COSEWIC
Assessment and Status Report

on the

Slender Yoke-moss
Zygodon gracilis

in Canada

ENDANGERED
2019

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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COSEWIC
Assessment Summary

Assessment Summary – November 2019

Common name
Slender Yoke-moss

Scientific name
Zygodon gracilis

Status
Endangered

Reason for designation
In North America, this moss is confined to a single location on Haida Gwaii, British Columbia. The extremely small population occurs on a one square-metre patch of limestone cliff face near the ocean. Imminent threats to the species are the proliferation of young, dense woody vegetation adjacent to the cliff, exerting both direct (increased shade and moisture) and indirect (overgrowth by cyanobacteria) effects on the population. Other important threats include altered precipitation patterns, droughts and temperature extremes associated with climate change, quarrying of the high-quality Sadler limestone on which the species grows, and stochastic events such as inundation by tsunamis.

Occurrence
British Columbia

Status history
Designated Endangered in November 2019.

COSEWIC
Executive Summary

Slender Yoke-moss
Zygodon gracilis

Wildlife Species Description and Significance

Slender Yoke-moss (*Zygodon gracilis*) is a small to medium-sized, yellowish- to brownish-green moss that grows on dry vertical rock surfaces. The lanceolate to oblong-lanceolate leaves are spreading and recurved (bent backward) when wet and contorted and incurved when dry. The leaf margins are sharply toothed near the leaf apex and untoothed near the base. The prominent costa or “midrib” of the leaf extends to the leaf apex or just beyond. Spore-producing capsules have not been observed in Canada and have seldom been seen elsewhere.

The species is significant for its global rarity. The Canadian population is thought to have persisted in a coastal refugium during the last glaciation.

Distribution

Slender Yoke-moss is extremely rare. Its pattern of distribution has been characterized as “Western European-Western North American”. In North America the species is known from a single location on Moresby Island on the archipelago of Haida Gwaii (formerly known as the Queen Charlotte Islands) in British Columbia, Canada. Elsewhere it has been collected from one location in northern England, one in Poland, a few in the Alps (Austria, France, Germany, Italy, and Switzerland) and a few in the western Carpathian Mountains (Poland, Romania, and Slovakia).

Habitat

Slender Yoke-moss is a lithophyte (i.e., it grows only on rock). It typically colonizes dry limestone cliff faces in humid areas, but in England it occupies rock walls constructed of Carboniferous limestone.

Biology

Slender Yoke-moss has been observed in the same location for multiple decades in several countries. Male and female reproductive structures occur on separate plants, but sporophytes (spore-producing structures) have rarely been seen. Although specialized asexual reproductive structures have been induced in culture, they have not been found on plants in the wild. Therefore, it is unlikely that the Canadian population could increase by dispersal of spores. Rather, it persists through long-term clonal growth.

As a habitat-specialist occurring on dry vertical surfaces of very pure limestone in areas with high humidity, it is unlikely that Slender Yoke-moss could survive or successfully compete against other species if habitat conditions such as light, moisture, and air flow change.

Population Sizes and Trends

The population of Slender Yoke-moss in Canada consists of several small colonies (maximum 2 cm^2) scattered in an area of <1 m^2 on a vertical cliff face. The species was first discovered in 1961 and last observed 2018. The number of colonies was not documented in 1961, 1966, 1994, or when it was rediscovered in 2018. Based on the concept of 'an individual-equivalent', which has been adopted by the IUCN, the size of the population of Slender Yoke-moss is Canada is one, based on the single cliff face occupied by the species.

Threats and Limiting Factors

The most significant threats to Slender Yoke-moss are quarrying; impacts to the moss's habitat caused by young native trees; stochastic events like tsunamis; and the effects of climate change such as droughts and increased temperatures. The species could also be threatened by over-collecting for scientific study.

The main factors limiting Slender Yoke-moss are its apparent lack of reproduction; small populations throughout much of its range; a disjunct pattern of global distribution; and highly restricted habitat.

Protection, Status and Ranks

The global conservation status of Slender Yoke-moss is "Imperiled". It has been identified as a candidate for the IUCN Red List of European Bryophytes based on the following conservation ranks (by country): Austria ("Risk Assumed"), Switzerland ("Vulnerable"), Germany ("Extremely Rare"), Great Britain, Italy, and Poland ("Endangered"), and Slovakia ("Critically Endangered"). The species is confirmed from France and present in Romania but its conservation status in those countries has not been assessed.

In Canada, Slender Yoke-moss has been designated as “Critically Imperiled” at the national level. It is also “Critically Imperiled” in British Columbia and is included in the province’s Red List. It is not currently protected under the federal *Species at Risk Act* or the British Columbia *Wildlife Act*, or by any other legislation in Canada.

TECHNICAL SUMMARY

Zygodon gracilis

Slender Yoke-moss

Houppe gracile

Range of occurrence in Canada: British Columbia

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	Generation time estimated to be 33 years based on recommendations for species which never or rarely produce sporophytes and are not known to produce asexual reproductive structures (see Bergamini *et al*. 2019).
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No, the number of individuals is one, based on the 'individual-equivalent' concept adopted by the IUCN.
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Not applicable
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Not applicable
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Not applicable
[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.	Not applicable
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?	No

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	4 km²
Index of area of occupancy (IAO) (Always report 2x2 grid value).	4 km²

Is the population "severely fragmented" i.e., 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, there is only one subpopulation.
Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	One
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No, the extent of occurrence is based on a single subpopulation.
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	No, because the index of area of occupancy is based on a single subpopulation. Possibly inferred on the basis of potential loss due to tsunami and global warming.
Is there an [observed, inferred, or projected] decline in number of subpopulations?	No, there is only one subpopulation.
Is there an [observed, inferred, or projected] decline in number of "locations"*?	No, there is only one location.
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes, there is an observed decline in the quality of habitat associated with the growth of young trees alongside the cliff habitat of Slender Yoke-moss. The moss has been infected with lichen and cyanobacteria as a result of increased humidity because of the shading.
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)	**N Mature Individuals**
Moresby Camp	One 'individual equivalent', based on the moss occupying an area of approximately 1 m^2 on a single cliff face.
Total	One

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Not calculated

* See Definitions and Abbreviations on COSEWIC web site and IUCN (Feb 2014) for more information on this term

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? Yes.

Key threats to Slender Yoke-moss identified in the draft IUCN Threats Assessment (Appendix 1) include quarrying, problematic native species (trees), tsunamis, droughts, and temperature extremes. For details see Threats and Limiting Factors in this report, and Appendix 1.

