COSEWIC
Assessment and Status Report

on the

Porter's Twisted Moss
Tortula porteri

in Canada

NOT AT RISK
2016

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:

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Porter's Twisted Moss — Photo provided by author.

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COSEWIC
Assessment Summary

Assessment Summary – May 2016

Common name
Porter's Twisted Moss

Scientific name
Tortula porteri

Status
Not at Risk

Reason for designation
This species occupies a small proportion of exposed, weathered limestone surfaces in southernmost Ontario on the Niagara Peninsula and on Pelee Island. It is a small pioneer species with poor competitive ability. The highly restricted potential habitat of the species falls within an intensively populated and developed region and is generally subject to ongoing threats (quarrying, recreational use, air pollution, climate change). It has been extirpated from Middle Island due to the effects of Double-crested Cormorant. However, it has persisted in some natural areas for over 100 years and the probability that the species risks extinction in the near future is believed to be low.

Occurrence
Ontario

Status history
Designated Not at Risk in April 2016.

COSEWIC
Executive Summary

Porter's Twisted Moss
Tortula porteri

Wildlife Species Description and Significance

Porter's Twisted Moss (*Tortula porteri*) is part of the largely temperate moss family Pottiaceae. The leafy plants, which form thin turfs on calcareous rock surfaces, reach just 1 – 3 mm in height. They often bear erect, narrow, cylindrical spore capsules on stalks measuring up to 10 mm, which increases their detectability. Male and female reproductive structures are formed on separate plants. Porter's Twisted Moss is distinguished from similar, related species by microscopic and chemical characteristics.

The oldest Canadian specimens were collected in 1882, and the known Canadian range places this species among the suite of Carolinian species that reach their northern range limit in the southernmost parts of Ontario.

Distribution

In North America, Porter's Twisted Moss is known from the Eastern Deciduous Forest region. It occurs largely west of the Appalachian Mountains and east of the Great Plains, from Vermont west to Kansas and south to Mississippi. In southern Ontario, it is known from two Palaeozoic limestone regions of southern Ontario: the southern Niagara Escarpment, and Pelee and Middle Islands. Its presence on Quebec's Gaspé Peninsula, as suggested by two herbarium-based records, is doubtful. There is one documented location outside North America, in Venezuela.

Habitat

In Canada, Porter's Twisted Moss grows on weathered, porous calcareous rock that is free of other plant competitors, particularly on vertical and steeply sloping or undercut faces and in pits or protected depressions. It has been found on limestone and dolostone cliffs and boulders, as well as quarried rock forming walls and other human structures. These rock substrates are in a wide variety of habitats: dry, exposed sites, damp, rich forests, and water-washed lakeshores. Where canopy trees are present, they are usually deciduous. In Canada, an extremely small proportion of the available calcareous rock is occupied by Porter's Twisted Moss. This suggests that additional factors may naturally limit its local scale distribution.

The northern range limit of Porter's Twisted Moss appears to coincide with climate and geological boundaries. It has not been found north of the Hamilton area, where Niagara Escarpment rock exposures become more distant from the Carolinian life zone and from the moderating influence of the Great Lakes.

Biology

No studies on the biology of Porter's Twisted Moss are known. All dioicous mosses depend on water for the swimming sperm of male plants to achieve successful fertilization of female plants. Most colonies in herbarium collections bear capsules, suggesting that successful sexual reproduction is not rare. One spore capsule is produced per plant in a reproductive cycle. Several other features, including its minute size and apparent intolerance of competition, are consistent with an annual life cycle. Spores are likely dispersed in air and, to a lesser extent, in water. Plant fragments dislodged by animals or erosion are capable of regenerating into mature plants.

Once established, rock-dwelling mosses can survive drought, resuming growth within seconds of contact with water. Porter's Twisted Moss is associated with calcium-rich rocks, and may therefore respond negatively to acidity.

Population Sizes and Trends

The size of the Canadian population, within its very limited Canadian distribution, is unknown. To date, sampling has not been tailored to the life history of Porter's Twisted Moss, which may fluctuate with disturbance and other factors. Much potentially suitable habitat on Niagara Escarpment cliffs is difficult to search. The tendency of Porter's Twisted Moss to occur in small patches in extensive rock-dominated habitats makes its local abundance difficult to quantify. No trend data are known for Canada or the US. However, Porter's Twisted Moss has been present at two Canadian sites (Niagara Glen, Pelee Island) for more than 100 years. It has been extirpated or drastically reduced on Middle Island since it was first collected there in the 1980s.

Threats and Limiting Factors

The overall threat impact on Porter's Twisted Moss, as assessed using the IUCN-CMP Threats Classification Scheme, is low. This species could be negatively affected by human activities such as mining and quarrying, recreational activities (particularly rock climbing), and airborne pollutants. A small proportion of the Canadian population is affected by problematic native species (Double-Crested Cormorants on Middle Island). Intrinsic factors such as climate tolerance and substrate requirements are thought to naturally limit the occurrence of Porter's Twisted Moss, and climate change may have severe long-term effects on this species. Thirteen locations are known to date.

Protection, Status and Ranks

Porter's Twisted Moss is ranked "G3?" (possibly globally vulnerable). It is ranked N1 (critically imperilled) in Canada, and is not ranked in the United States. It is ranked S1 in Ontario, SU in Quebec, and SH in New York and Vermont, although some New York collections were made near Niagara Falls in the mid-1980s. Most known Canadian populations of Porter's Twisted Moss are within protected areas or along public trails, which may reflect the greater accessibility of these sites rather than the effect of habitat protection.

TECHNICAL SUMMARY

Tortula porteri

Porter's Twisted Moss

Tortule méridionale

Range of occurrence in Canada (province/territory/ocean): Ontario

Demographic Information

Generation time (usually average age of parents in the population)	Undocumented, but probably 1 year
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No trend data available
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	No trend data available
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	No trend data available
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	No trend data available
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	No trend data available
Are the causes of the decline a.clearly reversible and b.understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown, but probably not
Estimated extent of occurrence	6416 km^2 of which 50% is in water (Lake Erie), and just 65.1 km^2 is characterized by suitable natural Palaeozoic bedrock habitat
Index of area of occupancy (IAO) (Always report 2x2 grid value).	60 km^2; The species depends on exposed Palaeozoic bedrock with an extent of just 65.1 km^2 in the species' known range. The species occurs in a very small proportion of this generally suitable area. Thus, effective AO cannot exceed 500 km^2.
Is the population "severely fragmented" ie. is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	No
Number of "locations"□ (use plausible range to reflect uncertainty if appropriate)	At least 13

□See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term.

Is there an [observed, inferred, or projected] decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, inferred from declining habitat
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Yes, inferred from declining habitat
Is there an [observed, inferred, or projected] decline in number of “locations”?	Yes, inferred from declining habitat
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes
Are there extreme fluctuations in number of subpopulations?	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 subpopulation)

Subpopulations (give plausible ranges)	Number of Mature Individuals
	Unknown. 13 occurrences / locations are documented, but number of mature individuals is only known for three of these (Table 1), where fewer than 10 colonies were present.
Total	No estimates available

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not calculated

Threats (actual or imminent, to populations or habitats, from highest impact to least)

- Mining and quarrying (ongoing within Canadian range)
- Recreational activities (particularly rock climbing, ongoing on Niagara Escarpment)
- Problematic native species (Double-crested Cormorants on Middle Island)
- Airborne pollutants (pervasive in southern Ontario)
- Landslides

Was a threats calculator completed for this species and if so, by whom? YES

D. Fraser (discussion chair), R. Belland (SSC Co-chair), J. Doubt (report co-writer), R. Boles (CWS), E. Snyder (Ontario), R. Caners (SSC member), K. Golinski (SSC member)

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Unknown
Is immigration known or possible?	Possible, especially from Niagara Falls NY and US Lake Erie Islands.

Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?*	Yes
Are conditions for the source population deteriorating? *	Probably
Is the Canadian population considered to be a sink?*	No
Is rescue from outside populations likely?	Unknown

Data Sensitive Species

Is this a data sensitive species? No

Status History

COSEWIC: Designated Not at Risk in April 2016

Status and Reasons for Designation

Status: Not at Risk	**Alpha-numeric codes:** Not applicable
Reasons for designation: This species occupies a small proportion of exposed, weathered limestone surfaces in southernmost Ontario on the Niagara Peninsula and on Pelee Island. It is a small pioneer species with poor competitive ability. The highly restricted potential habitat of the species falls within an intensively populated and developed region and is generally subject to ongoing threats (quarrying, recreational use, air pollution, climate change). It has been extirpated from Middle Island due to the effects of Double-crested Cormorant. However, it has persisted in some natural areas for over 100 years and the probability that the species risks extinction in the near future is believed to be low.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Does not apply. There are insufficient data to quantitatively assess decline.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not apply. Although the IAO is below the threshold for Endangered, the number of currently known locations (13) approaches the threshold for Threatened and declines in area and suitability of habitat are observed and projected, they are not severely fragmented, the species isn't subject to severe fluctuations and additional locations may be discovered with future search effort.
Criterion C (Small and Declining Number of Mature Individuals): Does not apply. The number of mature individuals is unknown.
Criterion D (Very Small or Restricted Population): Does not apply. Although the IAO is in the same order of magnitude as the threshold for D2, ongoing decline is expected but not within 1-2 generations. As well, the number of mature individuals is unknown and the number of locations exceeds the threshold.
Criterion E (Quantitative Analysis): Does not apply. No quantitative analysis has been conducted.

