

COSEWIC
Assessment and Status Report

on the

Toothed Globe
Mesodon zaletus

in Canada



ENDANGERED
2019

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada



COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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

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Production note:

COSEWIC would like to acknowledge Annegret Nicolai for writing the status report on Toothed Globe, *Mesodon zaletus*, 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.

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Cover illustration/photo:

Toothed Globe *Mesodon zaletus* recorded by C. Goodrich and M. L. Winslow in 1890 in Leamington, University of Michigan Museum of Zoology, Bryant Walker collection, UMMZ 105034 (photo by UMMZ Mollusk Division).

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COSEWIC Assessment Summary

Assessment Summary – November 2019

Common name

Toothed Globe

Scientific name

Mesodon zaletus

Status

Endangered

Reason for designation

In Canada, this large terrestrial snail is near the northernmost extent of its global range in southern Ontario. The species is known from islands in Lake Erie and from Essex and Middlesex counties on the mainland. It is likely extirpated from six of nine known sites. Although the species has not been observed alive since 1994, it may still occur at three inaccessible sites where suitable habitat still exists. Main threats include increased droughts and flooding associated with climate change, invasive species, and pollution.

Occurrence

Ontario

Status history

Designated Endangered in November 2019.



COSEWIC Executive Summary

Toothed Globe *Mesodon zaletus*

Wildlife Species Description and Significance

Toothed Globe is a large land snail (adult shell width 2.4-3.1 cm) with a globose-depressed (flattened sphere), yellow, solid shell that has a tooth-like denticle in the opening. This species is part of the unique fauna of the Carolinian Forest in Canada and, similar to other terrestrial snails, may have significance for ecosystem function through nutrient cycling. A Canadian range-edge population would be important for the global conservation of this species as are other range-edge species.

Distribution

If Toothed Globe is still extant in Canada, its global distribution extends from southern Ontario southward to South Carolina in the east and Texas in the west. In Canada, the species may currently still occur on private and First Nations land in Essex and Middlesex counties. The species appears to have been extirpated from most southwestern Ontario sites, mainly Lake Erie islands.

Habitat

Toothed Globe inhabits cool, deciduous forests and may be found mainly in the litter of old-growth oak forests. The remaining habitat where the species may still occur is private, not protected, or managed by First Nations communities. The habitat at all sites is surrounded by unsuitable arable land or water.

Biology

Toothed Globe is an egg-laying land snail. Reproduction probably occurs in spring and late summer. Hibernation extends from early October until April in temperate regions. Aestivation in summer may occur only during prolonged drought. Sexual maturity is probably reached at 2–3 years and the species may reach an age of 8–10 years. The species may mainly feed on decaying plants or fungi in the litter. Active dispersal for colonization of new areas is on the order of tens of metres over several years. Passive dispersal by flooding of rivers or transportation by birds is possible but has not been documented. There is no evidence of transport by humans.

Population Sizes and Trends

The species is likely extirpated from at least six out of nine historically known occurrences. The presence of the species in the three remaining sites could not be confirmed.

Threats and Limiting Factors

Low dispersal ability and low physiological resistance to fluctuating environmental factors such as temperature and humidity are limiting factors. General threats to gastropods in Ontario are climate change (droughts, changes in frost regimes), pollution, and invasive species in addition to any direct and indirect impact by humans specific to each of the remaining three sites; these site-specific threats remain uncertain because the presence of the snail could not be confirmed.

Protection, Status and Ranks

Toothed Globe 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

Mesodon zaletus

Toothed Globe

Gobelet dentelé

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)	~5-6 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Yes (reduction in number of occupied sites if any are remaining)
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. Unknown b. Unknown c. Unknown
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EEO)	552 km ² (based on uncertain occurrences)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	12 km ² (based on uncertain occurrences)
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)	0-3 (based on uncertain occurrences)
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, historical decline
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, historical decline
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Yes, historical decline
Is there an [observed, inferred, or projected] decline in number of “locations”*?	Yes, historical decline (same as subpopulations)
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes (observed: historical habitat loss/degradation; projected: unprotected habitat in private sites)
Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of “locations”*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	N Mature Individuals
Hen Island	Uncertain (not surveyed, private land)
White Oak Woods	Uncertain (not surveyed, private land)
Caradoc Indian Reserve	Uncertain (not surveyed, First Nations land)
Whole range	Unknown (based on uncertain occurrences)

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

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

Was a threats calculator completed for this species?
No. (If the species is still extant in Ontario, only private and First Nations land may still harbour subpopulations.)

Threats: Uncertain

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.	Pennsylvania (S3), Ohio (SNR), Michigan (SNR), New York (SNR)
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
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.	

Status History

COSEWIC: Designated Endangered in November 2019.

Status and Reasons for Designation:

Status: Endangered	Alpha-numeric codes: B1ab(iii)+2ab(iii)
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* See [Table 3](#) (Guidelines for modifying status assessment based on rescue effect)

Reasons for designation:

In Canada, this large terrestrial snail is near the northernmost extent of its global range in southern Ontario. The species is known from islands in Lake Erie and from Essex and Middlesex counties on the mainland. It is likely extirpated from six of nine known sites. Although the species has not been observed alive since 1994, it may still occur at three inaccessible sites where suitable habitat still exists. Main threats include increased droughts and flooding associated with climate change, invasive species, and pollution.

Applicability of Criteria**Criterion A (Decline in Total Number of Mature Individuals):**

Not applicable. The number of mature individuals has never been known therefore population trend is uncertain.

Criterion B (Small Distribution Range and Decline or Fluctuation):

Meets Endangered, B1ab(iii)+2ab(iii). Both the EOO (552 km²) and IAO (12 km²) are below the thresholds for Endangered (<5,000 km² and 500 km², respectively), there are 3 locations of uncertain status which is below the threshold for Endangered (less than or equal to 5), and there is an observed and projected continuing decline in quality of habitat (biii) caused by a variety of threats.

Criterion C: (Small and Declining Number of Mature Individuals):

Not applicable. 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. Meets Threatened, D2, because the IAO (12 km²) and the number of locations are below the thresholds (20 km²; 5 or fewer, respectively), and because the snail is prone to the effects of human activities or stochastic events in an uncertain future such that once events occur, the species will meet the thresholds for critically endangered within 1 or 2 generations (5–12) years or become Extirpated.