3 Energy production and mining
3.2 Mining and quarrying

11 Climate change and severe weather
11.2 Droughts
11.3 Temperature extremes

10 Geological events
10.2 Earthquakes and tsunamis

8 Invasive / non-native and other problematic species and genes
8.2 Problematic native species / diseases

Other threats considered in the Assessment were:

6 Human intrusions and disturbance
6.3 Work and other activities: site verification and monitoring

8 Invasive / non-native and other problematic species and genes
8.1 Invasive non-native/alien species/diseases

11 Climate change and severe weather
11.1 Habitat shifting and alteration

What additional limiting factors are relevant?

Key biological and environmental factors limiting Slender Yoke-moss include the uncommon and patchily distributed habitat of dry, highly pure limestone cliffs with a north to northwest-facing aspect in humid sites; local and global rarity of the species; the long distance between the Canadian population and populations in Europe; and an absence of reproduction or other known means of dispersal.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	The nearest population is in England, where the species is very rare. Its condition is unknown.
Is immigration known or possible?	It is not known and is highly unlikely.
Would immigrants be adapted to survive in Canada?	Unknown
Is there sufficient habitat for immigrants in Canada?	Unknown
Are conditions deteriorating in Canada?[+]	Unknown
Are conditions for the source (i.e., outside) population deteriorating?[+]	Unknown

[+] See Table 3 (Guidelines for modifying status assessment based on rescue effect)

Is the Canadian population considered to be a sink?	No. This species is characterized by long-term clonal persistence throughout its global range and population declines are unlikely to be rescued from source populations.
Is rescue from outside populations likely?	No. Biological and environmental limitations to dispersal make immigration unlikely.

Data Sensitive Species

Is this a data sensitive species?	Yes. Its extreme rarity likely makes it attractive to collectors.

Status History

COSEWIC Status History: Designated Endangered in November 2019

Status and Reasons for Designation

Status:	**Alpha-numeric codes:**
Endangered	B1ab(iii)+2ab(iii); C2a(i); D1
Reasons for designation: In North America, this moss is confined to a single location on Haida Gwaii, British Columbia. The extremely small population occurs on a one square-metre patch of limestone cliff face near the ocean. Imminent threats to the species are the proliferation of young, dense woody vegetation adjacent to the cliff, exerting both direct (increased shade and moisture) and indirect (overgrowth by cyanobacteria) effects on the population. Other important threats include altered precipitation patterns, droughts and temperature extremes associated with climate change, quarrying of the high-quality Sadler limestone on which the species grows, and stochastic events such as inundation by tsunamis.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. There are no data to calculate percent decline.
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Endangered, B1ab(iii)+2ab(iii), because EOO and IAO are below the threshold and there is one location; and there is an inferred decline in quality of habitat.
Criterion C (Small and Declining Number of Mature Individuals): Meets Endangered, C2a(i), because there is an inferred continuing decline, the number of mature individuals is well below the threshold of 2500 individuals, and no subpopulation is expected to exceed 250 individuals.
Criterion D (Very Small or Restricted Population): Meets Endangered, D1, based on the number of mature individuals being 1, which is far fewer than 250. Haida Gwaii in general, and particularly limestone habitats throughout the archipelago, have been well-surveyed by bryologists. The very small Canadian population is consistent with global populations of the species as suggested by its conservation status in the countries where it occurs and its “G2” Global Conservation Status.
Criterion E (Quantitative Analysis): Not applicable. Analysis not performed

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 (2019)

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.

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2019

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Common Name (English): Slender Yoke-moss

Common Name (French): Houppe gracile

Scientific name: *Zygodon gracilis* Wilson

Synonyms: *Zygodon nowellii* Schimp.; *Zygodon viridissimus* var. *saxicola* Molendo (Karttunen 1984; Tropicos 2019).

Family: Orthotrichaceae Arn.

There are approximately 90 species of *Zygodon* throughout the world, including five from North America. Three have been found in British Columbia: *Z. gracilis, Z. reinwardtii* and *Z. viridissimus* var. *rupestris* (Vitt 2014). Slender Yoke-moss was first collected in North America by W.B. Schofield in 1961.

Morphological Description

Slender Yoke-moss is a small to medium-sized, yellowish- to dark-green moss that grows on cliff faces and rock walls. The shoots are up to 5 cm tall and have lanceolate to oblong-lanceolate leaves. The leaves are spreading and recurved (bent backward) when wet and contorted and incurved when dry. The margins of the leaves are sharply toothed near the leaf apex and entire (untoothed) toward the base. The prominent costa (or midrib of the leaf) almost reaches or extends just beyond the leaf apex. Sporophytes (spore-producing structures) are unknown in Canada and have rarely been observed elsewhere (Altherton *et al*. 2010; Vitt 2014; Stebel and Zarnowiec 2017).

Population Spatial Structure and Variability

Slender Yoke-moss is known from one occurrence in Canada and the spatial structure and variability of the population has not been studied.

Designatable Units

The Canadian population of Slender Yoke-moss is assessed as a single designatable unit.

Special Significance

Slender Yoke-moss is known from just one occurrence in North America. It is extremely rare throughout its global range (Schofield 1989, 1990; Ryan 1996; Stebel and Zarnowiec 2017)—despite being abundant at some sites—and has a global conservation

ranking of 'Imperiled' (G2) (NatureServe 2019). It is a candidate for the forthcoming *Red List of Threatened European Bryophytes* (Hodgetts 2015).

The species is one of several bryophytes of conservation concern in British Columbia (CESCC 2016; BC CDC 2019) that are thought to have persisted in a coastal refugium during the last glaciation (Schofield 1988).

DISTRIBUTION

Global Range

The global distribution of Slender Yoke-moss has been described as "Western Europe–Western North America" (Golumbia and Bartier 2004). The species is found in Canada; the Yorkshire area of northern England; the Alps (Austria, Germany, Italy, Switzerland), and the western Carpathian Mountains (Poland, Romania, Slovakia) (Figure 1). Outside Canada and England it is regarded as an alpine species (Schofield 1968; Frahm 2012). It was reported from Guatemala (e.g., Vitt 2014), but it has since been confirmed that the specimen was misidentified (Allen 1994). The Canadian population is highly disjunct from the European populations.