* See Table 3 (Guidelines for modifying status assessment based on rescue effect).

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
(2016)

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 and Climate Change Canada
Canadian Wildlife Service
Environnement et Changement climatique Canada
Service canadien de la faune
Canada

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

COSEWIC Status Report

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Porter's Twisted Moss

Tortula porteri

in Canada

2016

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

English Names: Porter's Twisted Moss, Porter's Screw Moss

French Name: Tortule méridionale

Scientific name: *Tortula porteri* (James) Broth.

Basionym: *Desmatodon porteri* James *in* Austin

Synonyms: *Barbula subcarnifolia* C. Müll. & Kindb. *in* Macoun & Kindb.
Barbula porteri (James) Kindb.
Barbula porteri subsp. *subcarnifolia* (Müll. Hal. & Kindb.) Kindb.
Desmatodon fisherae H.A. Crum
Desmatodon subcarnifolius (Müll. Hal. & Kindb.) Gier
Tortula porteri subsp. *subcarnifolia* (Müll. Hal. & Kindb.) Broth.
Tortula subcarnifolia (Müll. Hal. & Kindb.) Paris

Porter's Twisted Moss belongs to the large, principally temperate moss family, Pottiaceae. Many members of the Pottiaceae are adapted to harsh, dry environments.

The oldest Canadian specimens, collected in 1882 by Macoun (1892), were type specimens of *Barbula subcarnifolia*, which was later placed into synonymy with *Tortula porteri*.

Porter's Twisted Moss is named for the collector of the type specimen, Thomas Conrad Porter (1822-1901), a Pennsylvania pastor and natural sciences professor (Britton 1901). The long, spirally twisting peristome teeth of some *Tortula* species form a tapered, "screw"-like cylinder, from which the genus' common name (Twisted Moss) is derived. Porter's Twisted Moss does not display this trait.

Morphological Description

Detailed descriptions of Porter's Twisted Moss may be found in Crum and Anderson (1981, as *Desmatodon porteri*), Zander (2007) and Faubert (2013). Illustrations are presented in Figure 1, and photographs are provided in Figure 2.

Leafy, green plants (gametophytes) reach 1-3 mm in height, forming thin light- to dark-green turfs. They are differentiated from similar small mosses by the presence of features such as flat, untoothed leaf margins bordered by cells that are slightly larger and paler, with fewer papillae, than the interior laminal cells. These features can be seen with a high-powered hand lens, though they must be confirmed with a microscope.

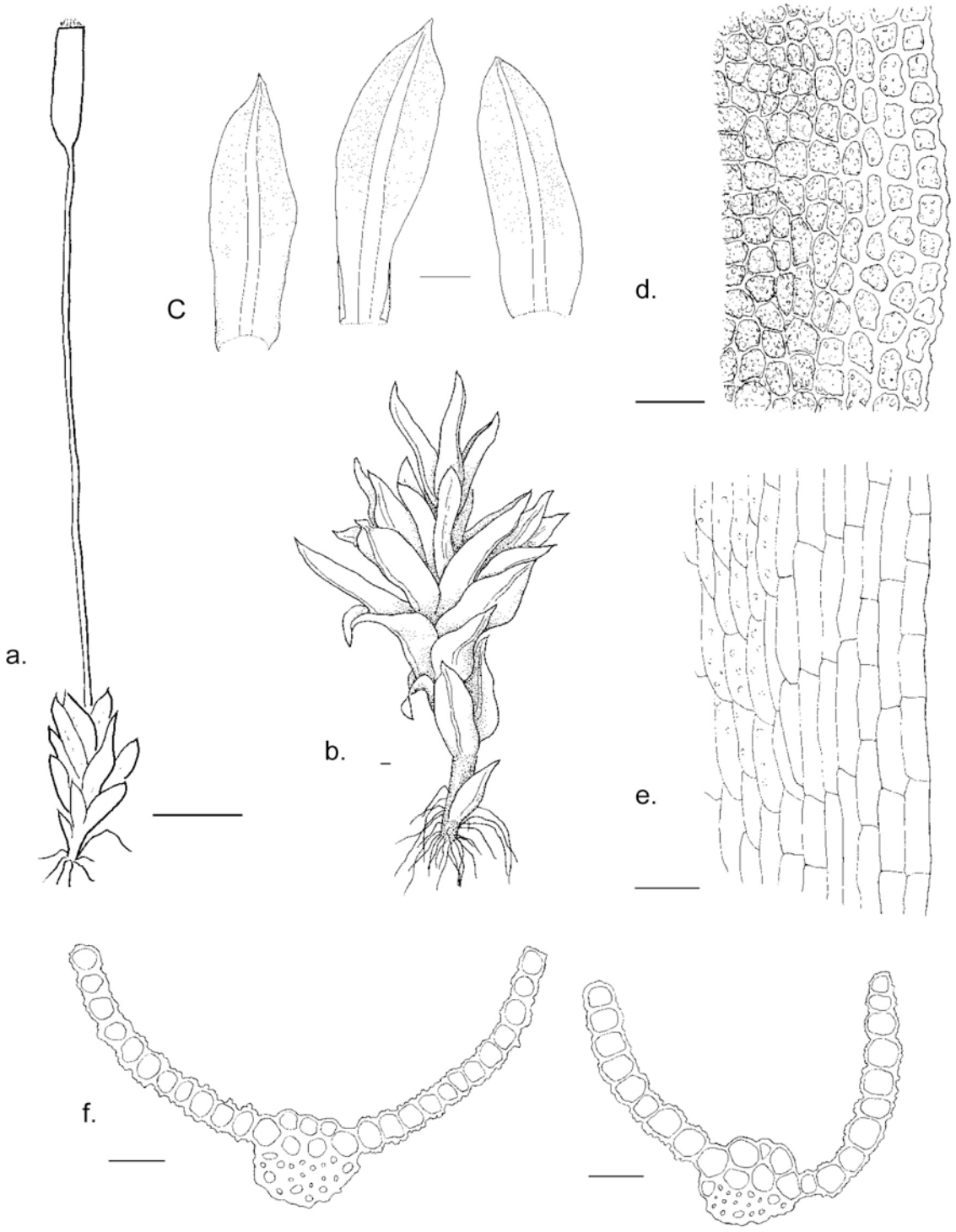

Figure 1. Illustrations of Porter's Twisted Moss (*Tortula porteri*): a. Whole plant with mature capsule (bar = 1.25 mm); b. Gametophyte (whole vegetative plant; bar = 0.25 mm); c. Leaves (bar = 125µm); d. Lower marginal leaf cells (bar = 25µm); e. Median marginal leaf cells (bar = 25µm); f. Leaf cross-sections (bar = 25µm). Illustrated by Linda Ley. Illustrations a. and b. are reproduced from Faubert 2013.

Figure 2. Photographs of Porter's Twisted Moss (*Tortula porteri*) in typical situations: a. on dry rock, such as b. the rocks ringing a former fire pit, c. on a damp rock of a d. forested cliff, and e. in the pit of f. a lakeshore boulder. Photos by J. Doubt, taken in southern Ontario in 2014.

Male and female reproductive structures are produced on separate plants. Following successful fertilization, a single, 4-10 mm stalk supporting a spore capsule (sporophyte) develops at the apex of each female plant. Spores of Porter's Twisted Moss are smaller than average for moss spores, measuring 8-10 µm.

Porter's Twisted Moss is most likely to be confused with another member of the Pottiaceae, Heim's Pottia (*Hennediella heimii*), from which it differs in lacking marginal teeth on the leaves and in having thicker median leaf cell walls (resulting in a less flaccid overall aspect). The application of 2% KOH solution turns the leaf cells of Porter's Twisted Moss yellow, rather than red as in Heim's Pottia (Zander 2007). Porter's Twisted Moss is also very similar to Blunt-leaved Twisted Moss (*Tortula obtusifolia*), from which it can be distinguished by flat (rather than rolled) leaf margins and acute (rather than rounded) leaf tips. Furthermore, male and female reproductive structures occur only separately, on different plants, in Porter's Twisted Moss, whereas in Blunt-leaved Twisted Moss they typically (although not exclusively) occur together on the same plant.

Population Spatial Structure and Variability

No studies of population structure or variability have been reported for Porter's Twisted Moss.

Designatable Unit

There is not sufficient information on the species' genetic structure, distribution, dispersal, or ecology to adequately assess the discreteness or significance of any portion of the Canadian population. It is assessed as a single designatable unit.

Special Significance

Porter's Twisted Moss is largely restricted to eastern North America. In Canada, it appears to be associated with the Carolinian zone, occurring only on Canada's southernmost islands, and on the southern tip of the Niagara Escarpment Biosphere Reserve. Both areas are known for their high numbers of locally, provincially and/or nationally rare species (e.g., Riley *et al.* 1996, Carolinian Canada 2015). It reaches the northernmost edge of its global range limit in Canada; plant populations at range edges are commonly associated with unique genetic characteristics (e.g., Sexton *et al.* 2009).