Criterion E (Quantitative Analysis):

Not applicable as analyses have not been done.



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.

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

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Toothed Globe *Mesodon zaletus*

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2019

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Kingdom: Animalia

Phylum: Mollusca

Class: Gastropoda

Order: Pulmonata

Suborder: Stylommatophora

Family: Polygyridae

Genus: *Mesodon*

Species: *Mesodon zaletus*

(Binney, 1837)

Common English name: Toothed Globe

Common French name: *Gobelet dentelé*

Originally recognized as *Helix zaleta* by Binney in 1837, the species was also called *Helix exoleta* by Binney in 1851 and *Mesodon exoleta* by Binney in 1878 (Pilsbry 1940), *Polygyra zaleta* by Pilsbry in 1900 (Pilsbry 1940) and later by Goodrich (1916) for Lake Erie islands subpopulations. Finally, Pilsbry (1940) placed it in genus *Mesodon* as currently accepted (Turgeon *et al.* 1998).

Morphological Description

Toothed Globe is a relatively large land snail with adult size 2.4-3.1 cm (measured as maximum shell breadth) with a yellow, globose-depressed (like a flattened sphere), solid shell (Pilsbry 1940). The shell has oblique striae (shallow grooves on the surface of the shell), and a reflected, white, nearly 3 mm wide lip in the shell opening (= aperture, where the body retreats) of adults. The upper wall in the opening has a white tooth-like denticle (see photo on front cover). When the shell is not thickened by age, the tissue on the inside of the shell (i.e., the mantle) is boldly marked with confluent black spots and visible through the shell. Body colour is greyish brown or blackish and paler below.

Toothed Globe could be easily confounded with Big-tooth Whitelip (*Neohelix dentifera*) which is about the same size and also has a reflected lip and a parietal tooth. However, Toothed Globe can be distinguished from Big-tooth Whitelip by its higher, polished shell with a narrower last whorl and a less broad, more descending opening (Pilsbry 1940). Big-tooth Whitelip has a greyish to light brown body colour (Hotopp and Winslow 2012a).

Population Spatial Structure and Variability

If there is still an extant population in Canada (Table 1), at least three subpopulations may currently exist: one on Hen Island in Lake Erie and two mainland subpopulations in Leamington (former White Oak Woods) and in the Caradoc Indian Reserve. Genetic differences are expected for these subpopulations because there is probably no gene flow:

(1) dispersal over open water is incidental (see **Dispersal and Migration**), (2) dispersal between ecologically unconnected and widely separated habitat through barriers and unsuitable habitat (see **Dispersal and Migration**) is unlikely:

- (1) The Hen Island subpopulation is separated by approximately 35 km of open water from the closest subpopulation on the mainland in Leamington (former White Oak Woods). 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).
- (2) Gene flow is probably also absent between other mainland subpopulations, because they are separated by a minimum 45 km (between Caradoc and Leamington). Anthropogenic changes to the landscape dramatically decreased forested habitat on the mainland, with less than 5% remaining as scattered patches of less than 10 ha (ERCA 2002).

Table 1. Collections of Toothed Globe (*Mesodon zaletus*) from Ontario and verification of all sites during fieldwork in 2013-2017, except Hamilton, where the exact site is uncertain. No other collections are known and all collections consist of adult-sized specimens because juvenile polygyrids are difficult to identify. Collections are curated by the Canadian Museum of Nature (CMNML), by the Field Museum of Natural History (FMNH), by the Carnegie Museum (CMNH), by the University of Michigan Museum Zoology Collection (UMMZ), and by R.G. Forsyth (RGF).

County/Island	Locality	First Record	Last record*	Collectors	Surveys (2013-2017) and status
Middle Sister Island		1915 (C. Clapp, G.H. Goodrich, B. Walker: CMNH84954)	2013 (old weathered shell)	M. Oldham, A. Harris, R. Foster, A. Nicolai (RGF13.138)	Only one weathered shell under 50 cm layer of mulch; probably extirpated
East Sister Island		1915	1915 (alive)	C. Clapp, G.H. Goodrich, B. Walker (CMNH84951)	Not found. Extirpated
Hen Island		1916	1916 (alive)	W.P. Holt (CMNH84969)	No access. Habitat available; probably extant but uncertain
Middle Island		1916 (Goodrich 1916)	2013 (old weathered shell)	M. Oldham, A. Harris, R. Foster, A. Nicolai (RGF13.170)	Only one weathered shell in huge pile of shells on south side; probably extirpated
Pelee Island	Fish Point	1936	1936 (alive)	G. Boggess (CMNH62.32780)	Not found. Extirpated
Essex Co.	Leamington	1890 (C. Goodrich & M.L. Winslow, UMMZ 105034)	1994 (alive)	M. Oldham (in White Oak Woods, field number 16066c in Grimm collection)	No access. Most recent specimen(s) not located (R. Forsyth pers. comm. 2019). Habitat available; probably extant but uncertain

County/Island	Locality	First Record	Last record*	Collectors	Surveys (2013-2017) and status
	Oxley	1905	1905 (alive)	B. Walker (CMNH84826)	Not found. Extirpated.
Middlesex Co	Caradoc Indian Reserve	1980	1980 (alive)	B. Martin (CMNML96175)	No access. Habitat available; probably extant but uncertain
	Hamilton	No date		(FMNH96581)	Not found. Extirpated.

*All records consist of 1-2 adults.

Designatable Units

All Canadian subpopulations are within the Great Lakes Plains ecological area. Evidence of the species' presence or local adaptations (e.g., morphological differences) as well as genetic data in Canada are unavailable. A single designatable unit is therefore recognized in Canada.

Special Significance

If extant, Toothed Globe in Canada may only occur in the Carolinian Forest Region and in the remaining deciduous forest zone just northeast of the Carolinian Forest Region along the Lake Ontario shore. Canada is near the northern limit of the species' 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 watching).

Snails and slugs represent 2.5 to 6% (assuming densities of 2-38 snails/m²) of the total animal biomass of boreal forest ecosystems (Hawkins *et al.* 1997b). Snails and slugs 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); and (iii) 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).