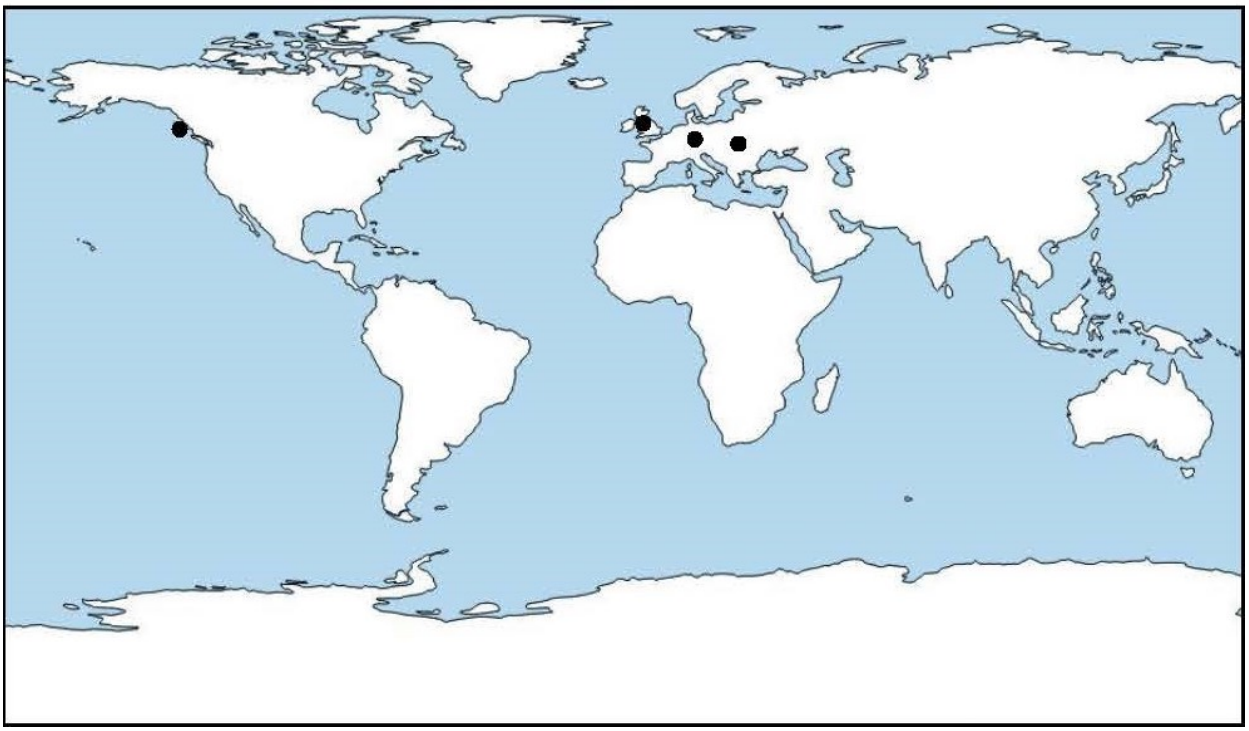

Figure 1. Global distribution of Slender Yoke-moss (*Zygodon gracilis*) including Canada, England, the Alps (Austria, France, Germany, Italy, and Switzerland) and western Carpathian Mountains (Poland, Romania, and Slovakia) in Europe.

Canadian Range

The Canadian population of Slender Yoke-moss is located on northeastern Moresby Island on Haida Gwaii (formerly known as the Queen Charlotte Islands), British Columbia, at the site of an abandoned logging camp known as Moresby Camp at the head of Gillatt Arm in Cumshewa Inlet. It has been estimated that the Canadian population accounts for approximately 35% of the global population (CESCC 2016), but that figure seems high considering recent reports documenting its occurrence in several countries in Europe (e.g., Müller 2007; Aleffi *et al*. 2008; Ştefănuţ and Goia 2012; Hodgetts 2015; Pescott 2016; Stebel and Zarnowiec 2017). A more accurate estimate of the Canadian portion of the global population would be around 10%, based on records from nine countries in Europe (Hodgetts 2015) and Canada.

Extent of Occurrence and Area of Occupancy

Based on the single known subpopulation of Slender Yoke-moss in Canada, the extent of occurrence (EOO) is 4 km^2. For reference, the substrate on which it occurs—Sadler Limestone—is estimated to cover 54 km^2 across Haida Gwaii (Figure 2a), very little of which is above ground, near water, unshaded, or occurring as cliffs with a north or northwest aspect.

The index of area of occupancy (IAO) of Slender Yoke-moss in Canada is 4 km^2 based on a single 2 km x 2 km grid cell.

Search Effort

Bryologists have collected widely throughout Haida Gwaii. The archipelago was particularly well-travelled by W.B. Schofield, who spent 16 field seasons on the islands and collected more than 11,000 specimens from 1961–2002 (Schofield 1989; Golumbia and Bartier 2004). Other bryologists and botanists are known to have collected over 2000 additional specimens. In total, bryophytes have been collected from more than 260 sites, including 33 sites associated with limestone deposits. Four sites were searched for the purposes of this report (Table 1).