DISTRIBUTION

Global Range

Porter's Twisted Moss is associated, in North America, with the Eastern Deciduous Forest region. It occurs from Vermont west to Kansas and south to Mississippi (Figure 3). The species is concentrated west of the Appalachian Mountains and east of the Great Plains.

Figure 3. Approximate known global distribution of Porter's Twisted Moss.

A single, reliably identified (successively confirmed by Richard Zander and Maria Cano in 2007) Venezuelan specimen (E.B. Sharp 599b, 1976, MO 5633906) is unusual not only because it is the only non-North American record for Porter's Twisted Moss, but also because it is the only specimen of which we are aware that was collected from wood rather than its normal substrate of rock. Further study is required to clarify the significance of this apparent outlier to the understanding the species' broader distribution and ecological associations.

Specimens from the Gaspé Peninsula are presumed to be mislabelled or misidentified.

Canadian Range

In Canada, Porter's Twisted Moss is known from 14 occurrences (Table 1, Figure 4) in two Palaeozoic limestone regions of southern Ontario: the Niagara Escarpment between Niagara Falls and Hamilton, and Pelee and Middle islands in Lake Erie.

Table 1. Summary of known specimens and reports of Porter's Twisted Moss in Canada, including collections examined. Specimens flagged with * were not examined by one or more of the writers; all are considered to be reliably identified. NY = New York Botanical Garden, MO = Missouri Botanical Garden, UBC = University of British Columbia, LL = private herbarium of Linda Ley. Where substrate and canopy information is ambiguous, it is quoted verbatim. Locations flagged with + included the quoted number of additional observations of Porter's Twisted Moss, for which no collections were made.

Numbers in the left-hand column assign occurrences to "locations", in the COSEWIC sense. Where no number is given, the occurrence either is an older, less precise record for another listed location, or, in the case of the Quebec occurrence, a record that has been discounted.

Records were sought in literature and collections (herbaria ACAD, CANM, NBM, OAC, NY, MO, TRTC, UBC, UWO, the Devonian Botanic Garden (ALTA-DBG), and the amalgamated database of the Consortium of North American Bryophyte Herbaria, and the Ontario Natural Heritage Information Centre.

Occurrence	Year(s) Collected	Specimen(s)	Substrate, canopy, abundance where quantified	Land tenure
Niagara Falls	1892	Cited in Eckel (2004)	Unknown	Unknown
1. Niagara Falls: Queen Victoria Park	1896	Cameron 1896	Unknown	NP (likely)
2. Niagara Falls: Smeaton's Cove	1985	*MO 2553454	Stream bed rocks, "Locust Grove"	NP

Occurrence	Year(s) Collected	Specimen(s)	Substrate, canopy, abundance where quantified	Land tenure
3. Niagara Glen[+17]	1901 1901 1901 1901 1901 1950 1985 1985 1985 1985 2014	CANM 131849 *NY 349657 *NY 349640 *NY 349637 *NY 349636 CANM 131848 ROM *MO-2553451 *MO-2553453 *MO-2553456 *MO-2553455 CANM 335609	“On limestone rocks” “On limestone rock” “On limestone rocks” “On limestone rock” “On limestone boulder” “On limestone boulder” Block (base), Woodland Boulder (N-facing) Boulder (solution cups/depressions) Boulder field, Woodland Boulder (face), Deciduous	NP
4. Cave Springs	1964 1964 1964 1964 2014 2014 2014 2014 2014 2014 2014 2014 2014 2014 2014 2014 2014	CANM 131847 CANM 131850 CANM 131851 *UBC B82188 CANM 335623 CANM 335624 CANM 335625 CANM 335630 CANM 335631 CANM 335634 CANM 335635 CANM 335636 CANM 335637 CANM 335639 CANM 335640 CANM 335641 CANM 335652	“On dry, exposed limestone cliff” “On dry limestone cliff” “On limestone boulder” “On dry, exposed limestone cliff” Boulder, Mixedwood Low outcrop, Maple Outcrops (grike), Maple Escarpment cliff (face), Deciduous Outcrop, Deciduous Stone of old fire pit, Maple-Beech Stone of old fire pit, Maple-Beech Low outcrop, Deciduous Escarpment cliff (face), Deciduous Boulder (in hollow), Deciduous Boulder (low on), Deciduous Boulder (low on), Deciduous Outcrop (face), Deciduous	NPCA
5. Louth Conservation Area[+7]	2014 2014 2014	CANM 335605 CANM 335612 CANM 335613	Outcrop (face, pits), Deciduous Outcrop (face), Deciduous Boulder (face, pits), Open parking	NPCA
6. Rockway Conservation Area[+3]	2014	CANM 335618 LL 2662	Cliff (face), Deciduous Outcrop (ledge), Deciduous	NPCA
7. Woolverton Conservation Area	2014 2014 2014	CANM 335653 CANM 335656 CANM 335658 LL 2645	Cliff (low on face), Deciduous Cliff (face), Deciduous Boulder (low on), Deciduous Outrcrop (low on). Deciduous	NPCA
8. Pelham Road	2014		Quarried blocks (all surfaces), Abundant within a localized 5 m x 5 m area	Private
Pelee Island	1882 1882 1882	CANM 197807 CANM 197808 *NY 349639	<locality information for these collections is not specific>	Unknown
9. Pelee Island – Lighthouse Point	2014	CANM 335712 CANM 335716	Boulder (face), Open shoreline, Occasional within 20 m x 20 m	Crown (shoreline)
10. Pelee Island – North shore	2014	LL 2924	Boulder (shallow depression), Open shoreline , 1 colony in depression on top surface of boulder	Crown (shoreline)
11. Pelee Island – Sheridan Point	2014	CANM 335726 CANM 335727	Boulder (face), Deciduous, 5 closely-occurring colonies seen, largest of which 10 cm x 10 cm Small rock (face), Deciduous shrub	Crown (shoreline)
12. Pelee Island – Mill Point	2014	CANM 335731	Boulder (in pit), Open shoreline, 7 colonies on a single boulder, all less than 2 cm in diameter	Crown (shoreline)

Occurrence	Year(s) Collected	Specimen(s)	Substrate, canopy, abundance where quantified	Land tenure
13. Pelee Island – Winery Nature Preserve	2014	CANM 335728	Small boulder (face), Cedar-decid., One boulder approx. 1m x 1m x 0.5m with many colonies varying in diameter from 1 cm to 20 cm; one boulder with a dead (brown) colony 20 cm in diameter; 6 small (<5 cm diameter) colonies; 2 small (<5 cm diameter) colonies elsewhere nearby	Private
14. Middle Island (likely extirpated)	1981 1983	CANM 275068 CANM 286425	“Rocky dolomite shore”	Parks Canada
Gaspé (suspect locality)	1882	CANM 131852 *NY 349635 *NY 2317160	“On rocks” “On rocks” “On rocks”	Unknown