This species 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

Toothed Globe is distributed across eastern North America. The northern limit is southern Ontario, New York, and Michigan. The east-west distribution in the US is from New York to Iowa in the north and from South Carolina to Texas in the south (Figure 1). See **Non-Legal Status and Ranks** for the detailed list of US states where the species was known to occur. While Oughton (1948) and Perez and Cordeiro (2008) include Wisconsin in the species' range, there are no confirmed records. Getz *et al.* (2017) includes South Carolina in the species' range as confirmed by specimens in the Field Museum of Natural History and in the Florida Museum of Natural History; see **Collections Examined**.

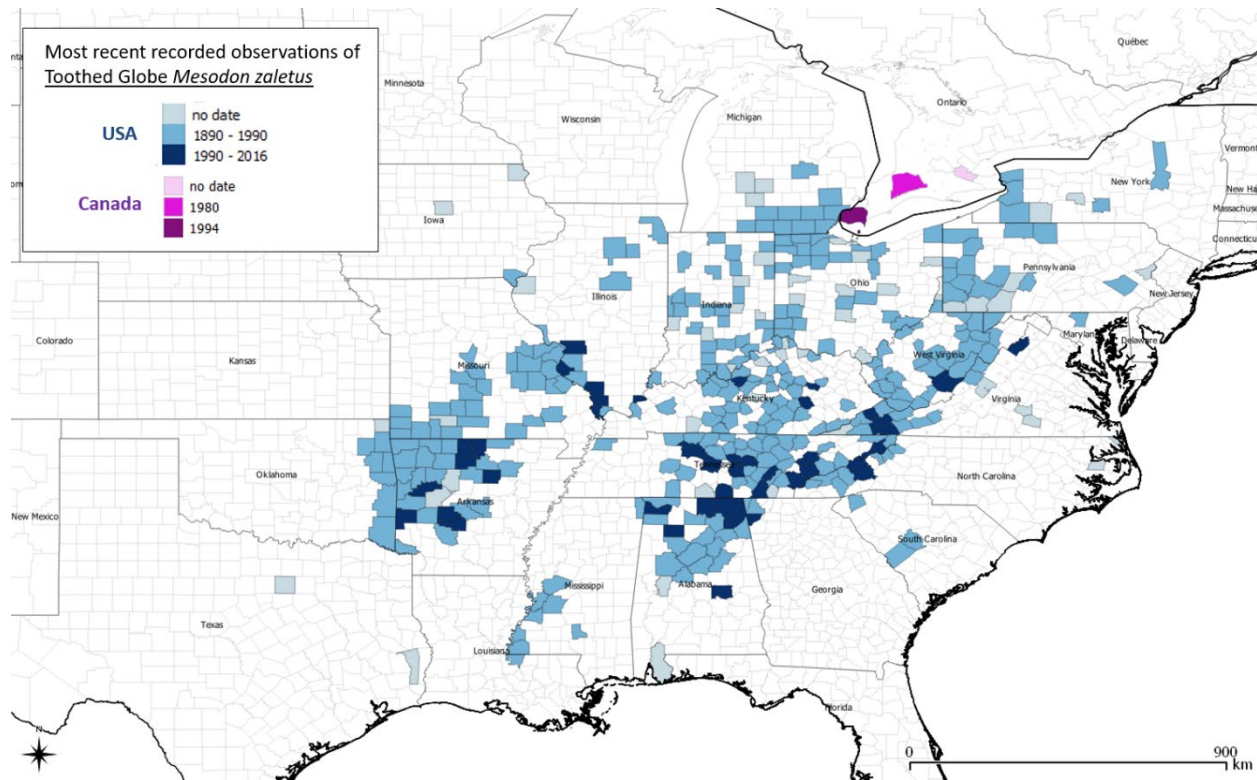


Figure 1. Global distribution of Toothed Globe (*Mesodon zaletus*), Canadian counties in Ontario where the species might still occur (purple, refer to Figure 2 for exact possible distribution) and US counties (blue: records from no date and 1890 to 2016). Note that the species does not occur in the entire county. Occurrences per county are based on the most recent records in collections (see Collections Examined) and literature (Pilsbry 1940; Robertson and Blakeslee 1948; Hodges 2016).

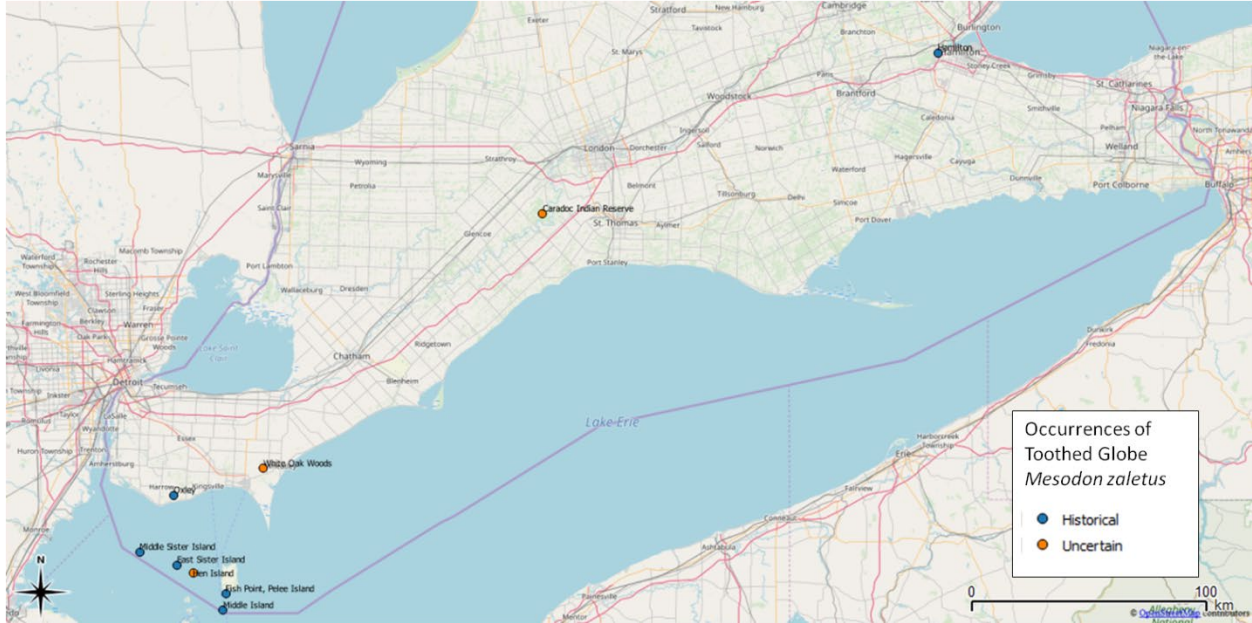


Figure 2. Distribution of Toothed Globe (*Mesodon zaletus*) in Canada based on uncertain occurrences and historical records compiled for this report. “Uncertain” means the presence of the species is uncertain, because habitat was not accessible (private or First Nations land).