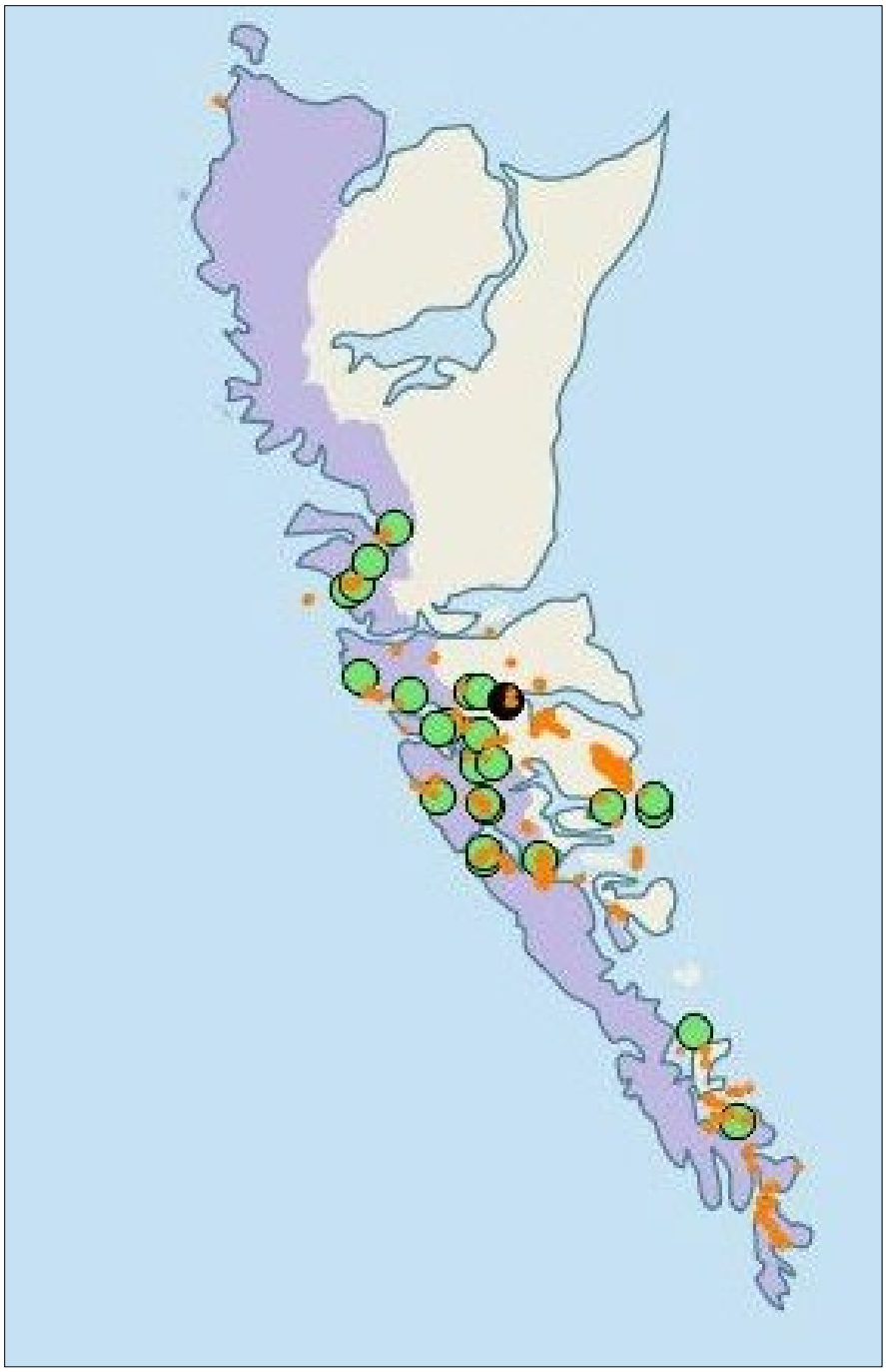

Figure 2a. Canadian distribution of Slender Yoke-moss (*Zygodon gracilis*) (black dot), collection sites on limestone (green dots) and Sadler Limestone (orange), the only type of limestone with very high calcium carbonate ($CaCO_3$) content on the archipelago.

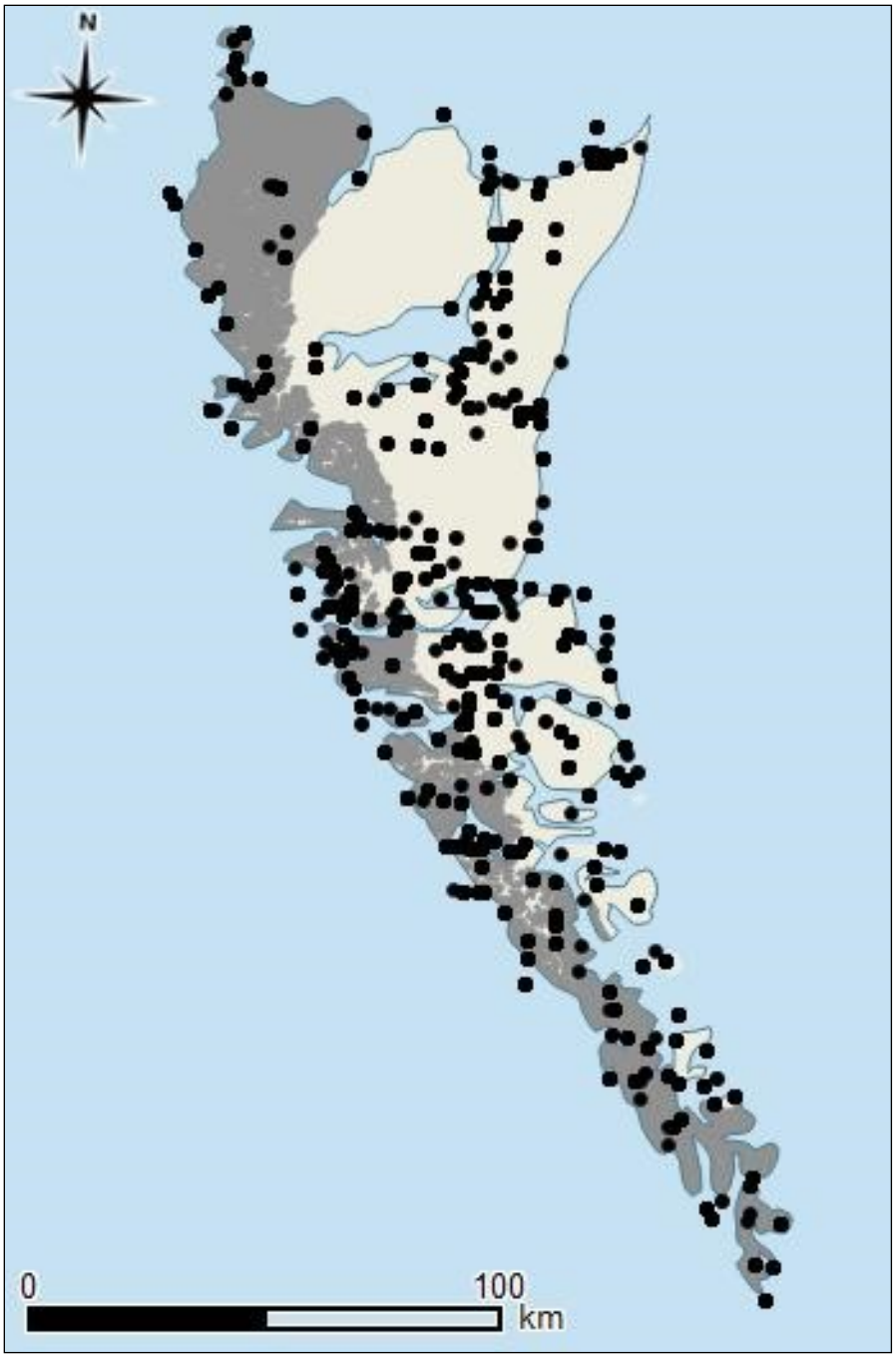

Figure 2b. Bryophyte collection sites on Haida Gwaii, British Columbia, based on herbarium specimens at UBC with additional records from D.H. Vitt, K. Hassel, B. Shaw, and K. Golinski.

Table 1. Targeted search effort for Slender Yoke-moss (*Zygodon gracilis*).

