.83	-	-	-	-
VG	-	-	-	-	0.79	0.22	0.24	0.05
SF	-	-	-	-	-	0.11	0.10	0.04
MF	-	-	-	-	-	0.07	0.13	0.18

The elasticity matrices for A) *Braya fernaldii* undisturbed and B) *B. fernaldii* anthropogenically disturbed. **Values in bold represent the vital rates that had the largest proportional impact on the population growth rate**. Stages: S- seed, SL- seedling, VG- vegetative growth, SF- single rosette, flowering plant, and MF- multiple rosettes, flowering plant.

A)

Stage	S	SL 1	SL 2	SL 3	SL 4	VG	SF	MF
S	0.0100	0	0	0	0	0	0.0189	0.0607
SL 1	0.0796	0	0	0	0	0	0	0
SL 2	0	0.0796	0	0	0	0	0	0
SL 3	0	0	0.0796	0	0	0	0	0
SL 4	0	0	0	0.0796	0	0	0	0
VG	0	0	0	0	0.0796	**0.2300**	0.0324	0.0075
SF	0	0	0	0	0	**0.0755**	0.0237	0.0068
MF	0	0	0	0	0	0.0440	0.0309	0.0704

B)

Stage	S	SL 1	SL 2	SL 3	SL 4	VG	SF	MF
S	0.0015	0	0	0	0	0	0.0100	**0.1138**
SL 1	**0.1238**	0	0	0	0	0	0	0
SL 2	0	**0.1238**	0	0	0	0	0	0
SL 3	0	0	**0.1238**	0	0	0	0	0
SL 4	0	0	0	**0.1238**	0	0	0	0
VG	0	0	0	0	**0.1238**	0.0470	0.0080	0.0015
SF	0	0	0	0	0	0.0421	0.0059	0.0021
MF	0	0	0	0	0	0.0911	0.0263	0.0319