Canadian Range

Toothed Globe is historically known from several islands in Lake Erie and from Essex and Middlesex counties on the mainland of southwestern Ontario (Table 1). Toothed Globe was found alive on Middle and Middle Sister islands in 1916 (Goodrich 1916) but because only two old weathered shells were found in 2013, one from each of the islands, the species is probably now extirpated from these two islands (Table 1). The current status of the species on Hen Island, another historically inhabited site, is unknown because access was not obtained to search this private island owned by the Quinnebog Fishing Club (2019). Since 1916 no gastropod surveys have occurred on Hen Island; however, forest habitat appears intact.

On the mainland, records of Toothed Globe are from near Leamington and Oxley in Essex County, and from the Caradoc Indian Reserve in Middlesex County (Table 1). The current status of the subpopulations near Leamington and on the Caradoc Indian Reserve are uncertain (Table 1). Habitat appears to be intact at White Oak Woods near Leamington and the Caradoc Indian Reserve. The subpopulation at Oxley is probably extirpated because this snail was not found in recent searches in the last forested area of Oxley and the record consists only of live snails collected in 1905 (Table 1).

There is one historical, undated record from “Hamilton” (Table 1) with the exact site also being unknown (i.e., it is uncertain if “Hamilton” refers to the city or township). La Rocque (1953) includes the Niagara region in his range description without any detailed sites, probably due to the record from Hamilton. Some sites in and around Hamilton,

specifically in lowland forests, and on the Niagara Escarpment, as well as old-growth forests in Norfolk County were searched in 2013-2017 (Table 2). Time for field verification was insufficient to visit all places on the Niagara Escarpment outside Hamilton and in Norfolk County. During other recent gastropod surveys along the entire extent of the Niagara Escarpment by Nekola (2003, 2010), the species was not found. No direct occurrence information is given in Nekola (2010), but data analysis and results imply the absence of Toothed Globe in his Canadian samples. Oughton (1948) did not find it during large surveys in Norfolk County. Three historical records, one each from Lambton County, Kettle Point (1890, UMMZ 142283), Prince Edward County, Bloomfield (1980, MM 2.4-1736), and Essex County, Point Pelee (1931, UMMZ 178022) were misidentifications.

Table 2. Summary of general gastropod survey sites in southwestern Ontario in 2013-2017; if Toothed Globe (*Mesodon zaletus*) had been present, it would have been detected. 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). CA – Conservation Area, NCC – Nature Conservancy of Canada, TTLT – Thames Talbot Land Trust. (NAD83, 17T or 18T/N UTM). In addition and since 2014, Parks Canada Agency has yearly examined seven 2x2 m plots on Middle Island; Toothed Globe has not been found.

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	M. z. records
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	Old single shell (from 2013)
Middle Sister Island, Lake Erie	3.5	TD1, RFF, AGH, AN, MJO	Apr 30					Old single shell (from 2013)
East Sister Island Provincial Park, Lake Erie	16.5	TD1, RFF, AGH, AN, MJO, RGF, RG, 2 park staff	Apr 30		Aug 13			No
Lighthouse Point Provincial Nature Reserve, Pelee Island (2 sites)	10	RFF, AN, MJO; AN, RGF	May 1; Aug 25		Aug 12	01 Sep	Aug 14	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	5.5	AGH, RFF, MJO, AN, RGF	May 2; Aug 25		Aug 14	03 Sep	Aug 17	No
Middle Point Woods – south part, NCC, Pelee Island	8	RFF, AGH, AN, RGF	May 1, 2; Aug 26	Aug 3		03 Sep	Aug 17	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	AN, MJO	May 2				Aug 14	No
Florian Diamante Nature Reserve, NCC,	11	AGH, RFF, AN, RGF	May 2	Aug 2	Aug 11, 12	02 Sep	Aug 14	No

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	M. z. records
Pelee Island								
Richard and Beryl Ivey Nature Reserve, NCC, Pelee Island	8	RFF, AGH, AN, RGF	May 1	Aug 2	Aug 12	02 Sep	Aug 16	No
Winery property, Pelee Island	6.5	RFF, AGH, AN, MJO, RGF	May 2	Aug 2		31 Aug	Aug 16	No
Porchuk Property, NCC, Pelee Island	8	AN, MJO, RGF, AN	May 2			01 Sep	Aug 15	No
Fish Point Provincial Nature Reserve, Pelee Island	21	RFF, AGH, AN, RGF	May 1	Aug 3	Aug 11	02 Sep	Aug 16	No
Fleck Property, Pelee Island	2	RFF, AN	May 2				Aug 15	No
Essex Region Conservation Authority Stone Road Alvar, Pelee Island	5	AGH, AN, RGF	May 2		Aug 11		Aug 16	No
Ontario Nature Stone Road Alvar, Pelee Island	9	AGH; AN, MM, RGF	May 2; Aug 27		Aug 11		Aug 16	No
NCC Stone Road Alvar, Pelee Island	4	RGF, AN			Aug 11		Aug 16	No
Cohen Shaughnessy Property, NCC, Pelee Island	4.5	AGH; AN, MM	May 2; Aug 27	Aug 3			Aug 15	No
Krestel Parcel, NCC, Pelee Island	5	AGH, AN, RGF	May 1	Aug 3	Aug 11		Aug 15	No
Finley Parcel, NCC, Pelee Island	1	AN		Aug 4				No
Fronzier Parcel, NCC, Pelee Island	1	AN, RGF			Aug 12			No
Point Pelee National Park (6 sites)	30	AGH, AN, MJO, RFF, RGF	Apr 28, 29			30 Aug	Aug 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
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	M. z. 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
Maidstone CA	2	RFF, AGH	April 29					No
Rondeau Provincial Park	6.5	MJO, JMB; AGH	May 17; Sep 4					No
Wheatley Provincial Park	3	AN					Aug 12	No
Sinclair's Bush	2	MJO, JMB	May 17					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

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	M. z. records
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	1	AN, JMB	April 1					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
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, Bottenwood, 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, SCRCA Shetland	1	EC					Sep 7	No
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

Site	Effort (person-hours)	Observers	Date(s) 2013	Date(s) 2014	Date(s) 2015	Date(s) 2016	Date(s) 2017	M. z. records
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
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

Bell (1859) recorded Toothed Globe from Quebec, but the record was doubted by Whiteaves (1870) who identified the specimen as Big-tooth Whitelip. The range of this latter species extends into Quebec. La Rocque (1953) indicates Quebec with three sites, Cap Rouge, Montmorency River, and Rouge River Valley, in the range description of Toothed Globe. However, no museum record or other literature supports the presence of Toothed Globe in Quebec.

