COSEWIC
Assessment and Status Report

on the

Carolina Mantleslug
Philomycus carolinianus

in Canada

THREATENED
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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Production note:
COSEWIC would like to acknowledge Annegret Nicolai for writing the status report on Carolina Mantleslug, *Philomycus carolinianus*, in Canada, prepared under contract with Environment and Climate Change Canada. This report was overseen and edited by Dwayne Lepitzki, Co-chair of the COSEWIC Molluscs Specialist Subcommittee.

For additional copies contact:

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

Tel.: 819-938-4125
Fax: 819-938-3984
E-mail: ec.cosepac-cosewic.ec@canada.ca
www.cosewic.ca

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Cover illustration/photo:
Carolina Mantleslug — Photo by Annegret Nicolai, Stone Road Alvar, August 2017.

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COSEWIC
Assessment Summary

Assessment Summary – November 2019

Common name
Carolina Mantleslug

Scientific name
Philomycus carolinianus

Status
Threatened

Reason for designation
In Canada, this large terrestrial slug inhabits undisturbed older-growth forests and riparian areas in the Carolinian Forest Region of Ontario, near the northern limit of its global range. The earliest reliable records (1994, 1995) are from two mainland sites in southwestern Ontario and Pelee Island. Recent searches have confirmed only a small number of additional sites within this small range. Suitable habitat in Canada has experienced historical loss and degradation, and continuing habitat fragmentation is problematic because this species has low dispersal ability. The species is threatened by climate change (extreme temperatures, droughts, and flooding), prescribed burns, and invasive species.

Occurrence
Ontario

Status history
Designated Threatened in November 2019.

COSEWIC
Executive Summary

Carolina Mantleslug
Philomycus carolinianus

Wildlife Species Description and Significance

Carolina Mantleslug is a large slug (adult body length of active animals averages about 7 cm) with a grey mantle covering the entire body. There are two central lines of black dots on its back. This species is part of the unique fauna of the Carolinian Forest in Canada and has significance for ecosystem functioning through nutrient cycling. The range edge population in Canada is important for the global conservation of this species.

Distribution

Carolina Mantleslug global distribution extends from as far north as northern Michigan southward to Florida in the east and Texas in the west. In Canada, the species is still extant on Pelee Island and in four mainland sites in Essex, Chatham-Kent, and Lambton counties, Ontario. The presence at two historical occurrences is uncertain, because they are privately owned and could not be accessed.

Habitat

Carolina Mantleslug inhabits riparian or wet deciduous forests and can be found clustered under logs or in the leaf litter when humidity is high. The species relies on a diversity of fungi and lichen species for food. The habitat at all sites is surrounded by unsuitable arable land or water. The slug occurs in about 981 ha of protected habitat and 96 ha of privately owned forest.

Biology

Carolina Mantleslug is an egg-laying land slug. Reproduction probably occurs in spring and late-summer. Hibernation extends from early-October until April in temperate regions. Sexual maturity may be reached after one year and the species may live for 3-4 years. Depending on diet, Carolina Mantleslug lays 1-2 clutches of about 70 eggs. Hatching success varies with temperature and can be as high as about 75%. Active dispersal for colonization of new areas is extremely slow, because the species stays confined to sheltered micro-habitat (logs). Passive dispersal by flooding of rivers is possible but has not been documented. There is no evidence of transportation by humans.

Population Sizes and Trends

The density of the species is most likely extremely low: <0.01 to 0.2 mature individuals/m^2. Population size and trends are unknown.

Threats and Limiting Factors

Although Carolina Mantleslug is more resistant to drought than other slugs, low dispersal ability and low physiological resistance to fluctuating environmental factors such as cold temperature are limiting factors. The main threats for Carolina Mantleslug are climate change (flooding, changes in frost regimes, and droughts) as well as prescribed burns. Invasive species, such as earthworms which are destroying the leaf-litter and disturb plant-fungi associations, as well as pollution from agriculture are threats with unknown impact.

Protection, Status and Ranks

Carolina Mantleslug has no legal designations. It is ranked as globally secure and nationally secure in the US but critically imperilled in Canada as well as in Ontario.

TECHNICAL SUMMARY

Philomycus carolinianus

Carolina Mantleslug

Limace á manteau de la Caroline

Range of occurrence in Canada: Ontario

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)	~2 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Inferred decline based on threats.
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations, whichever is longer up to a maximum of 100 years]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations, whichever is longer up to a maximum of 100 years] including both the past and the future.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. No b. Yes c. No
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	2439 - 2070 km^2 (with and without uncertain occurrences, respectively)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	44 - 36 km^2 (with and without uncertain occurrences, respectively)

Is the population “severely fragmented” i.e., is >50% of its total area of occupancy is 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?	a. No b. Yes
Number of “locations”* (use plausible range to reflect uncertainty if appropriate)	6-8 (based on different threat combinations
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Unknown
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Unknown
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Unknown
Is there an [observed, inferred, or projected] decline in number of “locations”*?	Unknown
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes (historical habitat loss/degradation; projected continuing decline due to threats)
Are there extreme fluctuations in number of subpopulations?	Unknown
Are there extreme fluctuations in number of “locations”*?	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Are there extreme fluctuations in index of area of occupancy?	Unknown

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**N Mature Individuals**
Pelee Island (due to distance and dispersal barriers, there could be three subpopulations on Pelee Island)	Unknown
Wheatley Provincial Park	Unknown
Rondeau Provincial Park	Unknown
Grape Fern Woods	Unknown
Sinclair’s Bush	Unknown
White Oak Woods (Leamington)	Unknown
Entire range	Unknown

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

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, whichever is longer up to a maximum of 100 years, or 10% within 100 years]?	Unknown, not done

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

Was a threats calculator completed for this species? Yes; Overall impact: HIGH-LOW Threats: Threat 11: Climate change and extreme weather (HIGH-LOW impact) Threat 7: Natural system modifications (LOW impact) Threat 4: Transportation & service corridors (NEGLIGIBLE impact) Threat 5: Biological resource use (NEGLIGIBLE impact) Threat 6: Human intrusions & disturbance (NEGLIGIBLE impact) Threat 8: Invasive & other problematic species & genes (NEGLIGIBLE impact) Threat 9: Pollution (UNKNOWN impact) What additional limiting factors are relevant? Low dispersal or migration capacity, low resistance to fluctuating environmental conditions

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Ohio (SNR), Michigan (SU)
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?*	Unknown but probably
Are conditions for the source population (i.e., outside) deteriorating?*	Unknown
Is the Canadian population considered to be a sink?*	Unknown
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species? Yes, is recommended by the Molluscs SSC due to a “moderate” score for intentional killing of individuals (Data Sensitivity Matrix, O&P F8) but no further withholding of information beyond what is indicated in the report is warranted.	Yes

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

Status History

Designated Threatened in November 2019.

Status and Reasons for Designation:

Status:	**Alpha-numeric codes:**
Threatened	B1ab(iii)+2ab(iii)
Reasons for designation: In Canada, this large terrestrial slug inhabits undisturbed older-growth forests and riparian areas in the Carolinian Forest Region of Ontario, near the northern limit of its global range. The earliest reliable records (1994, 1995) are from two mainland sites in southwestern Ontario and Pelee Island. Recent searches have confirmed only a small number of additional sites within this small range. Suitable habitat in Canada has experienced historical loss and degradation, and continuing habitat fragmentation is problematic because this species has low dispersal ability. The species is threatened by climate change (extreme temperatures, droughts, and flooding), prescribed burns, and invasive species.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. There are no data on population trends.
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Threatened B1ab(iii)+2ab(iii). Both the EOO (2,070 km^2) and IAO (36 km^2) are well below the thresholds for Threatened (<20,000 km^2 and 2,000 km^2, respectively), there are fewer than 10 locations (a), and there is a projected continuing decline in extent and quality of habitat (b(iii)) caused by a variety of threats.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable as the number of mature individuals is unknown.
Criterion D (Very Small or Restricted Population): D1 is not applicable because the number of mature individuals is unknown. Threatened, D2, is not applicable because the continuous IAO (36 km^2) is above the typical 20 km^2 threshold, as is the number of locations (5 or fewer).
Criterion E (Quantitative Analysis): Not applicable due to insufficient data to perform analyses.

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
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Canada

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

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Carolina Mantleslug

Philomycus carolinianus

in Canada

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Kingdom: Animalia
Phylum: Mollusca
Class: Gastropoda
Order: Pulmonata
Suborder: Stylommatophora
Family: Philomycidae
Genus: *Philomycus*
Species: *Philomycus carolinianus*
(Bosc, 1802)

Common English name: Carolina Mantleslug

Common French name: Limace á manteau de la Caroline

Originally recognized as *Limax carolinianus* by Bosc in 1802, the species was also named *Limax caroliniensis*, *Limacella lactiformis*, *Limallea lactescens*, *Limacella elfortiana*, and *Philomycus biseriatus* (Pilsbry 1948). Pilsbry (1948) included *Philomycus flexuolaris* Raffinesque 1928 and *Philomycus togatus* Gould 1848 within *Philomycus carolinianus* but also stated that the northern "race", *P. c. flexuolaris* was the only "race" whose range extended into Canada. At the time of Pilsbry (1948), the southern race *P. c. carolinianus* was only known from the US. These three species (*P. flexuolaris* [Winding Mantleslug], *P. togatus* [Toga Mantleslug], and Carolina Mantleslug) are now considered to be distinct (Turgeon *et al*. 1998) with anatomy of reproductive organs and external morphology continuing to be used to distinguish new species within this genus (Taber and Fleenor 2011).

The three species in the genus *Philomycus* currently believed to occur in Canada have distinct ranges. While *P. carolinianus* only occurs in southwestern Ontario (Grimm 1996), *P. flexuolaris* has a more eastern distribution ranging from southeastern Ontario to Prince Edward Island and Nova Scotia (Grimm 1996; Ovaska and Lepitzki 2011; COSEWIC 2014a) and *P. togatus* has been reported from north of Lake Huron (Kearney and Gilbert 1978) and from the Niagara Escarpment eastwards (Grimm 1996).

Morphological Description

Carolina Mantleslug is a large slug with adult size 6-10 cm (measured as body length in active individuals) and an ash-coloured mantle covering the entire body (Pilsbry 1948). The mantle is marbled dark grey to brown with two central lines of black dots (see cover photo and Figure 1). The slug is most often seen when inactive, so the head is not visible and only one pair of light grey tentacles may extend from beneath the mantle.

Carolina Mantleslug has been confused with other species of the genus *Philomycus* in many collections (e.g., Oughton 1948; Pearce pers. comm. 2016), because mantle colouration is highly variable within the species. Based on external morphology, it can also easily be confused with the genera *Pallifera* or *Megapallifera*, which are distinguished internally from *Philomycus* by the absence of a dart (Pilsbry 1948). Externally, *P. carolinianus* can be distinguished from *Megapallifera mutabilis* (Changeable Mantleslug) by the absence of lateral black dotted lines (Taber and Fleenor 2011).

Figure 1A. Carolina Mantleslug (*Philomycus carolinianus*) under a log in Stone Road Alvar, Pelee Island, May 2018, feeding on yellow fungi or lichen (above the slugs) as the colour of excrements on the left side suggest. (Photo by Annegret Nicolai.)

Figure 1B. Carolina Mantleslug (*Philomycus carolinianus*) eating fungi in Richard & Beryl Ivey Property, Pelee Island, August 2017. (Photo by Annegret Nicolai.)

Population Spatial Structure and Variability

Excluding the one uncertain occurrence in Leamington (Table 1, Figure 2), at least five subpopulations may currently exist: Pelee Island in Lake Erie, Grape Fern Woods in Lambton County, and Wheatley Provincial Park, Rondeau Provincial Park, and Sinclair's Bush in Chatham-Kent County. Given distances and barriers to dispersal, more than one subpopulation could occur on Pelee Island although the effects of barriers such as roads and ditches (see Threat 4.1) on gene flow on the island are unknown. Genetic differences are expected between the island and mainland and among the isolated subpopulations on the mainland because there is probably no gene flow and dispersal over open water or across long distances (see **Dispersal and Migration**). The Pelee Island subpopulation is separated by approximately 54 km of partially open water and mostly unsuitable land from the closest subpopulation on the mainland. Lake Erie was formed at the front of the retreating Laurentide ice sheet between 12,500 and 8,000 years ago (Forsyth 1988). The gastropod community presumably colonized the peninsulas and coastal areas of this newly formed lake earlier than 4,500 years ago, when rising lake levels isolated the islands from the mainland (Duncan *et al.* 2011).