	Site	Date(s)	Surveyor(s)	Result
1	East Limestone Island	July 16, 2017 July 17, 2017	Golinski, Goyette	Not found
2	Moresby Island, Moresby Camp	July 23, 2017 Aug 17, 2017	Golinski, Goyette	Not found
3	Moresby Island, Tasu, outcrops from second mine to below peaks	July 26, 2017	Golinski, Goyette	Not found
4	Moresby Island, Moresby Lake, northeast end	Sept. 18, 2017	Golinski	Not found
5	Moresby Island, Moresby Camp	Sept. 24, 2017	Golinski, Hassel	Not found
6	Moresby Island, Kootenay Inlet narrows, sloping cliffs on south side	Sept. 25, 2017	Golinski	Not found
7	Moresby Island, Moresby Camp	June 28, 2018	Golinski, Miles	Found

Schofield (1968) noted that although he had collected bryophytes from limestone substrates throughout Haida Gwaii, he observed *Zygodon gracilis* at only one place. As further evidence of the species' rarity and the small size of the subpopulation, only four specimens are known to have been collected by Schofield (three are deposited at UBC and one is at the University of Michigan) compared to multiple collections of other uncommon bryophytes.

HABITAT

Habitat Requirements

Slender Yoke-moss is a narrow habitat specialist. It occurs exclusively on vertical surfaces of dry outcroppings of highly pure limestone and rock walls consisting of Carboniferous limestone in England. It typically occupies surfaces with north or northwest-facing aspects where it intercepts mist and rain (Porley 2013). In Canada it occupies a cliff face of Sadler limestone (Figure 2a), which comprises massive, thick-bedded grey limestones with very high calcium carbonate ($CaCO_3$) content. Sadler limestone is the only type of pure limestone found on Haida Gwaii and is absent from the mainland coast of British Columbia. Most deposits of Sadler limestone are found in the Coastal Western Hemlock biogeoclimatic zone, but limited quantities are present in the higher-elevation Mountain Hemlock and Alpine Tundra zones.

Habitat Trends

Habitat trends have not been studied but limestone deposits outside parks and other protected areas on Haida Gwaii are known to be desirable for industrial purposes. The deposit of Sadler Limestone at Moresby Camp is highly pure and commercially valuable (Tolbert 1987). Although the portion of the cliff face occupied by Slender Yoke-moss is intact, there is ample evidence of disturbance to nearby parts of the outcropping, including disturbed vertical surfaces (likely caused by blasting), heavy-duty cable drape-netting

armoring parts of the cliff face, and a large old concrete wall attached to the cliff face. An incredible tangle of industrial cables and pulleys was left behind in the nearby coniferous forest (Appendix 3).

Whereas the moss's immediate habitat is physically undisturbed, young Sitka Alder (*Alnus viridis* ssp. *sinuata*) and Western Redcedar (*Thuja plicata*) trees have grown up alongside it and are shading the population. Changes to the microclimate may be causing overgrowth of several species of mosses, including Slender Yoke-moss, by cyanobacteria (*Nostoc*), lichens (including *Cladonia* and what appears to be *Leptogium*) and filmy fern gametophytes (Wright's filmy fern, *Hymenophyllum wrightii*) (Appendix 3). The cyanobacteria, lichens, and filmy fern were absent from Schofield's specimens collected in 1961 and 1994.

The trees are young and seem to have become established after the logging camp was abandoned; it is not known whether the area between the cliff face and the ocean was forested before the logging camp was established, but if it was, it is likely that the forest was relatively "open" in character and not densely treed.

BIOLOGY

Life Cycle and Reproduction

Slender Yoke-moss is dioicous (Longton 1992), meaning male and female gametangia occur on separate plants. Populations of the moss at most sites are either male or female. The species has the life strategy of a "perennial stayer" (Hodgetts 1996) (i.e., it is long-lived, expends little if any energy on producing spores or specialized vegetative structures, and occupies a very stable habitat). As previously noted, sexual reproduction has not been observed in Canada and examined specimens are sterile (Schofield 1968). Sporophytes have only been observed twice in England (Longton 1992), first in the mid-1800s and not again until 2002/2003 (Porley 2013), some 140 years later (Bachtold 2003; Pickerell 2003). Sexual reproduction has not been reported from other countries.

Although specialized asexual reproductive structures (protonemal gemmae) have been produced in culture in an *ex situ* pilot conservation program (Duckett *et al.* 2004; Rowntree and Rumsey 2005), gemmae have not been observed in the wild. The Canadian population of Slender Yoke-moss consists of a few small colonies which apparently persist through clonal growth. The IUCN has adopted the recommendations of Bergamini *et al*. (2019), which suggest that for species that are never or rarely observed to produce sporophytes and do not reproduce asexually, generation length be estimated at 33 years.

Physiology and Adaptability

Slender Yoke-moss is confined to north- and northwest-facing aspects of limestone cliff faces and rock walls in areas with high humidity and rainfall where it intercepts mist, rain, and fog (Porley 2013). The species' restriction to these habitat conditions suggests

that it has limited desiccation tolerance. Although the physiology and adaptability of the species have not been studied, it is expected that a species occupying such a narrow physiological niche and which has no effective means of dispersal would be unlikely to survive or successfully compete against other species if moisture regimes or intensity and duration of sunlight are altered. Scanty populations in multiple countries (see, e.g., Stebel and Zarnowiec 2017) further suggest the adaptability of the species is extremely low. As noted by Glime (2017), clonal growth habit in mosses has multiple advantages but, in the absence of other means of reproduction, increases the vulnerability of colony-forming species to permanent changes in the environment and to physical disturbance.

Dispersal and Migration

Schofield (1989) suggested that the globally disjunct populations of bryophytes on Haida Gwaii may be remnants of an extremely ancient flora, possibly of Tertiary origin, that survived in island refugia but are not expanding in range. Bryophytes typically disperse by wind-blown spores, although alternative means of dispersal do exist. As noted above, spores can only be produced if both sexes are present in proximity, and Slender Yoke-moss produces spores very infrequently or not at all. Sporophytes are not known from Haida Gwaii, nor are gemmae. Therefore, the potential for Slender Yoke-moss to disperse or migrate, even short distances, is extremely low to non-existent.

Interspecific Interactions

In northern England, female reproductive structures of Slender Yoke-moss have been damaged by mites (Bachtold 2003). In Canada, interspecific interactions between Slender Yoke-moss and other species have not been documented. However, as previously noted, young trees appear to be affecting light and moisture regimes in the moss's habitat, which may be facilitating the growth of cyanobacteria.

POPULATION SIZES AND TRENDS

The single known subpopulation of Slender Yoke-moss in Canada consists of one individual based on the concept of 'an individual-equivalent' because the species is known from a single cliff. As outlined by Bergamini *et al*. (2019) and adopted by the IUCN: "saxicolous taxa growing on cliffs or on other more or less flat surfaces: an 'individual-equivalent' = 1 m^2 [i.e., 1 m^2 in which the taxon occurs, whether as a single ramet or as a dense carpet of many ramets covering most of the surface]".

The subpopulation was first discovered by Schofield in 1961 and last observed in 2018. Although a small number of specimens have been collected for scientific study, the condition of the population has not been monitored.