The probable current range in Ontario consists of only uncertain, unverified occurrences at inaccessible sites on private (Hen Island, Leamington) or First Nations land (Table 1; Figure 2). The known historical occurrences of Toothed Globe has therefore been reduced from nine to potentially three uncertain sites (66% reduction), because it has not been seen alive at six other sites despite repeated and recent searches during the last 20 years (Table 1; Figure 2). Two of the uncertain sites have relatively recent records of live individuals in 1980 and 1994 (Table 1, Figure 2). Habitat in these sites is still intact, with older-growth forest, suitable for Toothed Globe. Thus, it seems likely that the species is still extant in these sites.

Extent of Occurrence and Area of Occupancy

The current extent of occurrence (EOO) and index of area of occupancy (IAO) of Toothed Globe in Canada are uncertain, but may include Caradoc First Nations land, former White Oak Woods in Leamington (private), and Hen Island (private) if the species is still extant. These sites represent only small areas of habitat. Using 2 km x 2 km grid cells on each site, IAO covers three grid cells (12 km²). EOO, as measured by the minimum convex polygon method on central points of each site, is 552 km². Much of this area is water (Lake Erie) and unsuitable land. If all historical records are included, the EOO was 8709 km² and the IAO was 28 km², using one grid cell for each site. Therefore, the EOO and IAO have been reduced by 94% and 57%, respectively, since the species was first known from Canada.

Search Effort

The probability of detecting Toothed Globe is relatively high, due to its large size and because empty shells remain on the forest floor for some time after the animals have died (>3 years, Říhová *et al.* 2018).

Notable historical surveys that did not find Toothed Globe include those conducted by John Oughton between about 1930 and 1940 (Oughton 1948), by Grimm between 1970 and the mid-1990s (Grimm 1996), and by Nekola (2003, 2010). 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, but Toothed Globe, including specimen(s) collected by M.J. Oldham in 1994 from White Oak Woods near Leamington (Table 1), were not found. The specimen(s) for M.J. Oldham's 1994 record is/are most likely lost (R. Forsyth pers. comm. 2019). Nekola's collection is not accessible.

Surveys between 1992 and 2012 were general land snail searches rather than targeted searches for Toothed Globe. 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). 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. Toothed Globe has not been found during these surveys that included all accessible historically occupied sites.

During the 2013–2017 general gastropod surveys in southwest Ontario, 135 sites were visited and re-visited for a total search effort of 460 person-hours (Table 2). The surveys in 2014–2017 targeted historically occupied sites of Toothed Globe and other species of conservation concern, while the surveys in 2013 focused on collecting specimens of multiple species. The surveys in 2013 resulted in approximately 210 alcohol-preserved samples of about 60 species being deposited at the Biodiversity Institute of

Ontario and 200 shell samples of about 40 species, currently being curated by R. Forsyth. During the 2013 surveys, two old weathered shells were collected and could serve as vouchers (Table 1).

Since 2014 Parks Canada Agency has surveyed seven plots (2x2 m) on Middle Island in spring and late summer. While these surveys target endangered gastropods, all detected species are recorded. Identifications are verified by A. Nicolai and these data are integrated into the gastropod dataset for southwestern Ontario.

HABITAT

Habitat Requirements

The habitat of Toothed Globe in Canada is similar to that used in the eastern US and described by Hubricht (1985) as “river bluffs, but also ravines and mountainsides”. According to Pilsbry (1940) the species lives up to 600 m elevation while Pearce and Paustian (2013) recorded the species from 900 m elevation in Pennsylvania and Hubricht (1985) mentioned US records from about 1500 m. In Arkansas, Toothed Globe was five times more abundant on the north slope of Magazine Mountain in Red Oak (*Quercus rubra*) dominated forests than on the rest of the mountain (Caldwell *et al.* 2014). In Tennessee, it was found in limestone areas of old-growth forests (Coney *et al.* 1982) where it was an indicator species for nature parks with less habitat degradation (Hodges 2016). Hotopp and Winslow (2012b) describe Toothed Globe’s habitat as leaf litter or moss in cool hardwood or mixed forests, especially on steep slopes along rivers. Nekola (2010) has found Toothed Globe in both acidic and neutral/calcareous habitats.

Habitat Trends

Climate change

The climate in areas adjacent to Lake Erie 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 (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 Sinclair 2013) 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 within the snails' habitat; 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).

Land management

Habitat loss is the main reason for the absence of Toothed Globe in most historically occupied sites. On private or First Nations land, where the species may still be extant, habitat seems to be suitable, but nothing is known about current or future land management or use. The Caradoc Indian Reserve (Chippewas of the Thames First Nation, IRI 42) comprises 39 km² of land. The community is involved in habitat and species at risk stewardship on their land. The Chippewas of the Thames received a Stewardship Award in 2017 from Lower Thames Valley Conservation Authority (LTVCA) for purchasing and planting over 3000 trees in order to establish new forests and wooded areas with different purposes: a maple syrup bush for production and for environmental education, river bank forestation to prevent soil erosion into the Thames River, providing edible landscaping, enhancing habitat for wildlife to increase biodiversity, and providing windbreaks and living snow fences (LTVCA 2018). The Chippewas of the Thames is also dedicated to developing a watershed stewardship strategy that includes training in traditional activities and knowledge related to the Thames River ecosystem (Anishinabek 2016). First Nation communities in southwestern Ontario including Chippewas of the Thames have representatives on the Source Protection Committee (Thames - Sydenham & Region Drinking Water Source Protection 2018).