Table 1. Collections of Carolina Mantleslug (*Philomycus carolinianus*) from Ontario and verification of all sites during fieldwork in 2013-2019. Records in the Royal Ontario Museum from Oughton (1948) were misidentified and appear not to be the first records for Canada. Collections are curated by Biodiversity Institute of Ontario, University of Guelph. The BIN corresponds to taxonomic units based on COI gene sequences obtained from each specimen. Record numbers from the Natural Heritage Information Centre of Ontario (NHIC) refer to specimens in personal collections. Slugs can only be found alive.

Locality	Site	First Record	Last record	Occurrence status (surveys in 2013-2017)
Pelee Island	Stone Road Alvar (SRA) – Krestel, NCC	2014, A. Nicolai	2018, A. Nicolai	Extant
	Stone Road Alvar (SRA) – Porchuk, NCC	2013, M.J. Oldham, A. Harris, R. Foster, A. Nicolai (NHIC170498631)	2017, A. Nicolai (BIOUG14152-F03)	Extant
	Stone Road Alvar (SRA) – Ontario Nature	2010, M.J. Oldham, S.R. Brinker (NHIC171215633)	2018, A. Nicolai	Extant
	Stone Road Alvar (SRA) – Shaugnessy, NCC	2017, A. Nicolai	2018, A. Nicolai	Extant
	Stone Road Alvar (SRA) - ERCA	2017, A. Nicolai	2017, A. Nicolai	Extant
	Fish Point PNR (FP)	1994, M.J. Oldham (NHIC53783)	2015, A. Nicolai, R. Forsyth	Extant
	Richard & Beryl Ivey, NCC (RBIP)	2013, A. Nicolai	2015, A. Nicolai (BIOUG09921-F11, BIOUG09922-B11, -B12, -C01, BIOUG15234-B07)	Extant
	Winery Woods (WW)	1995, M.J. Oldham (NHIC168440650)	2017, A. Nicolai	Extant
	Campground	1995	1995, M.J. Oldham (NHIC168440652)	No access. Private. Status uncertain.
Essex Co.	Leamington, White Oak Woods (private)	1994	1994, M.J. Oldham (NHIC168440649)	No access, private. Status uncertain but habitat available.
Lambton Co.	Grape Fern Woods (private)	2017	2017, E. Caroll (SCRCA)	Extant
Chatham-Kent Co	Wheatley PP	1995, M.J. Oldham (NHIC168440648)	2017, A. Nicolai	Extant
	Rondeau PP	2018, K. Jenni	2019, A. Nicolai (in R. Forsyth's collection),	Extant
	Sinclair's Bush (private and LTVCA)	2006	2006, M.J. Oldham (MJO322505)	Not found in 2013 and 2019, but habitat available. Status extant.

Figure 2. Canadian distribution of Carolina Mantleslug (*Philomycus carolinianus*) based on records compiled for this report. “Uncertain” occurrences refer to sites that have records older than 20 years and that could not be recently verified, because habitat was not accessible (private land). “Extant” means that live individuals have been found in these sites within the last 20 years.

In order to evaluate similarity of the COI gene within the Canadian range, a genetic study was conducted at the Biodiversity Institute of Ontario (BIO, Guelph, Ontario). DNA barcoding uses sequence diversity in a 648 base pair region of the cytochrome c oxidase subunit I (COI) gene to distinguish species (Hebert *et al.* 2003). At least one or two live individuals per site were collected from Pelee Island and Wheatley Provincial Park in 2013 and 2017 and processed at BIO using a standardized method for molluscs (Layton *et al.* 2014). The Barcode Index Number (BIN) algorithm was applied to delineate clusters corresponding to operational taxonomic units at the species level (Ratnasingham and Hebert 2013). Results from preliminary barcoding show that all COI gene sequences are very similar to each other (similarity > 99%). They were also assigned to one BIN in the Barcode of Life Database (BOLD; Ratnasingham and Hebert 2007): AAK7257. *Philomycus flexuolaris*, *P. togatus*, and *M. mutabilis* were all assigned to different BINs. Barcoding could also confirm the presence of *M. mutabilis* on Pelee Island in the same habitat as *P. carolinianus*. As these species are easily confused, only *P. carolinianus* was initially recorded from Pelee Island and not *M. mutabilis*. However, all occurrences of the two species on Pelee Island were verified either through barcoding or morphological parameters.

Designatable Units

All Canadian subpopulations are within the Great Lakes Plains ecological area. Evidence of local adaptations (e.g., morphological differences) as well as barcoding genetic differences in Canada are absent (see **Population Spatial Structure and Variability**). Given no discreteness and evolutionarily significance, there is only a single designatable unit in Canada.

Special Significance

Carolina Mantleslug in Canada only occurs in the Carolinian Forest Region, near the northern limit of the its global range. As shown by Fraser (2000), range-edge populations can have significance for genetic diversity, long-term survival, and evolution of the species, and provide opportunities for human recreation activities (e.g., recreational wildlife observations, in this case, snail/slug watching).

Snails, and by extension slugs (i.e., collectively gastropods), represent 2.5 to 6% (assuming densities of 2 - 38 individuals/m^2) of the total animal biomass of boreal forest ecosystems (Hawkins *et al.* 1997b). Gastropods generally play important roles in forest ecosystem functioning, specifically by (i) aiding in decomposition, nutrient cycling, and soil building processes (Mason 1970a,b; Jennings and Barkham 1979); (ii) providing food and essential nutrients to wildlife (South 1980; Churchfield 1984; Frest and Johannes 1995; Martin 2000; Nyffeler and Symondson 2001); (iii) aiding in soil biota dispersion (Peterson *et al*. 2015), and (iv) serving as hosts for parasitic worms (e.g., Rowley *et al.* 1987). Graveland *et al.* (1994) have shown that gastropod declines can have an important impact on population dynamics of forest passerines. Gastropod diversity can also indicate the degree of anthropogenic disturbance (Douglas *et al.* 2013).

Carolina Mantleslug is unknown to most Canadians. It has no commercial value and is not an agricultural or garden pest. Aboriginal Traditional Knowledge is not available.

DISTRIBUTION

Global Range

Carolina Mantleslug is distributed across eastern North America. The northern limit is southern Ontario, Michigan, and Vermont. The east-west distribution in the US is from Maine to Minnesota in the north and from Florida to Texas in the south (Figure 3). See **Non-Legal Status and Ranks** for the detailed list of US states where the species was known to occur.

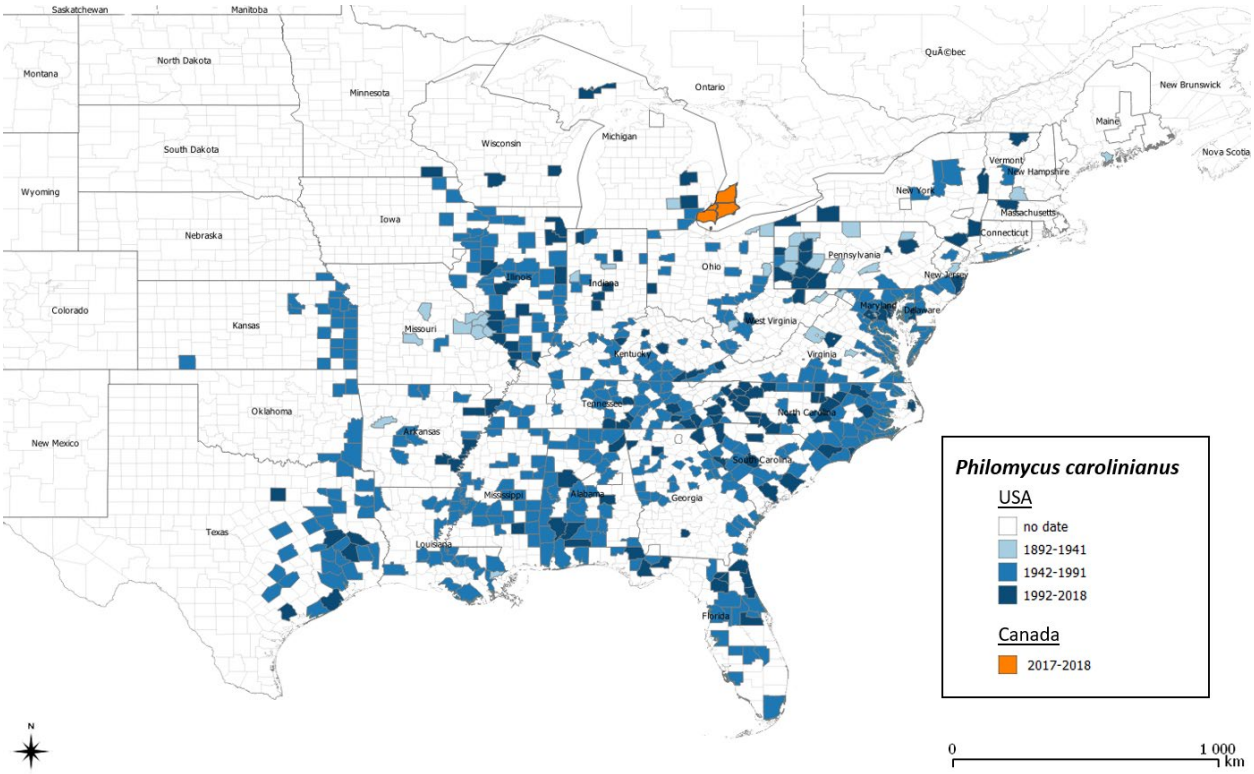

Figure 3. Global distribution of Carolina Mantleslug (*Philomycus carolinianus*). Canadian counties in orange (refer to Figure 2 for exact distribution) and US counties in variations of blue following the date of the record (from no date to 2018). Note that the species does not occur in the entire county. Occurrences per county are based on the most recent records in collections (see Collections Examined) and literature (Pilsbry 1948; Hubricht 1985; Paustian *et al.* 2013).

Canadian Range

Carolina Mantleslug was previously known in southwestern Ontario from two mainland sites (Leamington and Wheatley Provincial Park, records in 1994 and 1995, respectively) and from Pelee Island (Table 1, Figure 2). Oughton (1948) has 33 records of *Philomycus* that were misidentified as *M. mutabilis* from southeastern Ontario which corresponds to the current ranges for *P. togatus* and *P. flexuolaris*: from the Niagara escarpment eastwards (Grimm 1996). The range of *M. mutabilis* also partially overlaps that of Carolina Mantleslug, specifically on Pelee Island (Table 3) but extends to southeastern Canada (Milton: BIOUG27655-G01, -G02, -G03 with BIN: AAZ3142; Regional Municipality of Waterloo: iNaturalist number 10680985; Frontenac Co: iNaturalist number 13043818; iNaturalist (2019) identifications confirmed by A. Nicolai) and therefore contributes to misidentification issues. The two species occur in the same habitats on Pelee Island and in Rondeau Provincial Park.

The current range of Carolina Mantleslug in Ontario includes at least five known subpopulations: Pelee Island, Wheatley Provincial Park, Grape Fern Woods, Rondeau Provincial Park, and Sinclair's Bush. It is uncertain if the Leamington subpopulation is

extant because access was not gained to search this private landholding; however, habitat appears intact at White Oak Woods near Leamington. On Pelee Island the species has been recorded from eight sites in three natural area blocks within the last 20 years (Table 1):

1. Ontario Nature, Essex Regional Conservation Authority (ERCA) and three Nature Conservancy of Canada (NCC) properties on Stone Road Alvar (SRA): Krestel, Shaugnessy, and Porchuck,
2. Richard & Beryl Ivey Property (RBIP) of NCC and Winery Woods (WW),
3. Fish Point Provincial Nature Reserve (FP).

The 1995 occurrence from the Campground on Pelee Island (Table 1) could not be verified because access was not granted for a search. This occurrence is near SRA.

Extent of Occurrence and Area of Occupancy

The current extent of occurrence (EOO), based on records where Carolina Mantleslug has been observed, including uncertain occurrences (i.e., historical with no recent searches; Table 1, Figure 2), is 2439 km^2. Excluding the uncertain occurrence at Leamington, the EOO is only 2070 km^2. EOO, as measured by the minimum convex polygon method on central points of each site, is mainly water (Lake Erie) and unsuitable land.

Using 2 km x 2 km grid cells, IAO is currently 9 grid cells (36 km^2). If all historical occurrences, where the current presence of the species is uncertain (Table 1, Figure 2: Leamington and the campground on Pelee Island), are included, the IAO is 11 grid cells (44 km^2).

Search Effort

Carolina Mantleslug is a mostly inactive species that lives hidden under old, very moist, decaying logs. It can live inside the log and access cavities through holes smaller than its body diameter which makes it extremely difficult to find without entirely destroying the log.