Sampling Effort and Methods

The subpopulation of Slender Yoke-moss at Moresby Camp was relocated by bryologist Wynne Miles in 2018. It is located on a limestone cliff approximately 3 m above ground level.

Abundance

The abundance of Slender Yoke-moss at Moresby Camp was not documented when Schofield collected specimens in 1961, 1966, or 1994. However, the 1966 specimen label notes that the species was “very rare on dry limestone cliff” (Appendix 2). In 1968, Schofield reported in a publication on “mosses of particular interest” in British Columbia that the species was “sterile and extremely rare” (Schofield 1968). The description on the 1994 specimen collection simply states: “black tuft on cliff”. As previously noted, only four specimens of Slender Yoke-moss (including one duplicate) were collected by Schofield, which highlights the rarity of the moss compared to other uncommon species, of which multiple collections were made.

In 2018, the subpopulation of Slender Yoke-moss at Moresby Camp consisted of fewer than ten diffuse colonies of approximately 2 cm^2 each, scattered in an area of approximately 1 m^2 on a cliff-face.

Fluctuations and Trends

There are no estimates of fluctuations and trends in the Canadian population of Slender Yoke-moss. However, several specimens have been collected since 1966 and it is unlikely that the area occupied by the population is expanding given the lack of sexual reproduction and production of gemmae. This speculation is reinforced by the absence of observations of colony-expansion elsewhere (Pressel and Duckett 2004).

Rescue Effect

Populations of Slender Yoke-moss in England or central Europe cannot be expected to serve as sources of naturally dispersing propagules because of the long distance between sites and extreme rarity of sexual reproduction (e.g., Longton 1992).

In England, Pressel and Duckett (2004) successfully cultured Slender Yoke-moss in the lab and subsequently reintroduced it to a locality where it was known to occur. It successfully formed healthy colonies but did not produce gemmae or sporophytes and did not colonize adjacent areas.

THREATS AND LIMITING FACTORS

Threats

The two greatest known threats to Slender Yoke-moss are quarrying and climate change. The species is also threatened by earthquakes, tsunamis, and problematic native species. In North America it is known from a single occurrence and the entire population consists of one 'individual equivalent', making it extremely vulnerable to known threats and unanticipated stochastic events. An IUCN Threats Assessment of Slender Yoke-moss (Appendix 1) resulted in an overall assigned threat assessment of "Very High-Very High" based on the single 'individual equivalent' and an assigned generation length of 33 years, with three generations being equal to 100 years (see Bergamini *et al*. 2019).

Energy Production and Mining

Mining and quarrying (Threat category 3.2)

The population of Slender Yoke-moss on Haida Gwaii is found on a cliff face of a large outcropping of highly pure Sadler limestone (BCGS 2019). The mineral deposit was surveyed as part of City Resources (Canada) Limited's "Lime Claims" (Tolbert 1987). Although the claim is presently expired, limestone is evidently a desirable commodity as suggested by new claims on Sadler limestone deposits at Tasu. If the claim at Moresby Camp is reinstated or a new claim is made and quarrying proceeds, the entire known population of Slender Yoke-moss and its habitat in Canada and North America would be eliminated. Therefore, in the IUCN Threats Calculator the Scope of the threat is deemed to be "Pervasive", Severity "Extreme", and Timing "Moderate–Low". The overall calculated impact of quarrying on Slender Yoke-moss is "Very High".

Climate Change and Severe Weather

It is well-established that climate change will impact all biogeoclimatic zones of Haida Gwaii (Banner *et al*. 2014). Currently the climate in the areas where Slender Yoke-moss occurs at low elevation within the 'Submontane' variant of the 'Wet Hypermaritime' subzone of the Coastal Western Hemlock zone (CWHwh1) is characterized (as summarized by Banner *et al*. 2014) by cool, moist summers and mild, wet winters with little snowfall. Mean annual temperature is 7.4°C (ranging from 5.1–9.2°C), mean annual precipitation is 1948 mm (ranging from 1042–5458 mm) and average snowfall is 152 cm, with a record low of 42 cm and a high of 991 cm. Low cloud and fog are common, and relative humidity is typically high throughout the year. Near sea level, where Slender Yoke-moss is found, little precipitation falls as snow and snowpack is ephemeral.

Throughout the Skeena-Queen Charlotte region, it is predicted that mean annual temperature will increase by 1.4 °C from 1961–1990 baseline values by the 2050s, with the greatest increase in temperature occurring in summer (PCIC 2012; Vadenboncoeur *et al*. 2016). Average annual precipitation is predicted to increase by 7%—which could be construed as a positive change for bryophytes—but the timing and intensity of precipitation

events will shift, as will the form of precipitation, with major reductions in snowfall in winter and spring (PCIC 2012; Vadenboncoeur *et al*. 2016).

Predicting future climate is complicated by two major climatic cycles: the El Niño / La Niña Southern Oscillation (ENSO), which alternates between warm to cold phases every 3–5 years, and the Pacific Decadal Oscillation (PDO) which cycles between warm and cold phases every 40–60 years. Deviations from average values are expected to have major impacts on rare mosses like Slender Yoke-moss, Carey's Bristle-moss (*Seligeria careyana*), and Drooping-leaved Beard-moss (*Oxystegus recurvifolius*), which have very small populations, limited means of dispersal, and occupy a very narrow physiological niches in patchily distributed habitats and therefore could not easily migrate in response to climate change. Species with such characteristics are more vulnerable than most to the ongoing effects of climate change (see Gayton 2008). In the IUCN Threats Calculator, the threat of Climate Change has a Timing of "High", a Severity of "Extreme", and the entire population of Slender Yoke-moss will be affected, therefore the Scope is "Pervasive". The overall Calculated Impact is "Very High"

Habitat shifting and alteration (Threat category 11.1)

Habitat-shifting and alteration are occurring on a regional scale throughout coastal British Columbia (Harding and McCullum 1997) and will continue to affect all biogeoclimatic zones on Haida Gwaii (Banner *et al*. 2014). Owing to the isolation of the archipelago, it is thought that the initial effects of climate change on plants are being expressed as changes in vigour, relative productivity, and reproductive capacity; these are expected to be followed by altered distribution patterns (Banner *et al*. 2014). The uncertainty of projected climate change is compounded by the complex topography and pronounced ecological gradients on the archipelago (Banner *et al*. 2014).

The limestone cliff habitat of Slender Yoke-moss is expected to be affected by climate change sooner and more severely than forested habitats. As noted by Porley (2013), in Britain the species was formerly found in relative abundance at both low and high elevation but declines in the subpopulations at low elevation are correlated with statistically significant differences in altitude. This may indicate sensitivity to climate change, given that the average winter temperature in Britain has increased by 0.5 °C over the past century. Although Habitat Shifting has been observed in Masset, it has not been documented at Moresby Camp; therefore, it was not scored in the Threats Calculator.