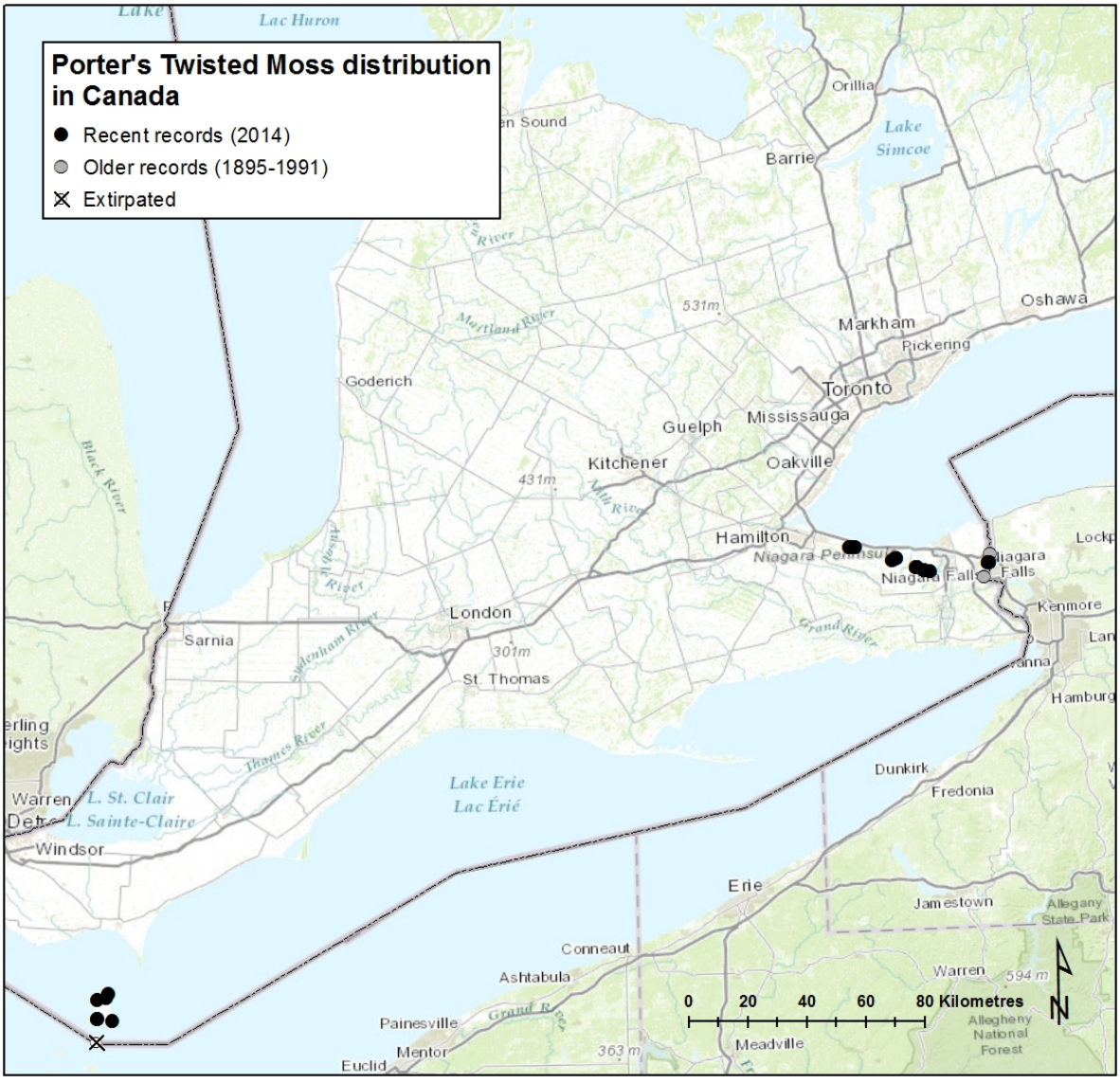

Figure 4. Known Canadian distribution of Porter’s Twisted Moss.

Despite herbarium records, the presence of Porter's Twisted Moss in Quebec is doubtful. In 1882, the same year that he collected the first Canadian specimens of Porter's Twisted Moss on Pelee Island (Table 1) John Macoun (1922, 1979) also visited the Gaspé Peninsula. One Macoun collection of Porter's Twisted Moss (Table 1) is labelled as having been collected on the "Gaspé Coast". If the label is accurate, the disjunct Gaspé population lies far north and east of the rest of its known distribution.

Three dedicated excursions associated with the current report were undertaken in hopes of confirming the existence of a Gaspé population, and searchers also took advantage of opportunities presented by other 2013-14 fieldwork to search suitable habitat. The search in Quebec took into account biographical and autobiographical information on Macoun, information from herbarium labels of other specimens Macoun collected on the Gaspé Peninsula, information on past botanical activity in the region, historical travel routes and landmarks, and the distribution of calcareous rock substrates. It included what was considered to be the most promising habitat in Parc national du Bic and Parc national Forillon and many other stations potentially visited by Macoun. No Porter's Twisted Moss was found.

The only other Quebec specimen labelled as Porter's Twisted Moss, from Percé (NY 349634), appears to represent a different species. No other investigators (including Lepage (1945-45, 1947), Kucyniak (undated), Zoladecki (1984), Favreau (1987), Belland and Favreau (1988), Belland and Schofield (1992), Faubert (2002, 2006, in press), as well as specimens in herbaria) have reported Porter's Twisted Moss in Quebec.

There have been previous examples of mislabelled specimens in Macoun's collections (e.g., Godfrey 1977), including specimens labelled as having been collected on the Gaspé Coast (Belland and Favreau 1988). On the other hand, discounted records have occasionally been shown to have been accurate for a given region (Brassard *et al.* 1989, Brodo *et al.* 2007).

Extent of Occurrence and Area of Occupancy

The Canadian extent of occurrence (EOO; area included in a polygon without concave angles that encompasses its geographic distribution) for Porter's Twisted Moss in Canada has been estimated to be 6416 km^2, 50% of which falls within Lake Erie water.

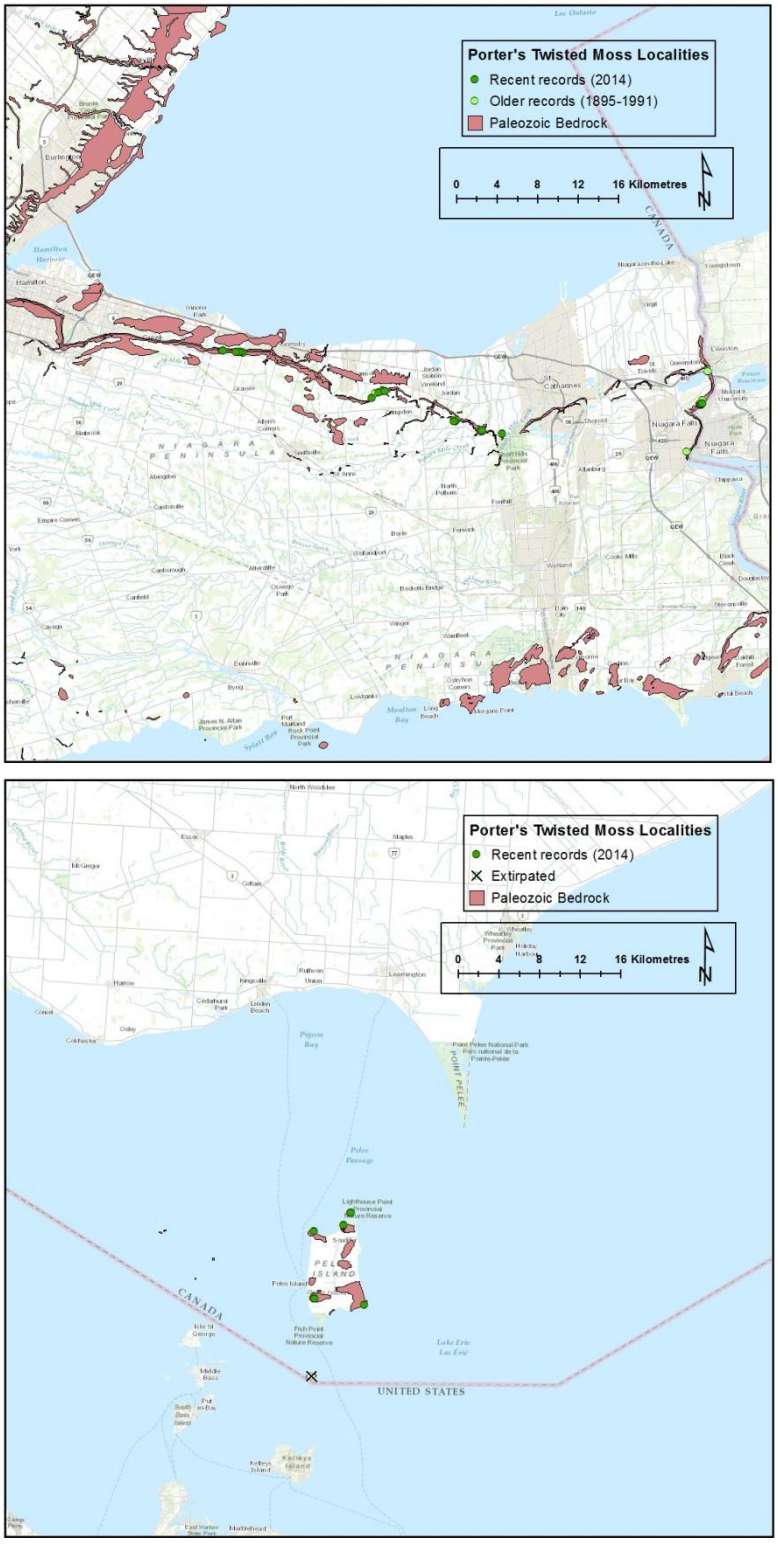

Figure 5. Distribution and extent of Palaeozoic bedrock in the southernmost part of Ontario, in relation to the known distribution of Porter's Twisted Moss.

Suitable natural Palaeozoic bedrock habitat composes just 65.1 km^2 within the EOO (Ontario Geological Survey 2010; GIS analysis by Alain Filion, COSEWIC Secretariat) (Figure 5). Two occurrences have been found outside (maximum 1200 m away) Palaeozoic bedrock zones, and these are associated with rocks quarried from nearby Palaeozoic bedrock exposures and moved for constructing walls or other human structures.

The known index of area of occupancy (IAO) is 60 km^2, which is very close to the area of the bedrock exposures (65.1 km^2) upon which the species relies. Furthermore, Porter's Twisted Moss occupies a very small proportion of this generally suitable area. Therefore, even when additional scattered subpopulations are found within the EOO, the effective IAO will remain extremely small.

Search Effort

For the current report, 90 person-hours of search effort were spent by both the report writer and Linda Ley in Quebec, and 120 in Ontario. Sites described on herbarium specimen labels were targeted first, and then, based on time available and consultation with local land managers and knowledge holders, other nearby sites with similar attributes were visited. The sites of these directed searches are summarized in Figure 6, along with the Ontario and Quebec collecting locations for four minute mosses (*Fissidens bryoides*, *Gymnostomum aeruginosum*, *Hymenostylium recurvirostre*, and *Seligeria* sp.) associated with the same habitats and substrates as Porter's Twisted Moss. It is reasonable to expect that, if Porter's Twisted Moss was present at these sites, it would have been noticed by a collector who also collected colonies of one or more of these other tiny plants. The known collection history of Porter's Twisted Moss is summarized in Table 1.