Notable historical surveys that mention Carolina Mantleslug include those conducted by John Oughton between about 1930 and 1940 (Oughton 1948) and by Grimm between 1970 and the mid-1990s (Grimm 1996). However, some of these identifications might be erroneous (COSEWIC 2014a). The Oughton collection contains only *P. flexuolaris* and *M. mutabilis* specimens (COSEWIC 2014a and as verified by A. Nicolai – see **COLLECTIONS EXAMINED**, Royal Ontario Museum). While Grimm identified *P. carolinianus* only in southwestern Ontario near the Lake Erie shore in riparian habitat, Oughton only found it on the Niagara escarpment and more eastward. Other *Philomycus* sp. identifications in the Grimm collection were not clear or doubtful (COSEWIC 2014a). Grimm mainly collected in eastern Ontario but his collection included specimens sent to him by others, including those

collected by M.J. Oldham (see next paragraph) up to around 2000. Both Grimm's wet (stored in alcohol) and dry (mostly shells) collection now at the Canadian Museum of Nature have been examined by R.G. Forsyth (R. Forsyth pers. comm. 2019). Because the examined collection did not contain the specimen from White Oak Woods (Table 1), its identification was not verified.

Surveys between 1992 and 2012 were general land snail/slug searches rather than targeted searches for Carolina Mantleslug. There are 2,349 geo-referenced collection records from searches by M.J. Oldham between 1992 and 2012. Oldham focused on conservation areas, parks, and other areas of interest, mostly in southeastern Ontario and sent his collection since about 2006 for identification and curation to R.G. Forsyth (R. Forsyth pers. comm. 2019). The identity of the specimen from Sinclair's Bush (Table 1) was verified. A few more surveys were done by J.M. Bowles in 1994 with 113 geo-referenced collection records and by A. Nicolai in 2012 with 364 geo-referenced collection records. Carolina Mantleslug has been found in the area reported by Grimm (1996).

During the 2013–2019 general gastropod survey in southwest Ontario, 135 sites were visited and re-visited for a total search effort of 621.5 person-hours (Table 2). These surveys focused on collecting specimens of multiple species and resulted in 934 alcohol-preserved samples (snails and slugs) with 99 assigned BINs at the Biodiversity Institute of Ontario and about 300 shell samples (snails only) of about 50 species, currently being curated by R. Forsyth. During these surveys, all previously known sites occupied by Carolina Mantleslug were visited (except the inaccessible White Oak Woods and Campground on Pelee Island sites, Table 1) and voucher specimens deposited at the Biodiversity Institute of Ontario (Table 1). The surveys in 2017-2018 were targeted on Carolina Mantleslug. In spring 2019, two additional sites were visited; the slug was not found at Sinclair's Bush but it was found at Rondeau Provincial Park.

Table 2. Summary of general gastropod survey sites in southwestern Ontario in 2013-2019 including for Carolina Mantleslug (*Philomycus carolinianus*). Survey Methods used allow for detection of all sizes of snail and slug. Observers were Jane Bowles (JMB), Tammie Dobbie (TD1), Tarra Degazzio (TD2), Robert Foster (RFF), Allan Harris (AGH), Annegret Nicolai (AN), Michael Oldham (MJO), Robert Forsyth (RGF), Hiroko Udaka (HU), Litza Coello (LC), Dwayne Lepitzki (DL), Suzanne Dufour (SD), Ron Gould (RG), Kara Layton (KL), Mykola Mykow (MM), Paul Catling (PC), Erin Caroll (EC), Kaija Jenni (KJ). Kristen Diessen (KD), Sarah Guillocheu (SG), Valérie Briand (VB). CA – Conservation Area, NCC – Nature Conservancy of Canada, TTLT – Thames Talbot Land Trust. Slugs can only be found alive.

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Black Oak Heritage Forest, south part, Windsor	14	AN, JMB, MJO	May 3, July 28, Aug 27-28, Sep 5							No
Former industrial area south of Black Oak Heritage Forest, Windsor	3	MJO	Sep 5							No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Black Oak Heritage Forest, north part, Windsor	4	AN, MJO,	Apr 29							No
Devonwood Conservation Area, Windsor	6	AN, MJO, DL, SD, RGF	April 29		Aug 22,					No
Springgarden Road Park, Windsor	2	AN, MJO	April 29							No
Ojibway Park, Windsor	5	AN, MJO, JMB	Apr 29, May 3							No
Malden Park, Windsor	2	AN, JMB	May 3							No
Oakwood, Windsor	2	AN, MM	Aug 27							No
Brunet Park, La Salle	1	AN	Aug 28							No
South Cameron Woodlot, Windsor	1	AN, MM	Aug 28							No
Peche Island, Windsor	2	AN, HU	May 19							No
Middle Island, Point Pelee National Park, Lake Erie	38	RFF, AN, MJO; AN, TD1, TD2, RG, RGF, 1 park staff, 1 student	May 1; Aug 29		Aug 13		Aug 28			No
East Sister Island Provincial Park, Lake Erie	16.5	TD1, RFF, AGH, AN, MJO, RGF, RG, 2 park staff	Apr 30		Aug 13					No
Middle Sister Island, Lake Erie	3.5	TD1, RFF, AGH, AN, MJO	Apr 30							No
Lighthouse Point Provincial Nature Reserve, Pelee Island	16	RFF, AN, MJO; AN, RGF	May 1; Aug 25		Aug 12	01 Sep	Aug 14	May 6		No
Sheridan Point, Pelee Island	1	AN					Aug 14			No
Erie Sand and Gravel NCC parcel, Pelee Island	4.5	AN, MJO, AGH, RGF	May 2		Aug 12					No
Middle Point Woods – north part, NCC, Pelee Island	6	AGH, RFF, MJO, AN, RGF	May 2; Aug 25		Aug 14	03 Sep	Aug 17	May 5		No
Middle Point Woods – south part, NCC, Pelee Island	10	RFF, AGH, AN, RGF	May 1, 2; Aug 26	Aug 3		03 Sep	Aug 17	May 6		No
Middle Point Woods – Novatney, NCC, Pelee Island	3	AN, MJO, RGF	May 2			03 Sep	Aug 17			No
Gibwood Property, NCC, Pelee Island	3.5	AN, MJO	May 2				Aug 14	May 9		No
Florian Diamante Nature Reserve, NCC, Pelee Island	21	AGH, RFF, AN, RGF	May 2	Aug 2	Aug 11, 12	02 Sep	Aug 14	May 5		No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Richard and Beryl Ivey Nature Reserve, NCC, Pelee Island	12	RFF, AGH, AN, RGF	May 1	Aug 2	Aug 12	02 Sep	Aug 16	May 9		Alive
Winery property, Pelee Island	7.5	RFF, AGH, AN, MJO, RGF	May 2	Aug 2		31 Aug	Aug 16	May 9		Alive
Porchuk Property, NCC, Pelee Island	14	AN, MJO, RGF, AN	May 2			01 Sep	Aug 15	May 8		Alive
Fish Point Provincial Nature Reserve, Pelee Island	33	RFF, AGH, AN, RGF	May 1	Aug 3	Aug 11	02 Sep	Aug 16	May 7		Alive
Fleck Property, Pelee Island	2	RFF, AN	May 2				Aug 15			No
Essex Region Conservation Authority Stone Road Alvar, Pelee Island	7	AGH, AN, RGF	May 2		Aug 11		Aug 16	May 9		Alive
Ontario Nature Stone Road Alvar, Pelee Island	19	AGH; AN, MM, RGF	May 2; Aug 27		Aug 11		Aug 16	May 8, 9		Alive
NCC Stone Road Alvar, Pelee Island	4	RGF, AN			Aug 11		Aug 16			No
Cohen Shaughnessy Property, NCC, Pelee Island	8.5	AGH; AN,MM	May 2; Aug 27	Aug 3			Aug 15	May 9		No
Krestel Parcel, NCC, Pelee Island	9	AGH, AN, RGF	May 1	Aug 3	Aug 11		Aug 15	May 8		Alive
Finley Parcel, NCC, Pelee Island	1	AN		Aug 4						No
Fronzier Parcel, NCC, Pelee Island	1.5	AN, RGF			Aug 12			May 6		No
Point Pelee National Park (10 sites)	40	AGH, AN, MJO, RFF, RGF	Apr 28, 29			30 Aug	Aug 11	May 11		No
Oxley Swamp, NCC	4	AN, HU	May 20				Aug 12			No
Cedar Creek CA	4	RFF, AGH	April 29				Aug 13			No
Kopegaron Woods CA	5	RFF, AGH, AN, MJO	Apr 29, 30				Aug 12			No
Two Creeks CA	3	MJO	May 18				Aug 13			No
Andrew Murray O'Neil Memorial Woods	1	AN					Aug 13			No
Canard River CA	2	AN, MJO	April 29							No
Canard River Scout Camp (former)	3	AN, RGF				29 Aug				No
For the Birds (East of Gore Rd, Road 13)	1	AN, RGF				29 Aug				No
Maidstone CA	2	RFF, AGH	April 29							No
Rondeau Provincial Park	16.5	MJO, JMB; AGH; KJ, KD, SG, AN	May 17; Sep 4					Oct 9	May 20	Alive

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Wheatley Provincial Park	3	AN					Aug 12			Alive
Sinclair's Bush	6	MJO, JMB, KD, KJ, SG, AN	May 17						May 20	No
Thames Grove CA	1	AN, JMB	May 3							No
Moraviantown First Nation (2 sites)	9	AN, JMB	June 7							No
John E. Pearce Provincial Park	2	MJO	May 15							No
Newport Forest, TTLT	3	AN; AN, HU	April 21; Sep 01							No
Wardsville Woods TTLT	1	JMB	May 17							No
Backus Woods, NCC, Norfolk Co	6	MJO; AGH	May 15; Sep 2				Aug 9			No
Lake Erie Farms, NCC, Norfolk Co	2	AN					Aug 9			No
St. Williams Conservation Reserve	2	MJO	May 15							No
Calton Swamp	1	MJO	May 15							No
Lake Whittaker CA	2	AN, HU	June 8							No
Westminster Ponds, London	1	AN	April 7							No
Komoka Provincial Park	1	AN, HU	Jan 13							No
Western University, London	0.5	AN	April 15							No
Canatara Park, Sarnia	7	JMB, MJO; AGH; AN, LC, RGF	May 16, Aug 3; Sep 22			28 Aug				No
Tremblay Beach CA	1	AN, RGF				29 Aug				No
Ruscom Shores CA	1	AN, RGF				29 Aug				No
Killaly Meadows, London	1	AN	May 4							No
Lambton United Church Camp	2	AGH	Aug 3							No
Highland Glen CA	1	AGH	Aug 3							No
Joany's Woods TTLT	11	AN, JMB, VB, SG	April 1					Aug 4	May 21	No
Port Franks	2	AGH	Aug 4							No
Pinery Provincial Park	2	AN	May 5; July 07							No
C.M. Wilson CA	2	MJO, JMB	May 16							No
Paxton Wood, Chatham	2	MJO, JMB	May 16							No
Skunk's Misery	2	MJO, JMB	May 16							No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Avon trail near St. Mary's	1	AN	Jul 27							No
Long Point Provincial Park	2	AGH	Sep 2							No
Bickford Oak CA	4	AN, LC, RGF	Sep 22			28 Aug				No
Brigden Crown Game Reserve (3 sites)	5	AN, LC, RGF	Sep 22			28 Aug				No
Wawanosh CA	1	AN, RGF				28 Aug				No
Moore Wildlife Refuge CA	2	AN, LC	Sep 22							No
Perch Creek CA	2	AN, LC	Sep 21							No
Floodway CA	2	AN, LC	Sep 21							No
Petrolia CA	1	AN, LC	Sep 22							No
Rouge Park, Scarborough	4	AN	Sep 14, 15							No
High Park, Grenadier Pond, Toronto	1	MM	Sep 22							No
Clements Property, Buttenwood, Alvinston	5	MJO, RGF, AN			Aug 14, Sep 1		Aug 11			No
A.W. Campbell CA, Alvinston	2	AN					Aug 10			No
Grape Fern Woods, Shetland	1	EC					Sep 7			Alive
Karner Blue Parcel, NCC, Port Franks	4	RGF, AN			Aug 17					No
Tall Grass Restoration Site, Port Franks	1	RGF, AN			Aug 17					No
Kettle Point, Indian Reserve	1	RGF, AN			Aug 17					No
Bruce trail, Burlington	2	RGF, AN			Aug 18					No
Britton Tract, Haltonville	2	RGF, AN			Aug 18					No
Cape Croker Park	1	AN			Aug 31					No
Elora Gorges CA	3	AN, KL, 1 student		Aug 5						No
Speed River Trail, Guelph	3	AN, KL, 1 student		Aug 5						No
Gorba Trail, Guelph	3	AN, KL, 1 student		Aug 5						No
Arboretum Guelph	1	AN		Aug 5						No
Bruce Peninsula National Park (11 sites)	11	AN		Jul 21, 22, 23						No
Rare, Charitable Research Area, Cambridge	4	AN, RGF			Aug 16					No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Dundas Valley CA, Hamilton	4	AN					Aug 7			No
Tiffany Falls CA, Hamilton	1	AN					Aug 7			No
Royal Botanical Garden, Cootes Sanctuary, Hamilton	5	AN					Aug 8			No
Port Bruce Provincial Park	1	AN, VB						Aug 10		No
Norfolk CA	1	AN, VB						Aug 11		No
Port Dover, Silver Lake	2	AN, VB						Aug 11		No
Port Dover, Lynn River Valley Trail (3 sites)	2	AN, VB						Aug 11		No
North Cayuga Slough Forest (3 sites)	2	AN, VB						Aug 11		No
Byng Island CA	1	AN, VB						Aug 11		No
Rock Point Provincial Park	1	AN, VB						Aug 11		No
Long Beach CA	1	AN, VB						Aug 11		No
Gord Harry Conservation Trail	2	AN, VB						Aug12		No
Wainfleet Bog CA	1	AN, VB						Aug 12		No
E.C. Brown CA	1	AN, VB						Aug 12		No
Mud Lake CA (2 sites)	1	AN, VB						Aug 12		No
Point Albino Woods (NCC, 2 sites)	2	AN, VB						Aug 12		No
Humberstone CA	1	AN, VB						Aug 12		No
Stevensville Conservation Park	1	AN, VB						Aug 12		No
St. John's CA (2 sites)	1	AN, VB						Aug 12		No
Short Hills Natural Area (NCC)	2	AN, VB						Aug 12		No
Short Hills Provincial Park	1	AN, VB						Aug 12		No
Brant CA (3 sites)	2	AN, VB						Aug 15		No
Vanderwater CA (3 sites)	4	AN, VB						Aug 13		No
MRCA Authority Land (Moneymore Road, Thomasburg)	2	AN, VB						Aug 13		No
MRCA Authority Land (Colonization Road, Thomasburg)	2	AN, VB						Aug 13		No
MRCA Authority Land (Rapids Road, Thomasburg)	1	AN, VB						Aug 13		No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	Date(s) 2018	Date(s) 2019	*P. c.* records
Geoheritage Walking Trail (Eganville)	2	AN, VB						Aug 14		No
C44 (Egan Line, Eganville)	1	AN, VB						Aug 14		No
C42 (Brehm Road, Eganville)	1	AN, VB						Aug 14		No
C62 (Tramore Road, Eganville)	1	AN, VB						Aug 14		No
Ottawa/Gatineau (14 sites)	40	AN, RGF, PC				Aug 23-26, Sep 6-7				No
North Stormont	2	RGF				Sep 6				No
Papineau MRC: Plaisance	8	AN, RGF				Aug 24				No
Metcalfe (near Ottawa)	6	AN, PC, RGF				Aug 25				No
Edwardsburgh/Cardinal	2	RGF				Sep 6				No
Casselman	2	RGF				Sep 7				No
Morris Island CA	3	AN, RGF				Aug 23				No