Droughts (Threat category 11.2)

The habitat of Slender Yoke-moss is a limestone cliff in an area that is regularly subject to fog and rain. Altered precipitation regimes in the CWHwh1 as predicted by ClimateBC (Wang *et al*. 2012) and other information sources for coastal British Columbia (e.g., PCIC 2012) include an overall increase in annual precipitation but a decrease in rainfall during summer and a decrease in precipitation falling as snow, particularly in winter and spring.

If rainfall decreases and causes prolonged drought, the moss would likely be exposed to microclimatic conditions outside its range of desiccation tolerance, causing physiological stress or possible death. In the IUCN Threats Calculator, the Timing of Droughts was deemed to be “High (Continuing)”; the Severity “Extreme-Moderate”, reflecting some uncertainty; and the Scope “Pervasive”, because the threat will affect the entire population. Overall, Droughts have a Calculated Impact of “Very high–Medium”.

Temperature extremes (Threat category 11.3)

Although there are no known studies demonstrating the tolerance of Slender Yoke-moss to temperature extremes, its occurrence solely in oceanic and mountainous climates suggest that it would not tolerate high temperatures. As with Droughts, the Timing of Temperature Extremes is scored “High (Continuing)”; the Severity “Extreme–Moderate”; and the Scope “Pervasive”. The Calculated Impact is “Very high–Medium”.

Geological Events

Earthquakes and tsunamis (Threat category 10.2)

The population of Slender Yoke-moss at Moresby Camp will likely be inundated by seawater in the event of a major tsunami (see Rabinovich *et al*., 2019), although the effects of inundation by seawater are unknown and there is no evidence that the site has been inundated in recent years. The population is located at the head of Cumshewa Inlet very close to the shoreline (<10 m) and near sea level (<10 m). Strong earthquakes are common on the Queen Charlotte Fault and have caused occasional tsunamis (Bevington *et al*. 2017). Furthermore, the threat of tsunamis will be exacerbated by future sea level rise, which at Prince Rupert on the mainland coast is projected to increase between 0.10–0.31 m (based on extreme low estimates of global sea level rise) and 0.95–1.16 m (based on extreme high estimates) by 2100 (Bornhold 2008; and see Thomson *et al*. 2008 for further discussion). The Timing of the threat is scored as “High–Low”, the Scope “Pervasive”, and the Severity “Serious”, with an overall Calculated Impact of “High”.

Invasive and Other Problematic Species and Genes

Invasive non-native / alien species (Threat category 8.1)

When sporophytes of Slender Yoke-moss were found in northern England in 2003, Headley and Rumsey observed damage to female reproductive organs (archegonia) caused by mites (Bachtold 2003; Porley 2013). Bachtold (2003) reported that the researchers would write an article on the topic, but to date, it does not appear to have been published. Mites have not been observed on the specimens of Slender Yoke-moss from Moresby Camp and are therefore not included in the Threats Calculator.

Problematic native species / diseases (Threat category 8.2)

Native Sitka Alder (*Alnus viridus* ssp. *sinuata*) and Western Redcedar (*Thuja plicata*) trees have become established immediately alongside the cliff face where Slender Yoke-moss occurs (see Appendix 3). The trees currently cast shade on the moss population and may be facilitating abundant growth of cyanobacteria on multiple species of mosses, including Slender Yoke moss. Future research may illuminate the extent to which the trees are affecting environmental conditions such as light, temperature, humidity, and air flow. Currently the Timing of the threat is scored as "High-Continuing", with Severity ranked as "Serious-Slight" to reflect uncertainty until the population can be more closely examined, and Scope as "Pervasive". The Calculated Impact is "High-Low".

Human Intrusions and Disturbance

Work and other activities (Threat category 6.3)

As early as 1966, Schofield noted that Slender Yoke-moss was very rare at Moresby Camp. Unless researchers and conservation practitioners take extreme care to avoid over-collecting for research (e.g., for DNA analyses) and damaging the population while monitoring it, the Canadian population of Slender Yoke-moss will be adversely impacted. In the Threats Calculator the timing was determined to be "High (Continuing)" because the moss is expected to be studied in the near future; the Severity is scored as "Negligible" because it is hoped that care will be taken to limit adverse effects; and the Scope is "Pervasive" because the entire population is subject to the threat. The calculated impact is "Negligible".

Transportation and Service Corridors

Roads and Railroads (Threat category 4.1)

The large outcropping of limestone at Moresby Camp is located near the end of a narrow, abandoned road or track, fewer than 10 metres from the ocean shore. In 2017 and 2018 flagging-tape indicating road-widening was attached to a nearby outcropping. However, there are apparently no known plans for roadwork to proceed (B. Wijdeven, pers. comm. 2018). Therefore, Roads was not included in the Threats analysis.

Limiting Factors

Slender Yoke-moss is limited by several factors including extreme rarity of reproduction, high habitat specificity, and a globally disjunct pattern of distribution (Porley 2013). In the British Isles the extant population is composed of numerous colonies occurring within a single hectad (an area of 10 km x 10 km). The species is dioicous and most colonies consist of either males or females. Vegetative reproduction has not been observed outside the laboratory.

Slender Yoke-moss is an example of Longton and Hedderson's (2000) model of rare bryophytes constrained by habitat rarity and a narrow range of climatic conditions (Söderström 2006; Porley 2013). In Britain, the species occurs primarily on north- and northwest-facing vertical surfaces of dry Carboniferous limestone (including rock walls) where it intercepts rain and mist (Porley 2013) and presumably stays moist for longer periods of time than it would on southern-facing surfaces. In Canada, Slender Yoke-moss occurs within a temperate climate zone on a limestone cliff that is similarly north-facing and intercepts rain and fog.

Number of Locations

The number of locations of Slender Yoke-moss in Canada is one because there is only one known occurrence. Haida Gwaii is among the most well-explored regions in Canada for bryophytes, but despite extensive collecting throughout the archipelago and targeted searches for the species, it has nevertheless been found at only one site.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Slender Yoke-moss is not protected under Canada's *Species at Risk Act* (SARA), the British Columbia *Wildlife Act*, or any other legislation (BC CDC 2019).

Non-Legal Status and Ranks

The global conservation status of Slender Yoke-moss is G2, "Imperiled" (NatureServe 2019), and its status in Canada is N1, "Critically Imperiled" (CESCC 2016). In British Columbia its status is S1S2, "Critically Imperiled" (BC CDC 2019), but it was reported as S1 by the Canadian Endangered Species Conservation Council (CESCC 2016). It is included on the province's "Red List" (BC CDC 2019).