BIOLOGY

Little information is available about the biology of Toothed Globe. General aspects of terrestrial snail biology are provided by the review of Barker (2001). Some information from other Polygyridae is available. However, this information could give misleading conclusions about the capacity of Toothed Globe to survive or to adjust to specific conditions, because Polygyridae include common species that are not of conservation concern and others, such as Flat Bladetooth (*Patera appressa*) that are strongly synanthropic, perhaps invasive (Grimm *et al.* 2010).

Life Cycle and Reproduction

Toothed Globe is an air-breathing (pulmonate), terrestrial snail that is a simultaneous hermaphrodite (possesses both male and female reproductive organs) and lays eggs (Pilsbry 1940). In general, both members of a mating pair exchange sperm and produce eggs. In another polygyrid snail, Whitelip Snail (*Neohelix albolabris*), self-fertilization can occur if mating probability is extremely low, resulting in very low reproductive success (McCracken and Brussard 2008). Usually, the frequency of such inbreeding is very low in most populations (McCracken and Brussard 2008). In most snail species, larger individuals lay more eggs than smaller ones (Heller 2001). In temperate regions, reproduction usually occurs in spring and late summer and egg clutches are deposited in shallow holes excavated in moist soil (Barker 2001). Clutch size is unknown for this species.

Most gastropods are crepuscular or nocturnal, and sympatric species often have different activity patterns (Asami 1993). During 2013-2017 surveys, observed snail species were mainly active in morning hours or after rain. The hibernation period of Toothed Globe probably extends from early October until mid-April; the exact timing is expected to vary depending on conditions in particular years. Typical hibernation sites in other species are shallow depressions in the forest floor covered with leaf litter or soil at depths of 5 to 10 cm (Pearce and Örstan 2006). Aestivation in various species of snails occurs occasionally during periods of prolonged heat and drought in temperate regions (Nicolai *et al.* 2011). During aestivation, snails usually remain inactive in moist microhabitats, such as in soil, under leaf litter, and under logs. During these longer periods of inactivity, hibernation and aestivation, the snails cover their shell opening by a slightly calcified epiphragm. Polygyridae in aestivation and hibernation with epiphragms were observed during 2013-2017 surveys in August and November, respectively.

In general, growth occurs only during periods of activity (spring to fall). In other species (e.g., Brown Garden Snail *Cornu aspersum*, Roman Snail *Helix pomatia*, and Corsica Helix *Tyrrhenaria ceratina*), the adult shell size (~2 cm in width) is reached after 1 to 2 years and sexual maturity after 2 to 3 years (Nicolai 2010; Nicolai *et al.* 2010; Charrier *et al.* 2013). Adult Toothed Globe can have old, thick and already weathered shells, as observed in Broad-banded Forestsnail (*Allogona profunda*; COSEWIC 2014a) and Eastern Banded Tigersnail (*Anguispira kochi kochi*; COSEWIC 2017), which indicates that the species is long-lived (maybe about 5-10 years). The estimated generation time is somewhere between the age at sexual maturity and longevity, probably 5-6 years.

Physiology and Adaptability

Physiological responses to environmental factors and their plasticity and adaptability have not been studied intensively in Polygyridae. Details of diet and feeding behaviour are unknown. Toothed Globe may, like other litter dwelling species such as Broad-banded Forestsnail (COSEWIC 2014a) and Banded Tigersnail (COSEWIC 2017), eat decaying plants (everywhere in the leaf litter) or microfungi on fallen logs on which the snails are found.

In general, snails require calcium for shell formation. Soil and bedrock calcium availability influence the snail species richness (i.e., number of species) of an area (Nekola 2005) and physiological processes, such as heat resistance in eggs (Nicolai *et al.* 2013). Heavy metals and pesticides in the soil are accumulated in tissues and may disturb physiological processes (Barker 2001).

Snails in regions with prolonged periods of drought and heat generally aestivate in buffered refuges and seal their shell aperture to avoid evaporation (Barker 2001; Pearce and Örstan 2006). In temperate regions, many species only aestivate in dry/warm summer conditions for a short period and have developed biochemical stress reactions that protect cellular architecture and processes (such as membrane fluidity, osmoregulation, and enzyme activity) and hence maintain survival mechanisms. Unusually long, hot, and dry periods with unusual timing can increase mortality, e.g., up to 70% in Roman Snail right after arousal from hibernation (Nicolai *et al.* 2011).

Snails are prone to freezing in winter. Different strategies that are somewhat plastic have evolved to enable survival at sub-zero temperatures (see review by Ansart and Vernon 2003). Within the same family, species have evolved different strategies which may give disadvantages to some species under climate change and human-caused microhabitat degradation (Nicolai and Ansart 2017). Mortality during hibernation is usually around 40% in some species and drives population dynamics (Peake 1978; Cain 1983). Usually, snails in temperate regions hibernate in buffered microsites which are additionally insulated by snow (Nicolai *et al.* 2011). Burch and Pearce (1990) suggest the availability of refuges which buffer environmental conditions, such as temperature and humidity, may be the most important factor limiting terrestrial snail abundance.

Dispersal and Migration

Active movement distances of Toothed Globe are unknown, but other Polygyridae of similar size move between 120 and 220 cm per day within a home range of 80 to 800 m², measured with the spooling technique (spool with thread attached to snail's shell) in Whitelip and Whitelip Globe (*Mesodon thyroideus*), respectively (Pearce 1990). In contrast, mark-recapture methods used for short-term observations underestimate the capacity of movement in snails because many species have home ranges. However, dispersal (i.e., displacement of home range) in general is low in land snails, e.g., 32.2 m over a 3-year study of Oregon Forestsnail (*Allogona townsendiana*) (Edworthy *et al.* 2012). Eggs and immature stages are not known to be dispersed by wind. However, some snails can survive short periods in water, in hypoxia (Nicolai and Ansart 2017), and the passage through bird intestines (Wada *et al.* 2012). Other snails have been found to be dispersed by bird migration (Kawakami *et al.* 2008) or, especially in riparian populations, by rafting on floating objects (Vagvolgyi 1975) or by fish (Altaba 2015). The likelihood of aerial or aquatic transport of Toothed Globe is unknown, but is probably small.