Generalized bryophyte collecting in the Niagara region is summarized in Olszewski (2010).

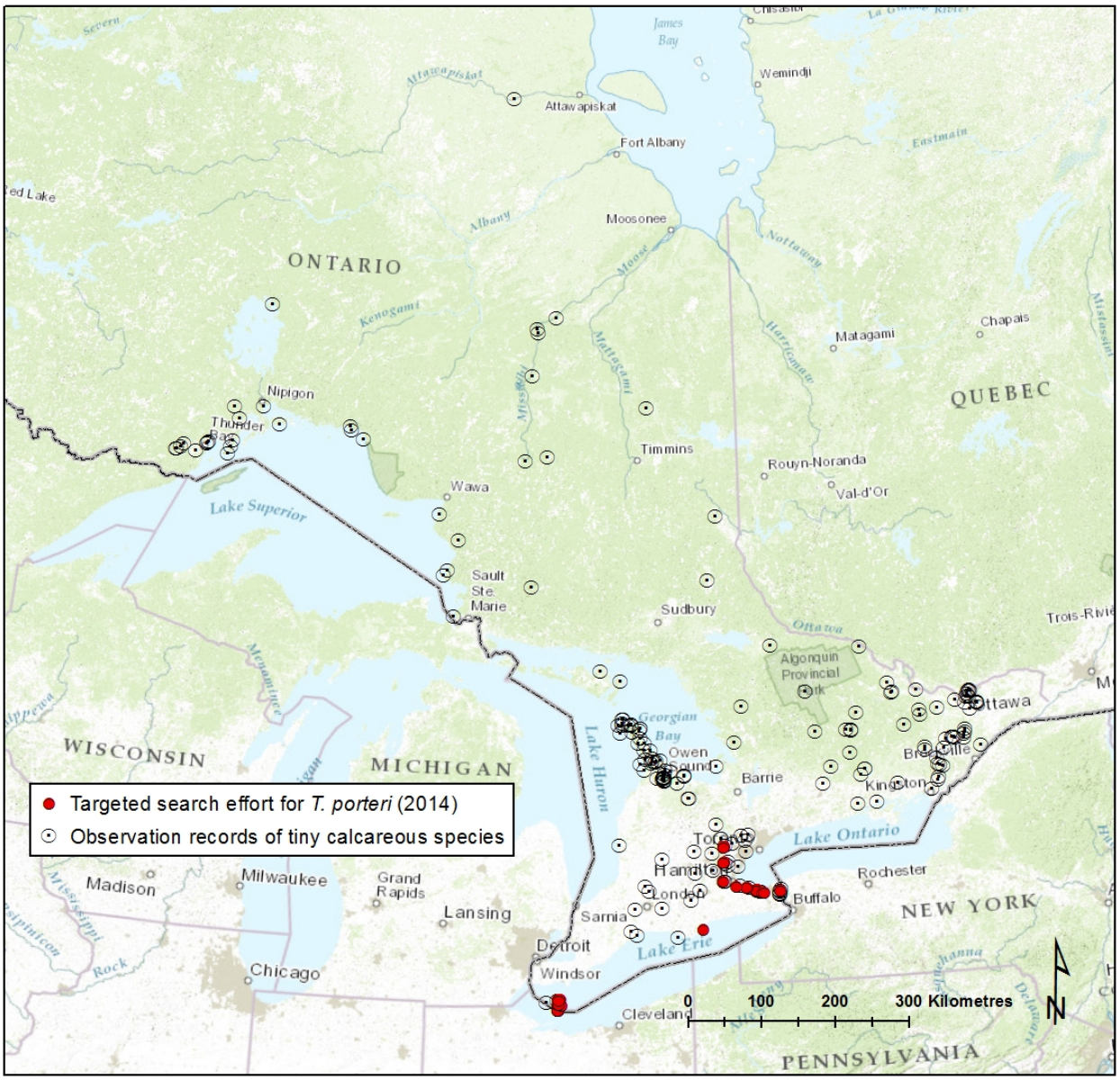

Figure 6. Canadian bryophyte search effort likely to have detected Porter's Twisted Moss if it was present, including targeted search effort within and near the species' known range, and generalized search effort that detected other minute bryophyte species of similar substrates.

HABITAT

Habitat Requirements

Porter's Twisted Moss is associated with calcareous rock substrates, attaching tightly to otherwise bare rock. Vertical substrates are mostly likely to remain clear – or become periodically clear – of larger species with which the diminutive Porter's Twisted Moss is ill-equipped to compete. It has been found on vertical and steep surfaces as well as horizontal ledges and boulder tops, and within pits in weathered calcareous rock. Bryophytes of rock substrates depend on micro-scale environmental variation that may be influenced by the slope, aspect, and relative exposure (as influenced by crevices, overhangs, and other microtopographical features) of the surfaces to which they are attached (Jonsgard and Birks 1993).

Porous, weathered, but otherwise solid rock appears to be more favourable for Porter's Twisted Moss than crumbly or newly exposed surfaces. Whether the setting is natural or anthropogenic appears to be inconsequential: in Canada, Porter's Twisted Moss was seen not only on forest cliffs and massive boulders, but also on the dolostone of retaining walls, trail cairns, parking lot barriers, and a fire pit. Substrates in the US portion of the species' range include old bricks and bridge abutments as well as naturally occurring limestone rock.

The extremely low proportion of available rock substrate occupied by this species at each site, and within each region where it occurs, suggests that additional habitat or natural limiting factors are important. These factors have not been investigated or identified.

Plants on rock outcrops are subject to drought, nutrient deficiency, and natural disturbance (e.g., Larson *et al.* 1989, references cited in Jonsgard and Birks 1993). Disturbance caused by rock fracturing and by falling rocks and debris, etc., result in periodic removal of plants, as does the pull of gravity when the growing plants eventually overcome the strength of their attachment to their vertical substrates.

Rock substrates occupied by Porter's Twisted Moss have been found both in shaded, damp forests and in dry, exposed areas. Within the limited experience of fieldwork associated with this report, colonies in drier situations seemed to grow taller and more densely, with more sporophytes per unit colony area than those in shaded, damp sites. The majority of canopy trees shading Porter's Twisted Moss in Canada are broadleaf (Table 1). Some collections have been made from shoreline rocks within the splash zones of freshwater waves. Salt water is detrimental to most mosses, and shoreline rocks on the Gaspé Coast were avoided while searching for Porter's Twisted Moss for this study.

The northern range limit of Porter's Twisted Moss appears to coincide with climate and geological boundaries. It has not been found north of the Hamilton area, where Niagara Escarpment rock exposures become more distant from the moderating influence of Lake Ontario and Lake Erie. Around that point, the escarpment also passes north of plant hardiness zone 6, and north of the Carolinian life zone, both of which reach their northern range limit around the eight-degree isotherm (latitude at which the average temperature is around 8°C), and it becomes largely east-facing rather than north-facing. Whereas Lockport and Clinton-Cataract group limestones and shales are exposed on the Niagara Peninsula, the Amabel formation dominates to the north (Ontario Ministry of Natural Resources – Ontario Geological Survey 1981, Ontario Geological Survey 2015). On Pelee Island, exposed limestone belongs primarily to the Dundee formation.

Porter's Twisted Moss may, more specifically, coincide with those regions of warmer-than-average climate described for southern Ontario viticultural areas. Haynes (2000) indicates the average annual temperature on and north of the Niagara Escarpment on the Niagara Peninsula is 9°C, and that the longest frost-free season occurs on the steep part of the Escarpment (i.e., characterized by exposed rock). Citing Shaw (1994, 1996), Haynes (2000) also notes that the area north of the Escarpment receives the highest number of rainfall days on the Niagara Peninsula. Pelee Island is also a long-time viticultural area with Palaeozoic bedrock exposures.

Habitat Trends

Greater understanding of the habitat requirements and population trends of Porter's Twisted Moss are needed before trends in this habitat can be effectively assessed.

Ongoing activities that change the amount of exposed, weathered rock (e.g., quarrying, recreational activities) or that alter the chemistry of the rock surface (e.g., airborne pollutants, problematic native species) have potential to create trends in habitat suitability (see THREATS AND LIMITING FACTORS, below). Most have likely contributed to downward trends in Porter's Twisted Moss habitat over the long term, and the impacts of Cormorants have likely extirpated the species from Middle Island since the 1980s.

BIOLOGY

Very little study has been devoted to Porter's Twisted Moss in particular, but some biological characteristics can be inferred from knowledge of other moss species. Mosses are small plants that lack roots and vascular systems.