Zygodon gracilis is a candidate for the forthcoming *Red List of Threatened European Bryophytes* (Hodgetts 2015). As reported by Hodgetts (2015) it is "Critically Endangered" in Slovakia; "Endangered" in Great Britain, Italy, and Poland; and "Vulnerable" in Switzerland. In Austria it has been designated as "Risk Assumed", whereas in Germany its status is "Extremely Rare". The species is confirmed from France although its current status is unknown, and it is "Regionally Extinct" in Romania. In 2017 Stebel and Żarnowiec assessed *Z. gracilis* as "Critically Endangered" in Poland.

Habitat Protection and Ownership

The only known location of Slender Yoke-moss in Canada is at Moresby Camp at the head of Gillatt Arm in Cumshewa Inlet on Moresby Island. It is on Crown land and is not protected.

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COLLECTIONS EXAMINED

Three specimens of Slender Yoke-moss were borrowed from the University of British Columbia (UBC) and examined:

1. Cumshewa Inlet, NW coast of Moresby Island, Queen Charlotte Islands, Dry marble cliff, August 25, 1961, 24/08/1961, Coll. W.B. Schofield #15517, Det. H. Person (?) (UBC B145602).

2. Moresby Logging Camp, Gilliatt (sic) Arm, Cumshewa Inlet, Moresby I., Queen Charlotte Islands, 50° 03′ N, 132° 01′ W, Very rare in dry limestone cliff, July 21, 1966, W.B. Schofield #32063 (UBC B145603).

3. Queen Charlotte Is., Moresby I., Moresby Campsite, Cumshewa Inlet head, limestone cliff near shore, Black tuft on cliff, June 28, 1994, W.B. Schofield #100935 (UBC B15498)

A duplicate of a specimen collected by Schofield, #32062, held by the University of Michigan but with a different date (July 31, 1966), was annotated by Dale H. Vitt (1-69): “Compares well with European material”.

Appendix 1. IUCN Threats Calculator for Slender Yoke-moss (*Zygodon gracilis*).

Species or Ecosystem Scientific Name	Slender Yoke-moss (*Zygodon gracilis*)		
Element ID	122728	**Elcode**	NBMUS7Z030
Date	5/4/2018		
Assessor(s):	Author; SSC: Jennifer Doubt, Nicole Fenton, Chris Lewis, Richard Caners, Rene Belland; BC: Brenda Costanzo, Dave Fraser; CWS: Ruben Boles; Facilitator: Dwayne Lepitzki		
References:			

Overall Threat Impact Calculation:

		Level 1 Threat Impact Counts	
Threat Impact		**high range**	**low range**
A	Very High	3	2
B	High	1	2
C	Medium	0	0
D	Low	0	0
Calculated Overall Threat Impact:		Very High	Very High
Assigned Overall Threat Impact:		**A = Very High**	
Impact Adjustment Reasons:		No adjustment: the species is known from a single location in Canada and North America and is globally rare.	
Overall Threat Comments:		Generation time is 33 years. Threats calculator based on a single unprotected site on Crown land. Note that the threat teleconference occurred In 2018 but was subsequently revised to reflect the new definition of individual and the Impact of Problematic native species/diseases was increased based on comparison of older and recent specimens.	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3	Energy production and mining	A	Very High	Pervasive (71-100%)	Extreme (71-100%)	Moderate - Low	
3.2	Mining and quarrying	A	Very High	Pervasive (71-100%)	Extreme (71-100%)	Moderate - Low	The population of Slender Yoke-moss on Haida Gwaii is found on the cliff face of a large outcropping of very pure limestone. The species' habitat would be eliminated if an expired mineral claim on the limestone deposit is reinstated.
6	Human intrusions and disturbance		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	
6.3	Work and other activities		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Future research and monitoring may have negligible effects on the population of *Zygodon gracilis*.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8	Invasive and other problematic species and genes	A	Very High	Pervasive (71-100%)	Extreme (71-100%)	High (Continuing)	
8.1	Invasive non-native/alien species/diseases						Mites have been found on Slender Yoke-moss in England, but none have been observed on specimens from British Columbia.
8.2	Problematic native species/diseases	AB	High-Low	Pervasive (71-100%)	Serious-Slight (31-100%)	High (Continuing)	Sitka Alder (*Alnus viridus* subsp. *sinuata*) and Western Redcedar (*Thuja plicata*) have become established alongside the cliff face where *Zygodon gracilis* occurs and the altered microclimate appears to be facilitating the growth and spread of cyanobacteria, lichens and filmy fern gametophytes which have invaded *Zygodon gracilis* colonies.
10	Geological events	B	High	Pervasive (71-100%)	Serious (31-70%)	High - Low	
10.2	Earthquakes/tsunamis	B	High	Pervasive (71-100%)	Serious (31-70%)	High - Low	It is highly likely that the population of Slender Yoke-moss would be inundated by a major tsunami. The site is located <10 m above sea level and <10 m from the shoreline at the head of Cumshewa Inlet, strong earthquakes are common on the Queen Charlotte Fault, and previous earthquakes have occasionally caused tsunamis.
11	Climate change and severe weather	A	Very High	Pervasive (71-100%)	Extreme (71-100%)	High (Continuing)	
11.1	Habitat shifting and alteration						The unsheltered, dry limestone cliff habitat of Slender Yoke-moss would be extremely vulnerable to habitat shifting and alteration, drought, and high temperature extremes. Habitat shifting has been observed at Masset but has not yet been observed at Moresby Camp.
11.2	Droughts	AC	Very High - Medium	Pervasive (71-100%)	Extreme - Moderate (11-100%)	High (Continuing)	The moss is restricted to humid sites and so is not thought to be desiccation-tolerant. Any changes to temperature or humidity are expected to have a significant impact on the species as has been suggested in Britain (Porley 2013)..

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.3	Temperature extremes	AC	Very High - Medium	Pervasive (71-100%)	Extreme - Moderate (11-100%)	High (Continuing)	See 11.2
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).							

Appendix 2. Photographs of the UBC herbarium specimens of Slender Yoke-moss (*Zygodon gracilis*). Photographs by Karen Golinski.

Appendix available upon request.

Appendix 3. a) Habitat of Slender Yoke-moss (*Zygodon gracilis*), Moresby Camp (left part of photo); b) potential habitat, east Limestone Island; disturbance and threats to Slender Yoke-moss at Moresby Camp: c) disturbed cliff face and concrete wall; d) drape-netting armoring; e) flagging tape (centre of photo) indicating future roadwork; f) cyanobacteria overgrowing moss. Photographs by Karen Golinski.