Table 3. Abundance of Carolina Mantleslug (*Philomycus carolinianus*) in several 2 x 2 m plots in different habitat types during fieldwork in 2017 and in several 10x1 m transects during fieldwork in 2018. In addition, random transects in each site were searched for Carolina Mantleslug. Records from 2013-2016 fieldwork are noted when species was not found in 2017 or 2018. *Megapallifera mutabilis* (Changeable Mantleslug) is sympatric in some areas and abundances in 2017/2018 as well as observations from 2013-2016 are indicated because it can be confused with Carolina Mantleslug. Collections of *M. mutabilis* are curated by Biodiversity Institute of Ontario (BIO), University of Guelph. The BIN corresponds to taxonomic units based on COI gene sequences obtained from each specimen. Presence of exotic gastropod species in each site is indicated.

Site	Field verification in 2017	*Philomycus carolinianus* total abundance in 2017	Field verification in 2018	*Philomycus carolinianus* total abundance in 2018	*Megapallifera mutabilis* total abundance in 2017/2018 and observed (museum number) and BIN at BIO	Exotic gastropod species
Wheatley Provincial Park	3 plots	1 adult	-	-		*Oxychilus cellarius*
Winery Woods	1 plot	1 juvenile	1 transects	-		
Stone Road Alvar – Porchuk, NCC	3 plots	4 juveniles, 2 adults	5 transects			
Stone Road Alvar – Shaughnessy, NCC	2 plots	2 juveniles	3 transects	1 adult	-/1 juvenile	
Stone Road Alvar – Krestel, NCC	1 plot	4 adults	3 transects		Observed in 2014 (BIOUG09921-F12), 2015 (BIOUG27665-G04), BIN:	

Site	Field verification in 2017	*Philomycus carolinianus* total abundance in 2017	Field verification in 2018	*Philomycus carolinianus* total abundance in 2018	*Megapallifera mutabilis* total abundance in 2017/2018 and observed (museum number) and BIN at BIO	Exotic gastropod species
					AAZ3142)	
Stone Road Alvar – Finley, NCC	1 plot		-	-		
Stone Road Alvar – ON Nature	3 plots	5 juveniles, 3 adults	4 transects	13 adults	1 adult/- (BIOUG37881-G12), BIN: AAZ3142	*Deroceras reticulatum*
Stone Road Alvar – ERCA	3 plots	2 adults	2 transects			
Florian Diamante, NCC	6 plots		12 transects			*Deroceras reticulatum*
Gibwood, NCC	2 plots		1 transects		1 juvenile/- (BIOUG37881-G07), BIN: AAZ3142	
Richard & Beryl Ivey, NCC	4 plots	Observed in 2014, 2015	3 transects	Observed in 2014, 2015	Observed in 2015 (BIOUG27665-G05), BIN: AAZ3142	*Deroceras reticulatum* *Arion fasciatus*
Middle Point Woods, NCC	3 plots		6 transects			
Lighthouse Point	3 plots		13 transects			*Deroceras reticulatum*
Fish Point	5 plots	Observed in 2013, 2015	7 transects	2 juveniles		*Cepaea nemoralis* *Deroceras reticulatum*
Sheridan Point	1 plot		-	-		*Deroceras reticulatum*
Total	**41 plots**	**12 juveniles, 12 adults**	**60 transects**	**2 juveniles, 14 adults**		

HABITAT

Habitat Requirements

Hubricht (1985) described Carolina Mantleslug habitat in the US as being floodplains, but also mountain areas up to 2000 feet (610 m) high. It prefers humid woods, especially with basswood (*Tilia* sp.), beech (*Fagus* sp.), and tulip trees (*Liriodendron* sp.; Pilsbry 1948). The species is mainly found in undisturbed wooded habitats (Chichester and Getz 1969). In Canada, it lives in low wet forests and riparian areas along the Lake Erie shore (Grimm 1996). During 2013-2018 surveys, it was found in riparian wet forest and on the floor of older-growth deciduous forest with abundant, well-decayed wood (amount not quantified) growing on sandy or rocky soil. Typical forest species on Pelee Island were oak (*Quercus* sp.), maple (*Acer* sp.), mulberry (*Morus* sp.), ash (*Fraxinus* sp.), and hickory (*Carya* sp.). In Wheatley Provincial Park habitat is composed of chestnut (presumably

American Chestnut *Castanea dentata* because it is the only species in Canada), Sassafras (*Sassafras albidum*), Black Gum (*Nyssa sylvatica*), and Pin Oak (*Quercus palustris*). In Rondeau Provincial Park, the deciduous forest is mainly American Beech (*Fagus grandifolia*) and Sugar Maple (*Acer saccharum*) and to a lesser extent basswood (*Tilia* sp.), tulip tree, White Ash (*Fraxinus americana*), and Green Ash (*Fraxinus pennsylvanica*) (Dobbyn and Pasma 2012). The forest grows on sandy ridges that form sloughs which may be flooded for most of the year. Sinclair's Bush is a deciduous forest with Pawpaw Tree (*Asimina triloba*) and tulip tree being species of conservation concern.

Carolina Mantleslug is a fungivore and usually does not eat plants. In a choice test of 50 mushroom species in 17 families versus White Mushroom (*Agaricus bisporus*), all tested mushroom species were preferentially consumed over White Mushroom, with a few noticeable preferences being Honey Fungus (*Armillaria mellea*), Gilled Bolete (*Phylloporus boletinoides*), Lurid Bolete (*Boletus luridiceps*), and Olivespore Bolete (*Boletus oliveisporus*; White-McLean 2012). Out of 38 plants that were presented to Carolina Mantleslug that had been starved for 5 days, none showed foraging traces (White-McLean 2012). *Philomycus* spp. also consumed a greater mass of lichen thalli than *Arion* spp. in New Hampshire, USA (Clyne *et al.* 2019). Powderpuff Lichen (*Cladina evansii*) was only slightly preferred over White Mushroom (White-McLean 2012). Thus, the presence of a diverse mushroom and lichen community is an important habitat requirement.

Habitat Trends

Climate change

The climate on Lake Erie islands and the adjacent mainland is much warmer than expected for its latitude because of the moderating effect of Lake Erie. Two-thirds of the year is frost-free. The warmer climate plays an extremely important role in allowing the persistence of flora and fauna at the northern edges of their ranges (Mann and Nelson 1980; North - South Environmental Inc. 2004).

Even though the species is near its northern edge in Canada, climate change will not necessarily result in conditions more comparable to the core of its range in the US. Hydrological regimes, snow cover, and temperatures can all influence survival at different times in the lifecycle. An increase in the frequency of extreme weather events, such as storms, freeze-thaw cycles, and droughts seen in northern parts of the range, may not be similar to what the species experiences further south. For a summary of Ontario climate models see McDermid *et al.* (2015). Using the prediction model from 1960-1990 to 2015-2045 on the Ontario climate change data portal (PRECIS model under A1B emissions scenario, Wang and Huang 2013), some climate change observations and predictions are as follows:

- Average winter temperatures will increase by 3.3°C in southwestern Ontario (from -3.8°C in 1960-1990 to -0.5°C in 2015-2045). Mean temperature close to 0°C increases the chances of increased frequency of freeze-thaw cycles in fall/winter (Nicolai and Ansart 2017) and more spring frosts (Augspurger 2013).

- There would also be longer periods between rainfall events with a greater risk of droughts especially in mid-continental regions (Meehl *et al.* 2007). Under climate change scenarios, changes to average and extreme temperatures will alter microhabitat conditions; both beneficial and adverse effects may ensue, but the overall effects are difficult to predict. Additionally, anthropogenic activity influences microhabitat structure although the link between habitat choice and physiology is poorly understood (Deutsch *et al.* 2008).

Since the draining of a wetland on Pelee Island in the mid-19th century, flooding of forest occurs every year in Fish Point and the Stone Road Alvar. The flooding has been less intense since 1970-1972 because much of the island's shoreline was fortified with armour stone, and a network of dykes criss-crosses the island (NCC 2008); however, these fortifications are absent from Fish Point. Winter 2017/2018 flooding was higher than previous years and dykes had to be repaired during spring 2018. In 2019, flooding was observed at SRA (A. Nicolai pers. obs.).

The tip of Fish Point is subjected to a natural process of sand erosion on the east side and deposition on the west side. This process is most likely similar to that occurring at Point Pelee (Kamstra *et al.* 1995) but it has not been studied at Fish Point. At the tip of Point Pelee the process is accelerated by sand extraction activity in other areas along the Lake Erie shoreline. The tip of Point Pelee is expected to retreat by 50 m over the next 50 years, because the coupled process of erosion and deposition of sand is disrupted (BaMasoud and Byrne 2011). Rondeau Provincial Park is also affected by erosion when the lake level is high (Cheskey and Wilson 2001). Climate change can also involve higher wind speed and longer, more frequent storms, thereby increasing erosion, but no data are available to confirm this possibility. Erosion at Fish Point was seen in 2013-2018, including loss of trees, and incursion of lake water inland at the south end. Although maybe not directly affecting gastropods in the short-term, there might be indirect effects such as increased exposure of the inner higher ground of Fish Point. Storms also led to tree fall and opening of the canopy in Rondeau Provincial Park (Cheskey and Wilson 2001).

Land management

After being logged in the mid-1880s, Pelee Island has since largely been developed for agriculture (NCC 2008). Viticulture and soybean farming are mainly on tile-drained marshland between the former four bedrock islands. Some alvar habitats are now protected on these former islands, most of them being former prairies or logged woodlots. About 15 to 20% of the natural vegetation cover is still intact (ERCA 2002), most of which is under management by the Nature Conservancy of Canada (NCC) or the Ministry of the Environment, Conservation, and Parks (MECP).