Life Cycle and Reproduction

Each Porter's Twisted Moss plant produces either male or female gametangia. Successful fertilization depends on water connecting the perigonia, from which swimming sperm are released in male plants, and the perichaetia, which hold the eggs in female plants. Success is therefore often less frequent in dioicous species like Porter's Twisted Moss as compared with autoicous species in which the male and female reproductive structures occur together on each plant (Crum 2001, Miles and Longton 1990). Although the maximum range of bryophyte sperm is about 10 cm (Mishler 1988, Schofield 1985, Bisang *et al.* 2004) on level ground, Porter's Twisted Moss often occupies vertical substrates, sometimes washed periodically by lake or pond water, which would create currents of water that substantially increase this distance. Furthermore, observation of abundant sporophytes for most colonies observed during fieldwork for this report suggests that male and female plants most often grow in close proximity. In many instances, the species is collected with capsules, although the increased visibility and easier identification of the plants at this stage of their life cycle is likely to bias their representation in herbaria. During fieldwork for this report, some colonies were fruiting very abundantly (e.g., Figure 1a).

A maximum of one spore capsule is produced at the apex of a fertilized female plant. A new reproductive cycle generally begins each year, with capsules apparently maturing over the summer in Canada. In spring, both old capsules from the previous year and immature green capsules may be present in the same colonies.

Porter's Twisted Moss does not produce specialized asexual reproductive structures (e.g., gemmae), but virtually any moss cell is capable of regenerating as a clone of its parent plant. Thus, fragments dislodged by animals or erosion of the rock may aid in vegetative reproduction.

Although many mosses adhere less tightly to their substrates than do rooted plants, colonies of Porter's Twisted Moss hold closely to their rock substrates, forming thin turfs that are often difficult to scrape off. When plants are removed by superficial disturbance, it is likely that fragments remain in the porous rock that are capable of regenerating into mature plants.

Porter's Twisted Moss, with its small plants, small spores, frequent spore production, and thin, turf-like colonial growth form, matches most closely During's (1979) "fugitive" life history classification. Fugitive bryophytes take advantage of unpredictable substrate availability and persist as long as the substrate remains free of competing, longer-lived, larger bryophytes. On vertical or overhanging rock, bare surfaces may remain available longer because it may be more difficult for other plants to establish. Furthermore, new areas of uncolonized rock are likely to become available due to the disturbance characteristic of cliff habitats.

Physiology and Adaptability

Mosses of dry substrates are able to survive long periods without water, resuming growth and activity within seconds of contact with water (e.g., Proctor *et al.* 2007). Their small size and lack of roots link them to the immediate moisture, chemistry, and light conditions where they occur, such that their substrate and microhabitat are often more important than their broader habitat. Without vascular systems, complex anatomy or cuticular waxes, mosses absorb water and nutrients – including pollutants – directly through all surfaces, like a sponge. Porter's Twisted Moss is associated with calcium-rich rocks, and may therefore respond negatively to excess acidity in its immediate environment. The buffering capacity of the limestone environment, on the other hand, may protect it (Adams and Preston 1992, Larson *et al.* 2007). Ecosystems associated with calcareous soils may similarly protect resident bryophytes (e.g., Bates 1993), especially those that grow on trees and rock surfaces (e.g., Rose and Wallace 1974, Adams and Preston 1992)

Dispersal and Migration

Spores appear to be particularly important for the dispersal of mosses with "fugitive" life history strategies (Miles and Longton 1990). The stalk upon which the capsule rests helps to elevate the mature spores, providing greater dispersal distance than would be possible within the still, boundary layer air occupied by the leafy plants below. The small spores of Porter's Twisted Moss are probably primarily dispersed by air currents (Crum 2001, Goffinet *et al.* 2009), facilitated by the elevation, vertical orientation, and/or exposure. Spores released from colonies bordering lakes or other water bodies are also likely to disperse in water. Dispersal by animal vectors is possible but probably less important given the substrates preferred by this moss.

Most spores likely land close to the parent plant but long-distance dispersal is possible in bryophytes (Miles and Longton 1992). Establishment of new colonies depends on spores or fragments landing on suitable substrates and remaining until germination occurs. In mosses, small spores (<20 µm) are thought to have much greater longevity in soil than large spores (>25 µm), which are more characteristic of ephemerals of predictably disturbed environments (During 1979).

Interspecific Interactions

Porter's Twisted Moss exemplifies Niagara Escarpment cliff species in its sensitivity to competition (Larson *et al.* 1989). Porter's Twisted Moss is adapted to avoid competition by completing its life cycle quickly on bare substrates, before its growing conditions change. Once larger, more competitive mosses become established, it is unlikely to persist.

There are no documented consumers of Porter's Twisted Moss and no animals are known to naturally limit or facilitate its growth. Some invertebrates and small vertebrates do eat spore-bearing capsules, but the leafy gametophyte plants are often less likely to be grazed (Glime 2013).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Ideally, localities for fugitive (During 1979) species like Porter's Twisted Moss would be searched repeatedly, over several years, to account for potential population fluctuations related to disturbance-dependent substrate availability. Furthermore, such species may persist as spores, protonemata or plant fragments in rock crevasses and pores. The necessity of microscopic examination to confirm the species' identification introduces a delay between collection and positive identification. Additional visits to the same site may then be needed. This kind of survey has not been done for Porter's Twisted Moss.

Additionally, many potential substrates and sites for the moss are inaccessible, particularly along the Niagara Escarpment, where only narrow bands at the top and base of the cliff are accessible by foot. While individual patches of Porter's Twisted moss are usually small (a few to a few hundred plants), assessing abundance throughout its known range on the Niagara Escarpment would require ropes and a considerable amount of time.

Abundance

The abundance of Porter's Twisted Moss has not been quantified. It occupies a restricted Canadian range, within which, despite local areas where it is frequently found (Eckel 1987, Table 1), there are large areas of unoccupied, apparently suitable habitat.

Although some colonies were measured during the fieldwork for this report (sites with very little Porter's Twisted Moss present), emphasis was placed on determining the presence and the distribution of the species.

Fluctuations and Trends

Although Porter's Twisted Moss is an annual moss adapted to unpredictable substrate availability, it has occupied some sites for over 100 years. It was recorded in Niagara Glen in 1901, 1950, 1985, and 2014. On Pelee Island, although the precise locality was not recorded, it was first collected in 1882, and several sites were confirmed in 2014. Cave Springs Conservation Area also still supports a relatively large population along the trail where it was first collected in 1964.

Although fieldwork associated with this report documented occurrences that were not previously reported (Table 1), they are not thought to be recently established populations.

On Middle Island, where a large nesting colony of Double-crested Cormorants (*Phalacrocorax auritus*) has established (Dobbie 2008) since Porter's Twisted Moss was collected there in the 1980s, the chemistry of virtually all rock surfaces has dramatically changed. Porter's Twisted Moss was not found in 2014, although the water-bathed bases of some lakeshore rocks may still support it.

The extent of natural habitat in Niagara Falls has diminished markedly with urban development since the earliest collections of Porter's Twisted Moss, so that its abundance there has almost certainly decreased over the past 150 years.

No trend data was found for Porter's Twisted Moss outside Canada.

Rescue Effect

Rescue by US populations is currently possible. At Niagara Falls, Canadian and US populations of Porter's Twisted Moss occur on opposite sides of the Niagara River. In Lake Erie, Porter's Twisted Moss is known from US islands in the same archipelago as Pelee and Middle Islands. Individuals from these US populations would be a source of rescue and would be adapted to conditions in nearby Canada.

As the climate changes and the range of suitable climate contracts (as discussed in the Threats and Limiting Factors section), rescue from US populations is expected to become increasingly less feasible.

THREATS AND LIMITING FACTORS

Limiting Factors

In addition to its dependence on close proximity of male and female plants, Porter's Twisted Moss is naturally limited by its ranges of tolerance for moisture, nutrients, and light. These ranges of tolerance have not been quantified. Liquid water is essential for fertilization and moisture is essential for photosynthesis and growth (see Habitat Requirements section). Its apparent restriction to the Carolinian zone suggests that its limitations may be linked to temperature and/or growing season length. Porter's Twisted Moss does not compete effectively with mosses or other plants.

Large areas of apparently suitable substrate remain unoccupied, even very close to occupied sites, suggesting that factors limiting this species are not yet understood.

Threats

Application of the IUCN-CMP Threats Classification Scheme (IUCN-CMP 2006) resulted in an overall calculated threat impact of "Low". The threats faced by Porter's Twisted Moss are discussed below, in order of decreasing impact.

1) Mining and Quarrying

Scope: small (1–10%), Severity: extreme (71–100%), Timing: high (continuing)

Porter's Twisted Moss removed along with the rock substrates that it inhabits, in the

event that the rock is quarried, is likely, in most circumstances, to die. Furthermore, Porter's Twisted Moss was not seen on recently cut rock – even in the abandoned quarries that were visited – during the fieldwork for this report, indicating that surfaces exposed by removing rocks may not be suitable for the growth of this moss. Ursic *et al.* (1997) found that quarry walls could be revegetated to native, bryophyte-dominated plant communities within 100 years of the cessation of quarrying, particularly with the development of shading trees at the top and the bottom of the quarry wall. However, the deeply weathered surfaces with which Porter's Twisted Moss appears to be associated probably take longer to develop.