In Ontario, the likelihood of dispersal from the US is nonexistent given the limited distribution and the snails' poor dispersal capabilities (see **Population Spatial Structure and Variability** and/or **Rescue Effect**). A potential northern expansion of the peripheral

Canadian population of Toothed Globe 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). Toothed Globe is not synanthropic (associated with human activity) and it is unlikely that it would be transported by human activity, for example with horticultural or agricultural products, and therefore be introduced to new habitats (Robinson 1999; Robinson and Slapcinsky 2005).

Interspecific Interactions

Trematodes (Barger and Hnida 2008; Barger 2011) and free swimming or attached flagellates were observed in other Polygyridae (Current 2007). Parasitic mites are also common in snails in general (A. Nicolai pers. obs.) with prevalence ranging from 46 to 78% within infested populations (Baur and Baur 2005). Depending on the mite species, infections can cause high mortality, reproductive perturbations, and reduced cold hardiness in some snail species (Baur and Baur 2005). Nematodes can also infect a snail population and increase mortality rate in 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).

Predation can be a source of mortality for land snails. 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.” Among carnivorous gastropods Draparnaud’s Glass Snail (*Oxychilus draparnaudi*) includes forest snails in its diet, especially Striped Whitelip (*Webbhelix multilineata*), Bristled Slitmouth (*Stenotrema barbatum*), and Flamed Tigersnail (*Anguispira alternata*; often observed in the same sites, Örstan 2006). Garlic Glass Snail (*Oxychilus alliarius*), an invasive predatory snail on Hawaii is negatively affecting native Hawaiian land snails (Curry *et al.* 2016). Draparnaud’s Glass Snail and Cellar Glass Snail (*Oxychilus cellarius*) were observed on Lake Erie islands and on the mainland of southwestern Ontario during 2013-2017 surveys. Introduced predators or an increase in abundance of native predators due to ecological disturbance can increase mortality due to predation.

Competition for food with other terrestrial gastropods, including exotic species, is a possibility for native Polygyridae in southwestern Ontario, but has not been documented. Introduced exotic gastropods, such as Grovesnail (*Cepaea nemoralis*) and various species of slugs, mainly Grey Fieldslug (*Deroceras reticulatum*) or Dusky Arion (*Arion subfuscus/fuscus*), present in many natural areas in Ontario, might be in direct competition for food as these species mainly eat decaying plant material or fungi.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Transect searches occurred during 2013-2017 surveys across all accessible sites (Table 2). In addition, litter in three to five 10x10m plots were searched without time-constraint at each site.

Abundance, Fluctuations and Trends

Only two old-weathered shells were found during field verification surveys in 2013-2017, one each on Middle and Middle Sister islands (Table 1). The last time any live individuals were collected in Canada was in 1994 (Table 1). As such, there is no population estimate or information on trends. It is uncertain if Toothed Globe is still extant in Ontario because private and First Nation lands were not included in recent searches. However, intact habitat remains in these three historically occupied localities which were not surveyed (Table 1).

Rescue Effect

Although snails 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, Michigan, Pennsylvania, and New York are separated by large water bodies, such as lakes Erie and Ontario and the St. Clair, Detroit, and Niagara rivers (Figures 1 and 2). The one exception is a subpopulation on Grosse Ile in the Detroit River (undated record: FMNH 96939) that is only a few hundred metres across the water from Amherstburg, Essex Co.; however, it is uncertain if the Grosse Ile subpopulation is still extant.

THREATS AND LIMITING FACTORS

Threats

Because it is uncertain if Toothed Globe is still extant in Canada, a threats assessment cannot be done, similar to what occurred for Proud Globelet (*Patera pennsylvanica*; COSEWIC 2015). However, a few general threats for forested habitats are presented here, in addition to the direct human impacts typically found on privately owned land, such as residential development, recreational activities, natural resources use, natural system modifications, and others. The threat categories are based on Salafsky *et al.* (2008) and the IUCN-CMP (World Conservation Union-Conservation Measures Partnership) unified threats classification system (Master *et al.* 2012).

Threat 4: Transportation & service corridors

Threat 4.1: Roads and Railroads

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 snail populations (Wirth *et al.* 1999), because snails tend not to cross roads (Baur and Baur 1990a). Road mortality has also been recognized as a threat for wildlife in protected areas, such as Point Pelee National Park (Parks Canada 2007).

In proximity to roads, air and water borne pollutants (e.g., heavy metals and road salt; Viard *et al.* 2004) represent threats from pollution (Threat 9), 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).

Threat 7: Natural system modifications

Threat 7.3: Other ecosystem modifications

There are several highly invasive plants in southern Ontario, including Garlic Mustard (*Alliaria petiolata*). They were observed displacing native vegetation and altering soil nutrient cycles, thereby slowing habitat restoration (Catling *et al.* 2015). Although a positive impact of an invasive plant on the land snail diversity has been documented in western Pennsylvania (Utz *et al.* 2018), invasive plants can also lead to a decrease in endangered snail abundance, as shown in Europe (Stoll *et al.* 2012).

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 snail communities. Earthworms, such as the Asian genus *Amyntas* that remove the surface leaf litter (Qui and Turner 2017), where snails 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 altering plant-fungi mutualisms (Paudel *et al.* 2016) thereby affecting understorey vegetation composition (Drouin *et al.* 2016) and potentially reducing available food plants. 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 *Amyntas* is present in Essex County (Reynolds 2014).

Double-crested Cormorant (*Phalacrocorax auritus*) nesting colonies have increased dramatically on Lake Erie islands since the early 1980s, especially on Middle Sister, East Sister, and Middle islands (COSEWIC 2017). They may be the reason for the extirpation of Toothed Globe from Middle and Middle Sister islands and have been identified as a threat to Eastern Banded Tigersnail through the accumulation of guano leading to soil chemistry modification, tree dieback, reduced plant species' richness, and an increased proportion of exotic species (North - South Environmental Inc. 2004; Boutin *et al.* 2011). Cormorants apparently do not nest on Hen Island (no cormorant impact visible from the boat during field verification in 2013-2017), possibly due to human presence on the island. Cormorant culls have occurred on Middle Island since 2008 (Thorndyke and Dobbie 2013); however, the long-term effectiveness could be low (Guillaumet *et al.* 2014).