Habitat connections among all four of the bedrock islands were re-established by restoring former fields adjacent to forested areas to forest and wetland on Pelee Island by NCC (NCC 2008) but all habitat patches are still unconnected at the micro-scale suitable for gastropods because the intervening restored land consists of former fields (now thickets), which still pose a barrier (e.g., in RBIP). Colonization or exchanges between

habitats on distant properties on Pelee Island are even more difficult because of barriers between the protected areas. Ditches as well as paved and unpaved roads or tracks as narrow as 3 m with both high and low traffic densities are barriers to snail dispersal (Baur and Baur 1990a; Wirth *et al.* 1999), a conclusion that also is applicable to slugs. Disturbed habitats such as cultivated or grazed fields and small cultured woodlots between fields do not seem to act as movement corridors, because no native snails or slugs were found in such sites on Pelee Island in 2013-2018. NCC controls invasive plants by mechanical removal or periodically with chemicals (NCC 2008). Herbicide use is still restricted to study plots (study in progress by NCC, no results currently available). Logging and grazing is forbidden, while hunting is still allowed on almost all NCC properties. Access for the public is possible on one biking and walking trail that goes through the Richard and Beryl Ivey Property.

Ontario Nature's main management goal is to enhance snake habitat, control for invasive grasses and maintain Chinquapin Oak (*Quercus muehlenbergii*) alvar. Prescribed fire is planned in late summer 2019 on the Stone Road Alvar owned by Ontario Nature but is only applied to grassy areas in the savannah. Access for the public is possible on walking trails that go through Ontario Nature properties of Stone Road Alvar.

No specific management actions are foreseen in the near future in other forested habitats of Carolina Mantleslug. Grape Fern Woods is a privately owned wetland and riparian forest monitored by the St. Clair Conservation Authority (Caroll 2018). Sinclair's Bush is managed by a landowner cooperative with the Lower Thames Valley Conservation Authority (LTVCA). Trails are accessible by the public; hunting is forbidden; ATV tracks were visible during the 2019 survey. In Fish Point Provincial Nature Reserve trails are maintained and species at risk are monitored. The Pelee Island Winery had restored red cedar savanna which is accessible by the public (NCC2008).

In Wheatley Provincial Park only 46 ha of 241 ha are nature reserve with the remainder being developed (campground and day use recreational area) or in the 30-year old forest ("environmental zone", MNR 1988). One third of the nature reserve is prairie and only the Ern Wiggle Tract is an old growth forest with typical Carolinian Forest species. Management over the last several years included felling hazard ash trees that were infested by Emerald Ash Borer (*Agrilus planipennis*), thereby opening the canopy and increasing woody debris and logs on the ground (Gould 2018). This may offer additional microhabitat for Carolina Mantleslug. Shore erosion only affects the recreational areas.

About half of the 3254 ha Rondeau Provincial Park is marshland, the other half is sandy deciduous forest or mixed-wood forest (about 800 ha), prairie, and savanna (Mann and Nelson 1980; Cheskey and Wilson 2001). Rondeau represents one of three major forest areas (Skunk's Misery, old-growth on 700 ha, and Clear Creek, young forest on 300 ha) still extant in Chatham-Kent County with only 4% of the county still forested (Cheskey and Wilson 2001). Deer browsing reduces understorey vegetation. After the peak of 600 White-tailed Deer (*Odocoileus virginianus*) in the 1970s, deer culling has resumed to recover vegetation (Crins 2007). In 2001, only 87 deer were left. Historically the park served as a source for wood and fish (Cheskey and Wilson 2001). Logging is not allowed

and 20 km of trails and 260 campsites offer year-round recreation activities (hiking, boating, skiing, etc.) for over 200,000 visitors/year. The tourism development zone is in the forested area; only 514 ha of the forested area is undisturbed (Dobbyn and Pasma 2012). Management includes removal of non-native plants (mechanical thinning or herbicides), prescribed burning in oak woodland and oak savannas (but not in the forest), planting of indigenous species in development zones, and protection of rare and endangered species (Cheskey and Wilson 2001). The tall-grass prairie in the park was fire-managed in 2004 (Crins 2007).

Habitat quality ranking

The habitats currently occupied by Carolina Mantleslug can be ranked AC (Excellent to Fair) for their capacity to sustain a viable slug population using the element of occurrence ranking key of NatureServe (Tomaino *et al.* 2008) on the best available information. This means the occurrences may persist for the foreseeable future with appropriate and ongoing protection or management. This is second growth forest or old growth forest that has historically been disturbed by logging and grazing. Spatial distribution of Carolina Mantleslug and suitable habitat across each site is patchy. Corridors between properties could be developed in the near future on Pelee Island.

BIOLOGY

Life Cycle and Reproduction

Carolina Mantleslug is an air-breathing (pulmonate), slug that is a simultaneous hermaphrodite (possesses both male and female reproductive organs) and lays eggs (Pilsbry 1948). In general, both members of a mating pair exchange sperm and produce eggs, but self-fertilization is possible but may result in lower reproductive success (White-McLean 2012). In temperate regions, reproduction usually occurs in spring as the presence of small juveniles in August 2017 (Figure 4) suggests. Clutch size for Carolina Mantleslug ranged between 65 and 75 eggs with a hatching success varying between 40 and 75% (White-McLean 2012). Duration of embryonic development ranges between 22 and 45 days (White-McLean 2012). In laboratory conditions (constant 21°C, slugs fed a diet made for Gypsy Moth [*Lymantria dispar dispar*]) reproductive size, about 4.5 cm, was reached between 120 and 220 days after hatching (White-McLean 2012). The fastest growing slugs reached adult sizes, about 6 cm, after 170 days, while the slower growing slugs reached only 5 cm after 270 days (White-McLean 2012). Fieldwork in southwestern Ontario in May 2018 resulted in many records of bigger juveniles, suggesting that they hatched in the summer the year before. Given that slugs hatch during summer and that growth is seasonal, maturity in natural conditions may be reached after 1 year. Carolina Mantleslug may live 3-4 years, like other slugs of the same size such as Tawny Garden Slug (*Limax flavus*; Welter-Schulter 2012). The estimated generation time is somewhere between the age at sexual maturity and longevity, probably 2 years.

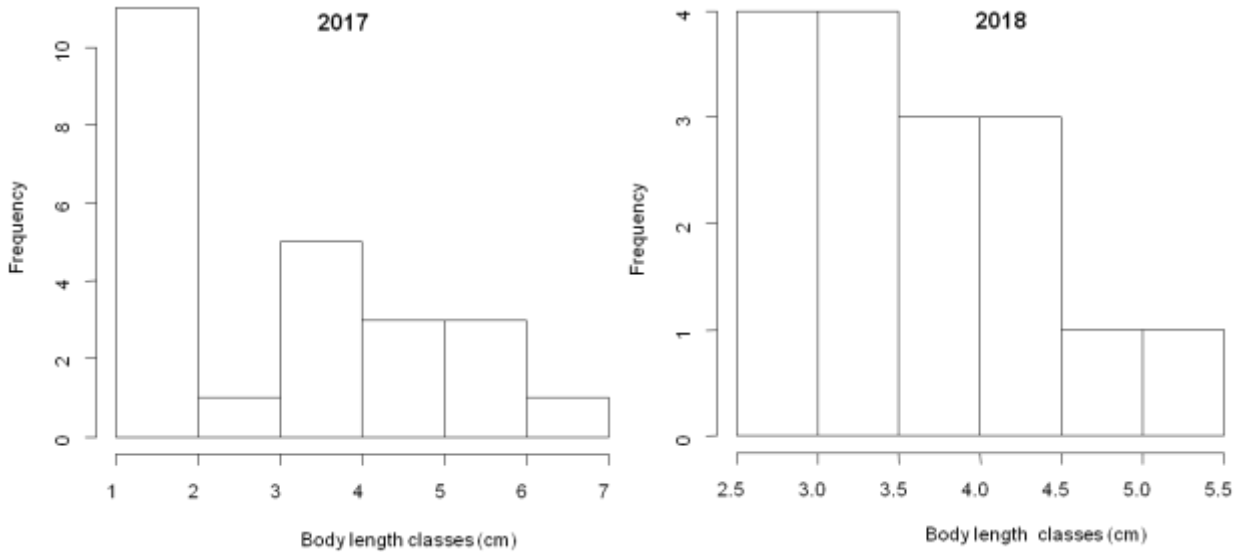

Figure 4. Body length of Carolina Mantleslug (*Philomycus carolinianus*) during 2017 (August) and 2018 (May) surveys in southwestern Ontario. The distributions in 2017 and 2018 were not normal (Shapiro-Wilks; 2017: W = 0.91, *P* = 0.042, *n* = 24; 2018: W = 0.9628, *P* = 0.7124, *n* = 16), indicating high recruitment.

Physiology and Adaptability

Carolina Mantleslug is crepuscular or nocturnal, but also comes out from under logs or from holes in logs during daytime as long as the log is moist (Pilsbry 1948). During 2013-2018 surveys in Ontario, Carolina Mantleslug was found in the litter in moist conditions, whereas during dry summers (e.g., August 2016) the species was still active, but only found under or in logs. Thompson *et al.* (2006) showed that Carolina Mantleslug has a high desiccation tolerance. Compared to Three-band Gardenslug (*Ambigolimax valentianus*) and Meadow Slug (*Deroceras laeve*), Carolina Mantleslug had the lowest cuticular permeability (water transfer through skin) and lowest water loss rate. Moreover, Carolina Mantleslug form huddles of several individuals, which has been shown to reduce water loss by 34% in *Limax* sp. (Cook 1981).

Carolina Mantleslug are more active at warmer temperatures (25°C) and inactive at cooler temperatures (15°C; Rising and Armitage 1969). Metabolic rate is low at 5°C (Rising and Armitage 1969) indicating that the slug hibernates, in contrast to European slugs, such as Leopard Slug (*Limax maximus*; Rising and Armitage 1969), *Arion* sp. (Slotsbo *et al.* 2012), and *Deroceras* sp. (Storey *et al.* 2007). These European species, also found in Canada and the latter two in Carolina Mantleslug habitat, may stay active under the insulating snow cover. They are freeze-tolerant, so their body fluids freeze between -1 and -5°C and some can survive freezing up to 2 days (Storey *et al.* 2007; Slotsbo *et al.* 2012).

Some reproductive processes in Carolina Mantleslug are sensitive to diet and temperature (White-McLean 2012), the latter being relevant to the threat of climate change. Hatching success was highest at temperatures ranging between 10 and 21°C and decreased significantly by more than half at 25-29°C. Embryonic development was fastest

at 25°C (about 17 days) and reduced at lower temperatures. This indicates that eggs laid in fall may overwinter and hatch in spring, as observed in other slug species, such as *Arion* sp., where eggs were freeze-tolerant (Ansart and Nicolai unpubl. data).

Heavy metals and pesticides in the soil are accumulated in tissues and may disturb physiological processes (Barker 2001). Even though they might not be harmful to gastropods themselves, they are transmitted in the food chain to other organisms, such as mollusc-predating arthropods (Douglas *et al.* 2015).

Dispersal and Migration

Carolina Mantleslug is a mostly inactive slug, so dispersal seems to be very slow compared to exotic slug species, such as *Arion* or *Deroceras* spp. For instance, in *Arion* sp. dispersal distance depends on body weight, with bigger individuals being more prone to dispersal and dispersing larger distances (several metres per day with a mean speed of 11 cm/min; Honek and Martinkova 2011). Information on dispersal for other inactive slug species is not available.

Eggs and immature stages are not known to be dispersed by wind. The likelihood of aerial or aquatic transport of adults is unknown, but is probably small. However, some exotic slug species can survive periods in water (Nicolai pers. obs.), and may be transported by water as the riparian distribution of Sheathed Slug (*Zacoleus idahoensis*) suggests (COSEWIC 2016). Rafting on floating objects (Vagvolgyi 1975), such as logs, may also be a mean of passive transportation in slugs.

In Ontario, the likelihood of dispersal from the US is nonexistent given the slugs' poor dispersal capabilities (see **Population Spatial Structure and Variability** and/or **Rescue Effect**). A potential northern expansion of the peripheral Canadian population of Carolina Mantleslug could be largely negated by historical and current habitat loss and degradation, important factors to consider for range peripheral species under climate warming (Gibson *et al.* 2009). Because Carolina Mantleslug does not actively search for fresh plant material as food, it is unlikely that it would be transported by human activity, for example with horticultural or agricultural products, and then be introduced to new areas (Robinson 1999; Robinson and Slapcinsky 2005).