Weathered surfaces of rocks moved from quarries appear to remain suitable for the growth of Porter's Twisted Moss, as demonstrated by a healthy subpopulation found on rocks lining the walkway of a store near St. Catharines. It is estimated that these rocks were quarried nearby in the early 1800s.

Although limestone regions of southern Ontario have been quarried for over 150 years (Tomlinson *et al.* 2008), and there are many active and inactive quarries within the Canadian range of Porter's Twisted Moss, potentially suitable substrate remains in unquarried areas. Much of the rock that has been where Porter's Twisted Moss has been documented is in protected conservation areas or along the Bruce Trail, within the Niagara Escarpment Biosphere Reserve (NEBR). Land use decisions within the NEBR are mandated to balance conservation and development (Niagara Escarpment Commission 2015a) according to policies defined in the Niagara Escarpment Plan (Niagara Escarpment Commission 2014), which is scheduled for review in 2015 (Niagara Escarpment Commission 2012, 2015b). Publicly accessible conservation areas are the main types of sites represented for documented subpopulations, simply due to ease of access, but suitable habitat outside these protected areas is assumed to exist as well. Quarrying may be a greater concern for these as yet unsampled sites.

2) Recreational Activities

Scope: large-restricted (11–70%), Severity: slight (1–10%); Timing: high (continuing)

Recreation is a main land use in natural areas along the Bruce Trail and the conservation areas of the Niagara Peninsula where Porter's Twisted Moss has been found. This species often occurs on vertical surfaces or within small pits in calcareous rock, which are not subject to normal foot traffic. Climbing and bouldering may erode mosses from rock substrates and prevent them from establishing. Studies have associated climbing routes with both reduced plant species diversity and reduced abundance of certain plant species (e.g., Faubert and Lapointe 2011, 2012, references cited in McMillan and Larson 2002 and Kuntz and Larson 2006). However, because site selection by both plants and climbers involves a variety of overlapping factors, a causal relationship is difficult to establish (e.g., Nuzzo 1996, Farris 1998, Kuntz and Larson 2006). Theil and Spribille (2007) caution, furthermore, against inferring the behaviour of individual species from the behaviour of the majority of species. Clark and Hessl (2015) found no effect of climbing on the bryophytes of a particular quartz-rich, West Virginia cliff. Physical substrate characteristics (e.g.,

weathering, porosity, moisture) preferred by Porter's Twisted Moss should be evaluated in the context of those most attractive to rock climbers.

Regardless of the potential impacts, Porter's Twisted Moss has been recorded in Niagara Glen for more than 100 years despite a long history of climbing and bouldering, and it occurs frequently there today under current recreational rules (e.g., climbers must purchase a permit, avoid closed boulders, and minimize damage to vegetation) that emphasize the preservation of biological diversity (Niagara Parks 2014).

3) Problematic Native Species

Scope: negligible (<1%), Severity: unknown, Timing: high (continuing)

A colony of Double-crested Cormorants has established on Middle Island since Porter's Twisted Moss was first collected there in the 1980s. Cormorants impact bryophyte habitat by introducing toxic nutrient levels and altering the chemistry of all available moss substrates. They also kill canopy trees, altering the light / moisture regime of the affected habitat. Nine SARA-listed species have been documented on Middle Island (Dobbie 2008).

Porter's Twisted Moss may be extirpated from Middle Island (it was not found there during a six-hour directed search in September 2014), and if it persists, it is almost certainly restricted to small colonies on undercut surfaces of shoreline rocks within the splash zone of waves. This was where the only saxicolous moss species were seen on Middle Island in 2014, and Porter's Twisted Moss was found in this type of habitat on nearby Pelee Island. A management plan (Dobbie 2008) targets a reduction in cormorant nests from about 5000 (as of 2007) to 600 – 1100. The extent of the moss population before the boom in cormorant numbers is not known, but it is assumed to have represented less than 1% of the Canadian population.

Human activity is likely to prevent the establishment of significant cormorant colonies on Pelee Island. Suitable cormorant habitat probably overlaps only minimally with the majority of Porter's Twisted Moss on the Niagara Peninsula, and would also be limited by human activity.

4) Air-borne Pollutants

Scope: pervasive (71–100%), Severity: unknown, Timing: high (continuing)

Pollutants and acid rain have potential direct, toxic effects on the health of plants and indirect effects through the alteration of substrate pH (e.g., Adams and Preston 1992, Bates 1993, Larsen *et al.* 2007). Porter's Twisted Moss is very reliably associated with calcareous rock substrates in North America, suggesting that it has specific chemical tolerances. On the other hand, bryophyte substrates with high pH may buffer the acids, protecting the bryophytes and lichens that inhabit them from some pollutant effects (see Physiology and Adaptability section). Mosses lack roots that would give them access to nutrients from the substrate, and most lack protective anatomical features (e.g., cuticle, bark) that would

protect their tissues from damaging pollutants. Certainly Porter's Twisted Moss, with a life strategy based on a simple, quickly-maturing plant, does not possess these features.

Although dense human population results in concentrated pollutant emissions in southern Ontario, ongoing reductions in NOx and SO_2 emissions in eastern Canada are addressing acid rain (CCME 2013). Increases in acid pollution are not anticipated in the foreseeable future. Porter's Twisted Moss has persisted in some southern Ontario locations through peak emissions in the latter part of the 20th century.

5) Landslides

Scope: unknown, Severity: extreme (71-100%), Timing: moderate (possibly in the short term, <10 years)

Cliff habitats are subject to natural temperature- and moisture-related fracturing and crumbling. On natural rock surfaces, Porter's Twisted Moss occurs on porous, weathered faces and would not readily recolonize freshly exposed substrate.

6) Climate Change

Scope: pervasive, Severity: unknown, Timing: Low (possibly in the long term, >10 years)

Little is known about the climate needs of Porter's Twisted Moss, but it is assumed, based on its distribution and its restriction to Canada's warmest areas, that climate is an important influence on its distribution. BIOCLIM modelling (by R. Cameron, Mosses and Lichens SSC) suggests there is currently 1,212,271 km^2 of suitable climate in North America with 21,254 km^2 in Canada (Ontario). Future projections to years 2036 and 2100 suggest the area of suitable climate will decline by 6% and 62%, respectively, for North America (Figure 7). Decline of suitable climate in Canada will be 15% and 100%, respectively (R. Cameron, unpublished). The model predicts that contraction of suitable Canadian climate will affect the Palaeozoic bedrock zones occupied by Porter's Twisted Moss on the Niagara Peninsula and on the Lake Erie Islands early in this decline (Figure 7).

BIOCLIM is a well-established bioclimatic model for exploring future trends in climate parameters that characterize a species' current range of distribution. Although BIOCLIM summarizes up to 35 climatic parameters within a species' known range and assesses the climatic suitability of current and future climate (Beaumonta *et al*. 2005), eight climate parameters considered to most influence *T. porteri* were selected in this case: annual mean temperature, temperature seasonality, annual temperature range, mean temperature of the coldest quarter, minimum temperature of the coldest month, annual precipitation, precipitation seasonality and isothermality. Five degree world climate data was used from Hijmans *et al*. (2005) in DIVA-GIS software (Hijmans *et al*. 2012). For future climate modelling the five degree world climate was adjusted for expected change based on the Canadian Coupled Global Circulation Model B2 scenario for Ontario. The B2 scenario for

southern Ontario for the period 2071-2100 projects a 3 to 5°C warming in summer and 4 to 5°C warming in winter compared with 1971-2000. Most of southern Ontario is projected to have up to 10% less precipitation during the warm season and up to 20% less precipitation in winter (Colombo 2007). No statistical climate model was run to investigate the nature of relationships between individual climate variables and the species' occurrence.