Interspecific Interactions

Other than Carolina Mantleslug being a host for the nematode Meningeal Worm (*Parelaphostrongylus tenuis*), a parasite of deer (Family Cervidae) in North America (Rowley *et al.* 1987), little else is known about the parasites of Philomycidae. Trematodes (Barger and Hnida 2008; Barger 2011) and free swimming or attached flagellates have been observed in Polygyridae snails (Current 2007). Parasitic mites are common in snails (A. Nicolai pers. obs.) and can cause reproductive perturbations (Baur and Baur 2005). Nematodes can also infect snail populations and increase mortality among juveniles (Morand *et al.* 2004). In snails reared in the laboratory, thus in a confined space, nematodes can cause extremely high mortality (Örstan 2006), although nematodes were

not efficient in controlling pest gastropods in an urban green space (i.e., open space, Fredon Inc. unpubl. data). Slugs in general can also disperse other nematodes that are useful for soil functioning (litter decomposition) by transitorily ingesting them (Peterson *et al.* 2015). Both slugs and snails are also known to disperse oribatid mites through ingestion and egestion (Turke *et al.* 2018).

Predation can be a source of mortality for land snails and slugs. Potential predators have been reviewed by Jordan and Black (2012): “Gastropods are an important food source to a vast number of species, including salamanders, frogs, toads, turtles, snakes, lizards, birds, shrews, voles, moles, rats, mice, chipmunks, and squirrels. Invertebrate predators of terrestrial mollusks include sciomyzid fly larvae, firefly larvae, parasitic wasp larvae, carabid and staphylinid beetles, ants, spiders, and harvestmen.” In European agricultural systems *Arion* spp. and carabid densities are negatively correlated, emphasizing a predator-prey relationship (Fusser *et al.* 2016).

Changeable Mantleslug is sympatric with Carolina Mantleslug in Ontario as was also observed in Wisconsin by Paustian *et al.* (2013). Competition for food with other slugs, such as Changeable Mantleslug or exotic species, is a possibility for native slugs in southwestern Ontario. Rollo (1983) has shown that the aggressive behaviour of Leopard Slug could considerably reduce reproductive success of two *Arion* species in British Columbia. Leopard Slug is introduced in Ontario, but has not been found in Carolina Mantleslug habitat (A. Nicolai pers. obs.). Introduced exotic gastropods, such as Grove Snail (*Cepaea nemoralis*) and various species of slugs, mainly Grey Fieldslug (*Deroceras reticulatum*) or Dusky Arion (*Arion fuscus/subfuscus*), present in many natural areas in Ontario, might be in direct competition for food with Carolina Mantleslug as these species mainly eat decaying plant material or fungi.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

The objective of field verifications in 2017 and 2018 was to increase search effort, to measure abundance and demography, and to better understand the distribution and ecology of Carolina Mantleslug. The method used was a visual search under logs and in the leaf litter on a wandering transect across different habitats per survey site. Searches usually occurred in the morning and evening when conditions were moister. All the old decaying logs on a wandering transect (about 15-20 logs/hour) were turned over and broken apart to see if slugs were present inside crevices. If the abundance of slugs was high (see **Abundance**, ~20% logs occupied), examining 3-4 logs was sufficient to detect its presence while if abundance was low (5% logs occupied), it was found after about 20 minutes of 5 people searching (4 logs/person/20 minutes). Leaf litter was searched close to logs. In addition, in all accessible, historically occupied sites on Pelee Island and in Wheatley Provincial Park, 2 x 2 m plots (in total 41 plots) were established in 2017 and 1 x 10 m transects in 2018 (in total 60 transects) in different habitat types to measure abundance and record exotic gastropods and sympatric native slugs (Table 3). Body size of Carolina Mantleslug was measured as inactive body length.

Grape Fern Woods was not surveyed; Carolina Mantleslug was incidentally discovered by St. Clair Regional Conservation Authority (SCRCA) staff. Rondeau Provincial Park and Sinclair's Bush were surveyed in May 2019 with an effort of two 5-person-hours and two 4-person-hours, respectively. These surveys were intended to understand the species' distribution in these sites; no plot sampling occurred.

Abundance, Fluctuations and Trends

Body length distribution indicates annual reproduction and high recruitment (Figure 4). In both years, juveniles are predominant. In August 2017 small juveniles (1-2 cm) from spring reproduction were abundant, while in May 2018 bigger juveniles (2-4 cm) were present. These bigger juveniles probably emerged in spring the year before.

A measure of density is required to determine overall abundance, but because only a few individuals were observed under well decayed logs in a few sites, densities in different habitats are difficult to estimate. Logs were not always present in the plots/transects and log density was not quantified.

There is a great heterogeneity in the distribution of this species within a habitat. If all sites where the species has been observed since 2013 on Pelee Island (Table 3) were combined, density of mature individuals would be $<0.2/m^2$ in 2017 and 2018. In Wheatley Provincial Park, density of mature individuals was also $<0.2/m^2$ in 2017. Densities at Rondeau, Grape Fern Woods, and Sinclair's Bush were lower, a maximum of $0.01/m^2$: Rondeau, surveyed in May 2019 with two 5-person-hours and only three individuals found; Grape Fern Woods was not surveyed and only one specimen found so far; Sinclair's Bush, surveyed with 4-person-hours in May 2019 and no slugs found. Assuming a density of $0.2/m^2$ evenly distributed over all the protected natural areas on Pelee Island and Wheatley Provincial Park and a density of $0.01/m^2$ elsewhere multiplied by areas of the various habitats yields a maximum of 995,000 Carolina Mantleslugs in Canada (1 ha = 10,000 m^2). However, this number must be viewed with extreme caution due the patchy, clumped distribution of the slug and its preferred habitat (decaying logs) and the assumption of equal slug density over the entire protected area. This maximum estimate was derived by multiplying slug density by the areas of the habitat patches: RBIP = 51 ha, SRA – Ontario Nature+NCC+ERCA properties = 243 ha, WW = 33 ha, and Fish Point= 110 ha (= a total of 437 ha on Pelee Island); Wheatley Provincial Park [Ern Wigle Tract] = about 30 ha; Rondeau forested area = 514 ha; Grape Fern Woods all parcels combined = 63 ha; Sinclair's Bush = 33 ha. Leamington has a total area of 15 ha, 5 ha of which could be suitable slug habitat and is not included in these abundance calculations. Given these caveats, the size of the Canadian population is essentially unknown.

Data collected so far are insufficient to determine trends and fluctuations.

Rescue Effect

Although gastropods have some capacity for passive dispersal (see **Dispersal and Migration**), rescue from outside Canada is unlikely due to barriers and population disjunction. The closest US subpopulations in Ohio and Michigan are separated by large water bodies, such as Lake Erie and the Detroit River (Figures 2 and 3).

THREATS AND LIMITING FACTORS

Threats

Direct threats facing Carolina Mantleslug were assessed, organized, and based on the IUCN-CMP (World Conservation Union-Conservation Measures Partnership) unified threats classification system (Master *et al.* 2012) using definitions in Salafsky *et al.* (2008). Threats are defined as the proximate activities or processes that directly and negatively affect the population. Results of the impact, scope, severity, and timing of threats are presented in tabular form in Appendix 1. The threats calculation was based on the extant subpopulations on Pelee Island (about 60% of the Canadian population), Rondeau Provincial Park (20%), Grape Fern Woods (10%), and Wheatley Provincial Park (10%), including all sites where live slugs were observed in 2013-2019 (Table 1); it was uncertain at the time of the threats assessment if the species was extant at Sinclair's Bush and density estimates were not available for all occupied areas. The overall calculated and assigned threat impact is HIGH-LOW (Appendix 1). Given the large ranges for scores for scope, the overall assigned threat impact would not change if the threats calculator was updated to include the slugs at Sinclair's Bush and Leamington. The threats are listed below according to their calculated level of impact, from highest to lowest impact. The numbering of threats corresponds to the categories and sub-categories of the threat calculator.

Threat 11: Climate change & severe weather – HIGH-LOW IMPACT

Using the framework for assessing species' vulnerability to climate change by Foden *et al.* (2013), Carolina Mantleslug can be considered highly vulnerable, because (i) it is exposed to climate change (spring frosts, absence of snow cover, droughts), (ii) it is sensitive (specific microhabitat conditions), and (iii) it has a low adaptive capacity (low intrinsic and extrinsic dispersal possibilities because it lives on an island and in "islands" of natural habitat). However, Carolina Mantleslug may be able persist at some level of climate change because it is less sensitive to droughts than other slug species ("potential persister" as described by Foden *et al*. [2013], see **Physiology and Adaptability**).

Threat 11.1: Habitat shifting and alteration (UNKNOWN IMPACT)

Parts of Carolina Mantleslug habitat in Fish Point PNR are in the wet forest, near the east shore which could be gradually lost in the future (see **Habitat Trends**). During winter 2018/2019 a substantial part of the forest on the southern tip was lost. Although this erosion seems to be a long and slow process, the high lake level combined with heavier storms in

the near future could accelerate this habitat loss. Rondeau Provincial Park also suffers erosion of the marshland which may affect the forest within the next 10 years. This means that water will invade the forest. The impact on the gastropod communities in these two sites is currently unknown, but this habitat loss could become important.

Threat 11.2: Droughts (LOW IMPACT), and Threat 11.3: Temperature extremes (MEDIUM IMPACT)

Southwestern Ontario is projected to have more extreme weather events including droughts, floods, and temperature extremes under climate change models (Varrin *et al.* 2007). McDermid *et al*.'s (2015) study, which is at a finer spatial scale, also suggests summer precipitation is likely to decline in the Lake Erie basin while winter precipitation is likely to increase. With increasing average temperature, spring frost is more frequent (Augspurger 2013), which can cause spring mortality as observed in snails when snow cover is absent (e.g., up to 90%, Nicolai unpubl. data; there is no similar information available on slugs). Droughts can cause high mortality in some gastropod species depending on the presence of shelter (e.g., 75% in *H. pomatia*, Nicolai *et al.* 2011). Carolina Mantleslug is mainly found in floodplains or higher mountain areas (Hubricht 1985), which suggests that it relies on moisture and lower temperatures in summer. However, it is more resistant to droughts than other sympatric slugs (Thompson *et al.* 2006). The huddling behaviour (see **Physiology and Adaptability**) also reduces water loss.

Threat 11.4: Storms and flooding (HIGH-LOW IMPACT)

Many sites on Pelee Island and in Grape Fern Woods are seasonally flooded wet forest (MNR 2005; NCC 2008). While much of Pelee Island was wetland habitat before it was dyked and drained for agriculture, all native snail and slug species on the island are found only on the former four bedrock islands and not in the former wetlands (see **Habitat Trends**). With increased precipitation due to climate change, flooding can be expected over a larger area. Even though Carolina Mantleslug is a specialist of wet forest, unusually high floods in the winter and spring when the slugs are inactive can increase mortality. Parts of Fish Point PNR and Stone Road Alvar, where the species occurs, are affected. In 2019, flooding was observed at SRA (A. Nicolai pers. obs.). Elevation (above sea level) on Pelee Island ranges from 175 m (~1 km north of the ferry dock along the western edge of the island) to 183 m (near Gibwood) with the lake level being 173 m (Natural Resources Canada 2019).

<u>Threat 7: Natural system modifications – LOW IMPACT</u>

Threat 7.1: Fire & fire suppression (LOW IMPACT)

Prescribed fire has become an important management tool for prairie and forest conservation in North America (Gottesfeld 1994; Williams 2000), particularly to limit the invasion of exotic species (Brooks and Lusk 2008) and to promote growth and reproduction of native prairie species (Towne and Owensby 1984). Burning directly and indirectly affects

survival of ground nesting animals, litter dwelling organisms, and soil invertebrates, including snails (Nekola 2002). In southwestern Oregon, both the distribution and abundance of four species of terrestrial gastropods studied were reduced after low-intensity prescribed fires (Duncan 2005). The effects were more severe on snails than on slugs (e.g., Blue-grey Taildropper, *Prophysaon coeruleum*), but slugs were not found at over a quarter of the sites that supported them during pre-fire surveys. The author suggested that at sites with continued persistence, slugs survived in deep fissures in coarse rock substrate or other underground refuges and suggested that the distribution of microhabitats that allow for vertical movements is important for the long-term viability of slug populations within the landscape. Whether similar refuges exist within Carolina Mantleslug habitat is unknown. Fire also reduces and modifies organic substrates and residues, which are sources of nutrients and buffer and shelter these organisms. Fire also changes microclimate when post-burn bare soil is heated by the sun, thereby increasing soil evaporation (reviewed by Saestedt and Ramundo 1990; Knapp *et al.* 2009). Fire destroys the upper part of soil habitat, the litter and uppermost humus layer, which is the most important factor affecting survival for litter-soil organisms (Bellido 1987). No information is available on the effects of fire on decaying logs, which are an important micro-habitat of Carolina Mantleslug (see **Habitat Requirements**).