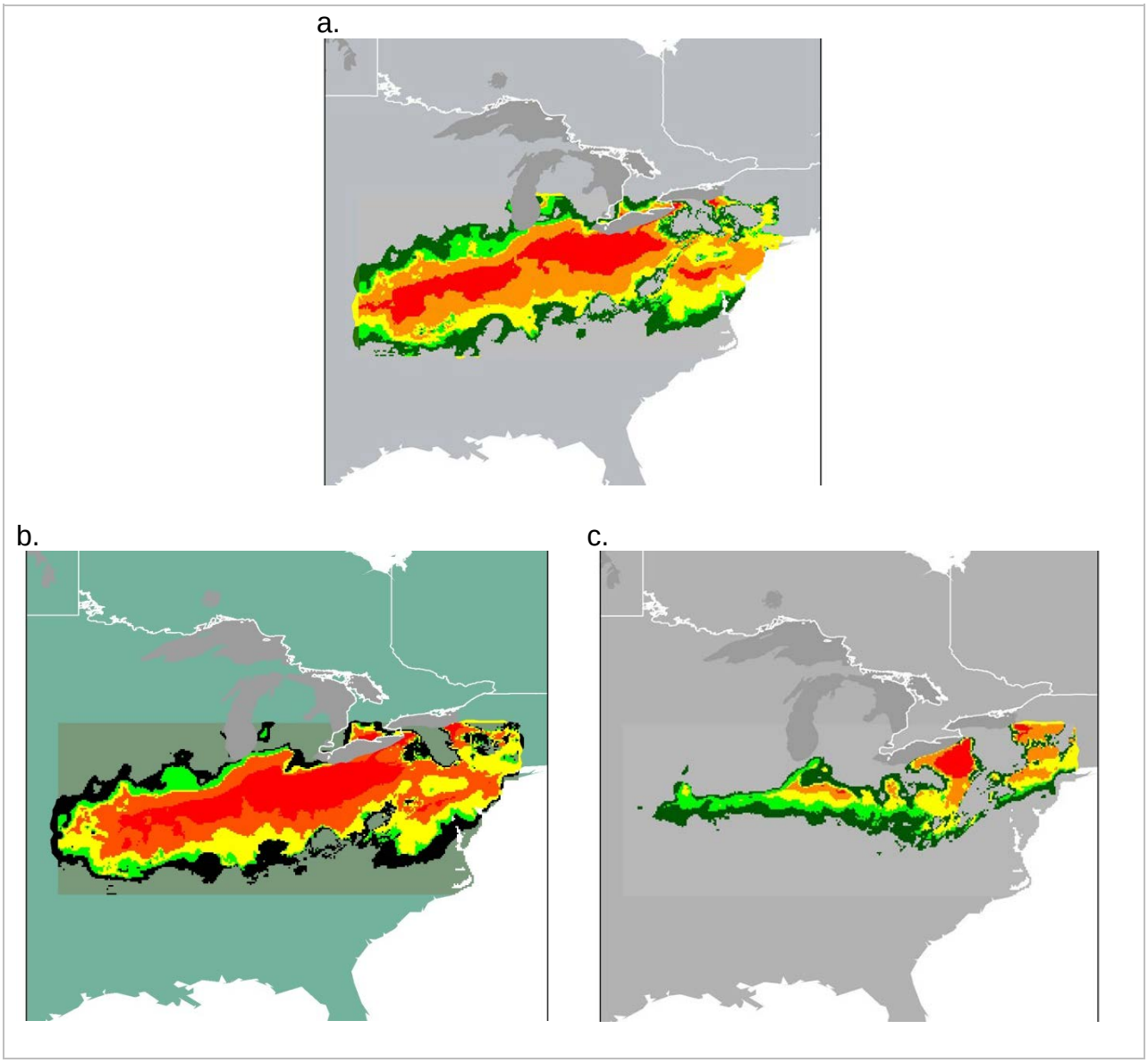

Figure 7. BIOCLIM-modelled a) current and projected, b) 2036 and c) 2100 area of suitable climate for Porter's Twisted Moss, using 8 climate variables with 5 degree world climate data. Future climate projection was from Canadian Coupled Global Circulation Model B2 scenario. Red indicates areas that are most suitable (closest to the multivariate mean) and dark green least suitable. Grey indicates no suitable climate. BIOCLIM was applied to herbarium data for Porter's Twisted Moss by R. Cameron, COSEWIC Mosses and Lichens SSC).

Number of Locations

"Location" defines a geographically or ecologically distinct area in which a single event will soon affect all individuals of the taxon present. Although Middle Island has been subject to a single threatening event, the number of locations is less clear for the rest of its Canadian population. The abundance of the species is unknown due to the large proportion of unsearched and/or inaccessible habitat. At least thirteen occurrences that are separated from adjacent occurrences by at least one kilometre have been recorded (Table 1) in Canada. It is assumed that more locations exist within the species' very limited Canadian range.

Although climate change poses a significant long-term threat to Canada's entire population of Porter's Twisted Moss, more immediate threats are unlikely to simultaneously affect more than one occurrence. Therefore, the number of Canadian locations of Porter's Twisted Moss is unknown, and exceeds the ten required to invoke status criteria that are based on number of locations.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Porter's Twisted Moss has no legal status in Canada or the United States.

Non-Legal Status and Ranks

According to NatureServe (2014), Porter's Twisted Moss is ranked "G3?" (possibly globally vulnerable). It is ranked N1 (critically imperiled) in Canada, and is not ranked in the United States. Similarly, it is not ranked in Arkansas, Connecticut, Indiana, Tennessee, and Virginia.

It is ranked S1 in Ontario (NHIC 2014) and SU in Quebec (pers. comm., Centre de données sur le patrimoine naturel du Québec, 2014). It is classified as SH (known only historically) in New York and Vermont, although New York collections made near Niagara Falls in the mid-1980s suggest the New York status may be misleading.

Habitat Protection and Ownership

Land tenure for known populations of Porter's Twisted Moss are summarized in Table 1. The majority are within protected areas or along public trails, reflecting the greater accessibility of these sites for surveying.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Jennifer Doubt is the Curator of Botany for the National Herbarium of Canada, Canadian Museum of Nature, and a field bryologist with over 15 years' experience. Jennifer has authored four COSEWIC Status Reports, two Status Appraisal Summaries, one provincial status report, and three national recovery documents on Canadian bryophytes.

Linda M. Ley has over 40 years' experience in bryology, 25 as a curatorial and research assistant in the Bryology Section of the Botany Division at the Canadian Museum of Nature. She was a member of the COSEWIC Mosses and Lichens Subcommittee for 12 years. Linda is a co-author of *An Enthusiast's Guide to Liverworts and Hornworts in Ontario* (1999), the *Atlas of Ontario Mosses* (1992), and *Type Specimens of Bryophytes in the National Museum of Natural Sciences, National Museums of Canada* (1984).

Jean Faubert is the president of the Société québécoise de bryologie and the editor of its journal, the Carnets de bryologie. He has studied bryophytes for over 30 years, with a personal herbarium of more than 10,000 specimens. Jean is the author of *Flore des bryophytes du Québec-Labrador* (Vol. 1, 2012; Vol. 2, 2013; and Vol. 3, 2014) which received The Henry Allan Gleason Award from the New York Botanical Garden as the outstanding recent publication of 2014. He is also a contributing author for the Bryophyte Flora of North America and an author and co-author of over 50 botanical publications.

COLLECTIONS EXAMINED AND KNOWN

Collections examined for this report are listed in Table 1.

Appendix 1. Threats calculator for *Tortula porter.*

Species	Porter's Twisted Moss, *Tortula porteri*
Date:	29/06/2015
Assessor(s):	Dave Fraser, Jennifer Doubt, Rene Belland, Julie Perrault, Ruben Boles, Eric Snyder, Karen Golinski, Richard Caners

Overall Threat Impact Calculation Help:		**Level 1 Threat Impact Counts**	
Threat Impact		**high range**	**low range**
A	Very High	0	0
B	High	0	0
C	Medium	0	0
D	Low	2	2
Calculated Overall Threat Impact:		Low	Low
Overall Threat Comments		Assumed to be an annual.	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						
3	Energy production & mining	D	Low	Small (1-10%)	Extreme (71-100%)	High (Continuing)	
3.1	Oil & gas drilling						
3.2	Mining & quarrying	D	Low	Small (1-10%)	Extreme (71-100%)	High (Continuing)	Ongoing limestone quarrying in the area occupied by the species.
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting						
5.4	Fishing & harvesting aquatic resources						
6	Human intrusions & disturbance	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	
6.1	Recreational activities	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	As many of the sites would be dangerous to access and can not be surveyed, there is a lot of uncertainty around the number of mosses affected by this threat. Range ranks were used for this reason.
6.2	War, civil unrest & military exercises						
6.3	Work & other activities						
7	Natural system modifications						
7.1	Fire & fire suppression						
7.2	Dams & water management/use						
7.3	Other ecosystem modifications						The substrate the species occupies is already sparsely vegetated.
8	Invasive & other problematic species & genes		Negligible	Negligible (<1%)	Unknown	High (Continuing)	
8.1	Invasive non-native/alien species						
8.2	Problematic native species		Negligible	Negligible (<1%)	Unknown	High (Continuing)	Cormorants on Middle Island were of concern in the past and have likely eliminated populations. The nature of the habitat has been completely changed. This is a historical threat. No future sites are expected to be inhabited by cormorants. Cormorants are being culled each year. Gulls may have the same effect. Pelee Island would also likely be too populated for cormorant nests on that island.
8.3	Introduced genetic material						
9	Pollution		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
9.1	Household sewage & urban waste water						
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.4	Garbage & solid waste						
9.5	Air-borne pollutants		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Mosses in general are sensitive to pollution.
9.6	Excess energy						
10	Geological events		Unknown	Unknown	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides		Unknown	Unknown	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	This moss tends to grow on weathered or older surfaces (perhaps more porous for water) so it would take a long time to recolonize a disrupted area.
11	Climate change & severe weather						Not considered a threat in the short term or long term
11.1	Habitat shifting & alteration			Pervasive	Slight - Extreme	Low (Possibly in the long term, >10 yrs)	BIOCLIM modeling suggests that key temperature and precipitation parameters that characterize the current North American range of Porter's Twisted Moss will likely change sufficiently by the year 2100 that suitable climate in North America will decline by 62%, with no suitable climate conditions remaining in Canada.
11.2	Droughts						
11.3	Temperature extremes						
11.4	Storms & flooding						