Portions of the Stone Road Alvar on Pelee Island were subjected to prescribed burns by Ontario Nature and the Essex Regional Conservation Authority (ERCA) in 1993, 1997, 1999, and 2005 (NCC 2008). There are plans by Ontario Nature for burns of the alvar in late summer 2019 to enhance snake habitat and control for invasive grasses. Direct impact of fire on slug populations may be reduced when habitat is widespread and recolonization from unburned areas is possible. When habitat areas are small, larger fires are expected to be detrimental to populations, while fires that are very patchy and restricted to an overall small area would be less harmful. The prescribed burn will take place on 11 ha of the Ontario Nature property where soil-litter depth ranges between 4 and 17 cm. The burn block consists of a mosaic of cool season grasses, alvar specific vegetation, tall grass prairie vegetation, and woody shrubs. Carolina Mantleslug was only found in the wooded part of Stone Road Alvar during fieldwork in 2013-2018. However, the threat should be considered given the risk of fire reaching forested habitat.

Rondeau Provincial Park also uses prescribed burns as a management tool in oak woodland and savanna. However, the interior forest is not considered in current burn plans as the park tries to preserve the closed canopy forest (Dobbyn and Pasma 2012).

Threat 7.3: Other ecosystem modifications (UNKNOWN IMPACT)

There are several highly invasive plants in southern Ontario, including Garlic Mustard (*Alliaria petiolata*) in Carolina Mantleslug habitat. It was observed displacing native vegetation and altering soil nutrient cycles, thereby slowing restoration (Catling *et al.* 2015). The impact of invasive plants on Carolina Mantleslug is unknown.

Non-native earthworms have invaded parts of Canada relatively recently and have altered forest floor habitats by reducing or eliminating the natural leaf litter layer and digging up and mixing the mineral soil with the organic surface layer (CABI 2016). While direct evidence of effects of exotic earthworms on terrestrial gastropods is lacking, Norden (2010) and Forsyth *et al.* (2016) suggested that invasive earthworms could indirectly alter terrestrial gastropod communities. Earthworms, such as the Asian genus *Amynthas* that removes the surface leaf litter (Qiu and Turner 2017), where gastropods live, would be a particular threat (see also Dobson 2017 and Lee 2017 for photographs of the effects of exotic earthworms on soil duff layers). Other indirect effects could result from earthworms feeding on forest plant seeds (Cassin and Kotanen 2016) or by altering plant-fungi mutualisms (Paudel *et al.* 2016) thereby affecting understorey vegetation composition (Drouin *et al.* 2016) and potentially reducing available fungi. This change in forest floor structure profoundly affects plant and litter-dwelling invertebrate communities (Addison 2009; Dobson and Blossey 2015) as well as bird abundance and nesting success (Loss *et al.* 2012). Invasive earthworms are present on the north shore of Lake Erie (Evers *et al.* 2012) and on Pelee Island (Reynolds 2011) as well as elsewhere in Ontario (Reynolds 2014). The Asian genus *Amynthas* is present in Essex County (Reynolds 2014).

Threat 4: Transportation & service corridors – NEGLIGIBLE IMPACT

Threat 4.1: Roads and railroads (NEGLIGIBLE IMPACT)

Woodlots are separated by roads and ditches in Ontario. Paved roads or tracks as narrow as 3 m with high or low traffic densities may fragment gastropod populations (Wirth *et al.* 1999), because snails tend not to cross roads (Baur and Baur 1990a). Reck and van der Reer (2015) cite a study by Martin and Roweck (1988) who documented local extinctions in a population of Rotund Disc (*Discus rotundatus*) in Germany after the original habitat became unsuitable and roads acted as barriers to movement. This conclusion could also be applicable to slugs. Road mortality has also been recognized as a threat for wildlife in protected areas, such as Point Pelee National Park (Parks Canada 2007). However, Carolina Mantleslug is not likely to be affected by road mortality as individuals rarely move away from under logs.

Threat 5: Biological resource use – NEGLIGIBLE IMPACT

Threat 5.1: Hunting & collecting terrestrial animals (NEGLIGIBLE IMPACT)

Individuals have been collected for genetic research which needed voucher specimens in the past. Current research on genetics (e.g., population studies) does not need to involve the collection of whole organisms, given new methods using mucus.

Threat 5.2: Gathering terrestrial plants (NEGLIGIBLE IMPACT)

Mushroom picking could be a potential threat as four edible mushrooms in Ontario (Northern Bushcraft 2018) may also be consumed by Carolina Mantleslug, especially Golden Chanterelle (*Cantharellus cibarius*; White-McLean 2012). However, mushroom picking does not seem a common activity in any of the protected areas containing Carolina Mantleslug habitat.

Threat 5.3: Logging and wood harvesting (NOT A THREAT)

Ash trees (*Fraxinus* spp.) that are infested by the Emerald Ash Borer (*Agrilus planipennis*) are usually cut and left on the ground. Logs are rapidly colonized by mushrooms providing food and shelter to slugs; therefore, logging may have a beneficial effect.

Threat 6: Human intrusions & disturbance – NEGLIGIBLE IMPACT

Threat 6.1: Recreational activities (NEGLIGIBLE IMPACT)

Since the ferry service expanded in 1992, there has been a marked increase in tourism on Pelee Island. Given the global trends in tourism and ecotourism, these increases can be expected to continue. Stone Road Alvar is a prominent site in Pelee Island ecotourism. The site attracts substantial numbers of birders, photographers, tourists, ecologists, and researchers. A short loop trail is close to the road. Large parts of Stone Road Alvar are not accessible due to high vegetation density and absence of trails. Visitor numbers are lower at NCC properties on Pelee Island. Hunting is allowed on all NCC properties. While trampling is not a threat to this inactive species, displacement of logs and rocks or disturbance of leaf litter can alter micro-habitat conditions.

Threat 6.3: Work & other activities (NEGLIGIBLE IMPACT)

Vegetation and species-at-risk monitoring (including snails and slugs) will continue to occur on Pelee Island. Snails and slugs will not be collected, but they could be affected by trampling and modifying microhabitat conditions in small areas of each site.

Threat 8: Invasive & other problematic species & genes – NEGLIGIBLE IMPACT

Threat 8.1: Invasive non-native/aliens species (NEGLIGIBLE IMPACT)

Competition with exotic terrestrial gastropods is also a potential threat (Whitson 2005; Grimm *et al.* 2010) through aggression (Kimura and Chiba 2010), density effects, and/or for food (Baur and Baur 1990b). Exotic gastropods can compete for resources and shelter with the remaining native species. Dusky Arion, Grey Fieldslug, and Grove Snail are widespread in southern Ontario. Carnivorous snails, such as Draparnaud's Glass Snail (*Oxychilus draparnaudi*) and Cellar Glass Snail *(Oxychilus cellarius*), found on Lake Erie islands and mainland of southwestern Ontario during 2013-2017 surveys, may directly affect native species (Mahlfeld 2000).

Threat 8.2: Problematic native species (NOT SCORED)

Wild Turkeys (*Meleagris gallopavo*) and Ring-necked Pheasants (*Phasianus colchicus*) were introduced to some areas of Ontario for hunting, and while turkeys are native to the mainland, they are introduced on Pelee Island (Threat 8.1). Both bird species are omnivorous and include snails in their diet (Sandilands 2005). Even though the impact of the invasive species on slugs is negligible (Threat 8.1), it could be considered a potential threat as it was for the Endangered Small-mouthed Salamander (*Ambystoma texanum*; COSEWIC 2014b).

Raccoons (*Procyon lotor*) are usually problematic in provincial parks with campsites, such as Wheatley and Rondeau, because campers provide food which leads to an increase in raccoon numbers (Cheskey and Wilson 2001). They are opportunistic feeders and predate ground-nesting and litter-dwelling animals. It is unknown how the predation affects gastropod communities.

Threat 9: Pollution – UNKNOWN IMPACT

Threat 9.1: Household sewage and urban waste water (NEGLIGIBLE IMPACT)

Air and water borne pollution (e.g., heavy metals and road salt) in close proximity to roads is a threat to gastropods (Viard *et al.* 2004), because heavy metals in the soil and plants are accumulated in tissues (Notten *et al.* 2005) and decrease food consumption, growth, and fecundity (Laskowski and Hopkin 1996). While road density is low on Pelee Island, provincial parks usually have roads.

Threat 9.3: Agriculture and forestry effluents (UNKNOWN IMPACT)

The impacts of pesticides on terrestrial gastropods are poorly known. Population level impacts of herbicides on terrestrial snails and slugs were not detected in agricultural (Roy *et al.* 2003) or forested (Hawkins *et al.* 1997a) landscapes, but laboratory studies have shown that exposure to some herbicides increases mortality of an aquatic snail species infected with parasitic trematode cercariae (Koprivnikar and Walker 2011) and could affect reproduction in terrestrial snails (Druart *et al.* 2011). Neonicotinoid insecticides are increasingly used as a coating on soy bean and maize seeds (Douglas and Tooker 2015) and were not harmful to Grey Fieldslug. It is currently unknown how these pesticides act on native slugs. The close proximity of agricultural land to wooded areas on Pelee Island and in Grape Fern Woods may expose slugs to pesticide drift.

Cumulative Effects

Logging, mining, agriculture, recreation, and the establishment of second growth forest are activities that are generally known to increase the abundance of invasive plants (Calinger *et al.* 2015). There is a quarry on Pelee Island and land owners do cut trees on their land. Invasive earthworm species facilitate Garlic Mustard invasion by quickly breaking

down leaf litter and creating good sites for establishment (Anderson 2012). Climate change and forest disturbance may also facilitate the spread of introduced species in Canada with largely unknown and untracked, but potentially serious impacts, on native gastropod faunas.

Limiting Factors

In Canada, Carolina Mantleslug exists near the northern limits of its distribution and northward expansion is probably limited by harsh winters, but more through human-caused fragmentation and habitat loss (Gibson *et al.* 2009) and physical barriers, such as the extensive bodies of water. Low dispersal ability restricts gene flow among subpopulations. At the microhabitat scale, availability of moist refuges that buffer environmental fluctuations is probably a limiting factor for population growth and persistence at particular sites.

Number of Locations

Given the distances among slug subpopulations and the various threats, there are between six and eight locations of Carolina Mantleslug in Canada. The lower end of the range occurs if all the known, recently occupied sites on Pelee Island (SRA, Fish Point, RBIP, WW) are combined yielding one location, with each of the five known or uncertain mainland sites (Leamington, Grape Fern Woods, Wheatley PP, Rondeau PP, and Sinclair's Bush) being single locations (Table 1; Figure 2). While the status of the slug subpopulation at Leamington could not be determined because it has not been recently surveyed, intact, suitable habitat is present. Similarly, Carolina Mantleslug was not found during surveys in 2013 and 2019 at Sinclair's Bush, but suitable habitat is present.

The most serious and plausible threats are due to the various effects of climate change (droughts, extreme temperatures, and flooding) and prescribed burns (Appendix 1). Because increasing frequency of droughts/frost could simultaneously affect all the occupied sites on Pelee Island, the entire island could be one location. Similarly, given the distance among the mainland sites, each could be a separate location under the threat of droughts and extreme temperatures under climate change. Rondeau, SRA, and Fish Point are also susceptible to floods with RBIP and WW being a potentially separate location on Pelee Island if SRA and Fish Point are combined into a single location under the threat from floods. An additional threat confined to SRA and Rondeau is prescribed fire.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Carolina Mantleslug is not protected by any legislation, regulations, customs, or conditions. It is not listed on the IUCN Red List (IUCN 2017), under the US *Endangered Species Act* (USFWS 2017), or under any provincial acts. It is not listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2017).

Non-Legal Status and Ranks

NatureServe (2019) provides the following ranks for Carolina Mantleslug for the US and Canada:

Global Rank: G5 – secure (last reviewed 8 October 2002)

National Rank (US): N5 - secure (last reviewed 8 October 2002)

National Rank (Canada): N1 – Critically imperilled (10 Aug 2017; same rank in CESCC 2016)

Subnational Ranks (S-ranks) as provided by NatureServe (2019) for the US and by CESCC (2016) for Canada are as follows:

SNR: Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Maine, Maryland, Mississippi, Missouri, New Jersey, New York, Ohio, Oklahoma, South Carolina, Texas, West Virginia

S5: North Carolina, Tennessee

S4/S5: Pennsylvania

S4: Kentucky, Virginia

S2: Michigan

SU: Wisconsin

S1: Ontario (Note: NatureServe 2019 rank is S1S2)

Habitat Protection and Ownership

Ownership of currently occupied habitat in Ontario is shown in Table 1. Sites owned by MECP, Essex Region Conservation Authority, Nature Conservancy of Canada, and Ontario Nature are protected areas. Management plans were reviewed in **Habitat Trends**. Grape Fern Woods is privately owned and not protected, but is overseen by St. Clair Region Conservation Authority. The former White Oak Woods near Leamington is an Environmentally Significant Area and currently protected through landowner cooperation with ERCA. One lot was up for sale in 2017. Winery Woods is owned by the Pelee Island Winery. Sinclair's Bush is protected through landowner cooperation with LTVCA.

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  - Ontario Region (13 March 2018)

- Museums:
  - Royal Ontario Museum (visit in August 2015)
  - Canadian Museum of Nature (29 November 2016)
  - Carnegie Museum of Natural History, Pittsburgh (29 November 2016)
  - University of Michigan, Museum of Zoology (29 November 2016)

- Parks:
  - Ontario Parks (many times in 2013-2017)

- Provincial / territorial representatives:
  - ON (8 December 2017)

- Conservation Data Centres or Natural Heritage Information Centres:
  - ON: Natural Heritage Information Centre (many times in 2013-2017)

- COSEWIC Secretariat:
  - ATK (7 June 2017, 8 December 2017)

- Conservation organizations:
  - NCC (many times in 2013-2017)
  - Ontario Nature (9 December 2016)
  - ERCA (9 December 2016)

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Annegret Nicolai is a biologist at the UMR CNRS 6553 EcoBio/OSUR of the University Rennes 1, France. She has a Ph.D. from the University of Bremen in Germany and from the University Rennes 1 in France. Her research involves investigating eco-physiological questions in terrestrial snails, specifically about the impact of climate change and resource availability on the physiology and reproduction in endangered and invasive species. She has very specific knowledge about the biology, anatomy, physiology, and ecology of terrestrial gastropods. In Germany she developed a captive-breeding program for the protected *Helix pomatia* and in France she was coauthor of the National Action Plan for the conservation of *Tyrrhenaria ceratina* in Corsica. In the Sinclair lab at Western University, Ontario, she investigated the overwintering strategy of the invasive species *Cepaea nemoralis*. Since 2012 she has been surveying terrestrial gastropods in Ontario and participating in the “barcoding of life” project at the University of Guelph. She became a member of the molluscs subcommittee of COSEWIC in 2014.

COLLECTIONS EXAMINED

The collections of the Canadian Museum of Nature, the Royal Museum of Ontario, Bishops Mills Natural History Centre, the Academy of Natural Sciences, Philadelphia, Carnegie Museum of Natural History, Pittsburgh, and occurrence data from the Natural Heritage Information Center of Ontario were examined by contacting curators (see **ACKNOWLEDGEMENTS** and **AUTHORITIES CONTACTED**). A global survey of museum records was searched through the Global Biodiversity Information Facility. This allowed the checking of a wide range of museum records including Canadian records:

- NatureServe Central Databases (accessed through GBIF data portal, http://data.gbif.org/datasets/resource/607, [DATE]) doi:10.15468/lysaex

and US records :

- Museum of Comparative Zoology, Harvard University (2016): Museum of Comparative Zoology, Harvard University. Dataset/Occurrence. http://digir.mcz.harvard.edu/ipt/resource?r=mczbase doi:10.15468/p5rupv, doi:10.15468/p5rupv doi:10.15468/p5rupv
- Field Museum: Field Museum of Natural History (Zoology) Invertebrate Collection doi:10.15468/6q5vuc
- Florida Museum of Natural History: UF Invertebrate Zoology doi:10.15468/sm6qo6
- Bailey-Matthews National Shell Museum (BMSM) doi:10.15468/49s45k
- Sam Noble Oklahoma Museum of Natural History: Recent Invertebrates Specimens doi:10.15468/glxcep
- SysTax: SysTax - Zoological Collections doi:10.15468/zyqkbl
- Queensland Museum: Queensland Museum provider for OZCAM doi:10.15468/lotsye
- North Carolina Museum of Natural Sciences Invertebrates Collection doi:10.15468/jzqd4x
- University of Kansas Biodiversity Institute Invertebrate Zoology Collection doi:10.15468/ubq6lh
- California Academy of Sciences: CAS Invertebrate Zoology (IZ) doi:10.15468/tiac99
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- Natural History Museum Rotterdam: Natural History Museum Rotterdam (NL) - Mollusca collection doi:10.15468/tgt9dj
- iNaturalist.org: iNaturalist Research-grade Observations doi:10.15468/ab3s5x
- Academy of Natural Sciences: MAL doi:10.15468/xp1dhx
- Biologiezentrum Linz Oberoesterreich: Biologiezentrum Linz doi:10.15468/ynjblx

Appendix 1. Threats assessment for Carolina Mantleslug (*Philomycus carolinianus*).

Species or Ecosystem Scientific Name	*Philomycus carolinianus* (Carolina Mantleslug)
Date (Ctrl + ";" for today's date):	6/27/2019
Assessor(s):	Dwayne Lepitzki (responsible Co-chair and threats facilitator), Joe Carney (Co-chair), Andrew Hebda (SSC member), Robert Forsyth (SSC member), Jill Crosthwaite (NCC), Erin Carroll (SCRCA), Kaylie Crawford (Rondeau Provincial Park), Meagan McCloskey (Point Pelee National Park), Christina Davy (COSEWIC member for Ontario), Elisabeth Sapiro (CWS), Annegret Nicolai (report writer), Bev McBride (COSEWIC Secretariat)
References:	Draft threats assessment provided with draft status report

Overall Threat Impact Calculation Help:

Threat Impact		Level 1 Threat Impact Counts: high range	low range
A	Very High	0	0
B	High	1	0
C	Medium	0	0
D	Low	1	2
Calculated Overall Threat Impact:		High	Low

Assigned Overall Threat Impact:	**BD = High - Low**
Impact Adjustment Reasons:	Given uncertainty in severity, low-high range maintained.
Overall Threat Comments	Generation time ~2 years so timeframe for severity and timing is 10 years into the future. Currently known from 5 localities: Pelee Island (3 clusters: Stone Road Alvar; Richard & Beryl Ivey Property + Winery Woods; Fish Point Prov. Nature Reserve); Wheatley PP; Grape Fern Woods; Rondeau PP. Status of historical occurrence at Leamington uncertain because privately owned and not accessible for surveys (Figure 2). Density estimates are only available from a few occurrences so could base scope on area of potential habitat within each occurrence. Report writer suggests 60% of the Canadian population is at Pelee Island; 20% Rondeau, 10% Wheatley, and 10% Grape Fern Woods.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & commercial development						Grape Fern Woods is privately owned and does not benefit from specific protection.
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						No new tourism or recreation expansions are planned in Erin Wigle Tract of Wheatley Prov. Park. Potential trail expansion on Nature Conservancy of Canada (NCC) properties will not overlap species' habitat (Finley/Krestel). Area managers are aware of the slugs and work will be mitigated to reduce impact.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						Agricultural drains could change hydrological flow patterns. Grape Fern Woods is privately owned and does not benefit from specific protection. Land at Grape Fern Woods could be sold and be subject to agricultural conversion, but timeline and outcome are unknown.
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						
3	Energy production & mining						
3.1	Oil & gas drilling						
3.2	Mining & quarrying						
3.3	Renewable energy						
4	Transportation & service corridors		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
4.1	Roads & railroads		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Road kill is negligible, because this slug doesn't move far from log/microhabitat. Roads could be a limiting factor (barrier to dispersal).
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals		Negligible				Collecting for genetics is based on mucus and not lethal.
5.2	Gathering terrestrial plants		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	Scope for mushroom picking is at the lower end of large although negligible in Rondeau. Severity likely negligible because people will remove the slug and likely would not collect the mushroom.
5.3	Logging & wood harvesting		Not a Threat	Small (1-10%)	Neutral or Potential Benefit	High (Continuing)	Historical threat but not happening now and not expected to increase, except for Grape Fern Woods (private, no protection). Cutting dead ash trees and leaving them on the ground provides habitat as long as the forest habitat is maintained. Some are being felled deliberately and there is possible local illegal collecting for firewood.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.4	Fishing & harvesting aquatic resources						
6	Human intrusions & disturbance		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	While trampling is not a threat in this species, displacement of logs and rocks or disturbance of leaf litter can occasionally alter micro-habitat conditions.
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Population studies and monitoring of the species may disturb some individuals, but efforts are made to reduce the impact. Researchers working on salamanders are aware of gastropods at risk on Pelee Island and take care to not disturb them.
7	Natural system modifications	D	Low	Restricted (11-30%)	Moderate (11-30%)	High (Continuing)	
7.1	Fire & fire suppression	D	Low	Restricted (11-30%)	Moderate (11-30%)	High (Continuing)	Prescribed burns will occur at Stone Road Alvar, Pelee Island (only alvar savanna in the Ontario Nature property: 11 ha, so 2% of Stone Road Alvar) in 2019. Forested Carolina Mantleslug habitat should not be affected, unless the fire spreads outside the prescribed burn boundaries. A study on the impact of fire on gastropods will occur at the same time. Rondeau park also uses fire as a management tool but mainly in open forest or savanna. (Point Pelee NP plans to study fire effect on gastropods. Even though the slug is not extant there, the study results may help to assess threats related to prescribed burns.)
7.2	Dams & water management/use						
7.3	Other ecosystem modifications		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Invasive plants (such as Garlic Mustard) are found on Pelee Island and at Rondeau. Invasive earthworms affect habitat by changing soil chemistry, potentially affecting the species. Invasive slugs are found on Pelee Island; however, it is not known if these are a threat.
8	Invasive & other problematic species & genes		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.1	Invasive non-native/alien species/diseases		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Exotic slugs (especially *Arion* sp.) are also fungivore and may compete for food. Introduced Wild Turkeys and Ring-necked Pheasants on Pelee Island could consume slugs, but potentially NOT the species of interest (non-native pheasants are also on the mainland).
8.2	Problematic native species/diseases						Raccoons in Wheatley and Rondeau; overbrowsing by White-tailed Deer at Rondeau is mitigated by deer culls.
8.3	Introduced genetic material						
8.4	Problematic species/diseases of unknown origin						
8.5	Viral/prion-induced diseases						
8.6	Diseases of unknown cause						
9	Pollution		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
9.1	Domestic & urban waste water		Negligible	Negligible (<1%)	Extreme (71-100%)	High (Continuing)	Pollution from roads, runoff (salt, cyanide): Pollution from roads is negligible, because there is only light traffic on Pelee Island and in the parks.
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	NCC restores fields in adjacent properties. Light use of herbicides on NCC properties, in the past and probably in the future. The same for Rondeau. Population level impacts of Glyphosate not detected in agriculture or forested landscapes but have been found in lab studies. Neonicotinoids used in soy bean culture does not affect pest slugs. Effect on other slugs unknown. Grape Fern Woods, surrounded by agricultural land, may be exposed to agricultural runoffs.
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events						
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides						
11	Climate change & severe weather	BD	High - Low	Large (31-70%)	Serious - Slight (1-70%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.1	Habitat shifting & alteration		Unknown	Restricted (11-30%)	Unknown	High (Continuing)	Extensive erosion occurred at Fish Point in winter 2018/2019. Parts of the forest at the tip are completely eroded. Tree fall has opened the canopy. Rondeau also suffers from erosion of the marshland which may affect the forest within 10 years. Water will invade the forest.
11.2	Droughts	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Effects of drought would most likely encompass entire range although severity of impacts may be reduced in some microhabitats. Species is quite resistant to droughts, because they huddle to reduce water loss.
11.3	Temperature extremes	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	Closely tied with droughts. Changes to spring/fall frost regimes (frost without snow cover) would most likely encompass entire range but severity would vary among microhabitats.
11.4	Storms & flooding	BD	High - Low	Large (31-70%)	Serious - Slight (1-70%)	High (Continuing)	Carolina Mantleslug lives in riparian forest (Grape Fern Woods) and in temporally flooded parts of Rondeau, Stone Road Alvar, and Fish Point and are therefore susceptible to drowning during floods. Great Lakes water levels are high, and this may not change in the next few years. Tree fall due to storms might be beneficial in interior areas of Pelee Island and Rondeau as long as the forest canopy is preserved.
11.5	Other impacts						

Classification of Threats adopted from IUCN-CMP, Salafsky *et al.* (2008).