Threat 8: Invasive & other problematic species & genes

Threat 8.1: Invasive non-native/alien species

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 food competition (Baur and Baur 1990b). Exotic gastropods can compete for resources and shelter with native species. Dusky Arion, Grey Fieldslug, and Grovesnail are widespread in southern Ontario. Carnivorous snails, such as Draparnaud's Glass Snail and Cellar Glass Snail, found on Lake Erie islands and the mainland of southwestern Ontario during 2013-2017 surveys, may directly affect native species.

Wild Turkeys (*Meleagris gallopavo*) and Ring-necked Pheasants (*Phasianus colchicus*) were introduced to some places of Ontario for recreational hunting. Both bird species are omnivorous and include snails in their diet (Sandilands 2005). The impacts on snail populations are unknown, but they are a potential additional source of predation and were recently listed as ongoing threats to the Endangered Striped Whitelip (COSEWIC 2018), *A. kochi* (two designatable units including Endangered Eastern Banded Tigersnail; COSEWIC 2017), Broad-banded Forestsnail (COSEWIC 2014a), and the Endangered Small-mouthed Salamander (*Ambystoma texanum*; COSEWIC 2014b).

Threat 9: Pollution

Threat 9.3: Agriculture and Forestry Effluents

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 to soy bean and maize seeds (Douglas and Tooker 2015) and were not harmful to Grey Fieldslug, but were to mollusc-predating arthropods (Douglas *et al.* 2015). It is currently unknown how these pesticides act on native gastropod species.

The close proximity of agricultural land to wooded areas in southern Ontario may also expose snails to pesticide drift.

Threat 11: Climate change & severe weather

Using the framework for assessing species' vulnerability to climate change by Foden *et al.* (2013), Toothed Globe can be considered highly vulnerable, because (i) it is exposed to climate change (spring frosts, absence of snow cover, droughts), (ii) it is sensitive (habitat specialist i.e., mature forests, specific microhabitat conditions), and (iii) it has a low adaptive capacity (low extrinsic dispersal possibilities because of restricted habitat available).

Threat 11.2: Droughts, and Threat 11.3: Temperature Extremes

Southwestern Ontario is projected to have more extreme weather events including droughts, floods, and temperature extremes under climate change models (Varrin *et al.* 2007). Snails may be vulnerable to increasing average temperatures accompanied by increased incidences of drought (Pearce and Paustian 2013). During 2013-2017 surveys, numbers of snails found in 2016, considered a dry year, were low compared to 2015, which indicates some vulnerability to drought. With increasing average temperature, spring frost is more frequent (Augspurger 2013), which can cause spring mortality in snails when snow cover is absent (e.g., up to 90%, unpublished data). Large snails are especially susceptible to freezing and rely on snow cover (Ansart *et al.* 2014). Droughts can cause high mortality in some species depending on the presence of shelter (e.g., 75% in Roman Snail, Nicolai *et al.* 2011). As a habitat specialist, Toothed Globe might explore (i.e., look for shelter) less than do habitat generalists (Dahirel *et al.* 2015).

Threat 11.4: Storms and flooding

Storms were identified as a predominant natural disturbance on Middle Island (Parks Canada 2008), immersing the south side of the island. During fieldwork in 2013-2017 large piles of weathered shells of several species were found on the south side of the island. They could be the result of massive mortality due to violent storms. With increased precipitation due to climate change, flooding can also affect other islands, such as Hen Island that might still harbour a subpopulation of Toothed Globe. The threat should also be considered when considering the potential of recolonization.

Cumulative Effects

Logging, mining, agriculture, recreation, and the establishment of second growth forest are activities and processes that are generally known to increase the abundance of invasive plants (Calinger *et al.* 2015). 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, Toothed Globe exists near the northern limit of its distribution (assuming it is still extant) and northward expansion is probably limited by human-caused habitat fragmentation and physical barriers, such as the extensive bodies of water. Low dispersal ability, together with low physiological resistance to fluctuating environmental factors such as temperature and humidity, restrict 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 of land snails in general at particular sites (Burch and Pearce 1990).

Number of Locations

Given the large distance between the three possibly extant subpopulations (Figure 2), it would be difficult for a single threatening event to rapidly affect all individuals of the species (IUCN 2012). Thus, given the variety of threats, the minimum number of locations is three – one for each potentially extant subpopulation.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Toothed Globe 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) and CESSC (2016) provide the following ranks for Toothed Globe for the US and Canada, respectively:

- Global Rank: G5 – secure (last reviewed 2 Dec 2009)
- National Rank (US): N5 – secure (last reviewed 8 Oct 2002)
- National Rank (Canada): N1? – critically imperilled (10 August 2017)

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

- SNR: Alabama, Arkansas, Georgia, Illinois, Indiana, Iowa, Louisiana, Maryland, Michigan, Mississippi, Missouri, New York, Ohio, Oklahoma, Texas
- S3: Pennsylvania

- S3/S4: Virginia
- S5: Kentucky, North Carolina, Tennessee, West Virginia
- S1?: Ontario (Note: S1S2 in Ontario according to NatureServe 2019)

Habitat Protection and Ownership

Ownership of potential currently occupied habitat in Ontario is shown in Table 1. The protection status is unknown. Private sites are assumed to be not protected. The former White Oak Woods near Leamington was up for sale in 2017; it is an Environmentally Significant Area and currently protected through landowner cooperation with Essex Region Conservation Authority. First Nations land is used and managed following Aboriginal ethic values within their community land management program which is benefiting wildlife (see **Habitat Trends**).

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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:
 - Parks Canada (many times in 2013-2017)
 - 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)
 - ON 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 mollusc subcommittee of COSEWIC in 2014.

COLLECTIONS EXAMINED

The collections of the Canadian Museum of Nature, the Royal Ontario Museum, 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 Centre 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 (GBIF 2016). 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>, [29 November 2016])
doi:10.15468/lysaex
- 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

and US records :

- NatureServe Central Databases (accessed through GBIF data portal, <http://data.gbif.org/datasets/resource/607>, [29 November 2016])
doi:10.15468/lysaex

- 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/sm6qp6
- Bailey-Matthews National Shell Museum (BMSM) doi:10.15468/49s45k
- Sam Noble Oklahoma Museum of Natural History: Recent Invertebrates Specimens doi:10.15468/glxcep
- Orrell T (2016): NMNH Extant Specimen and Observation Records. v1.6. National Museum of Natural History, Smithsonian Institution. Dataset/Occurrence. http://collections.nmnh.si.edu/ipt/resource?r=nmnh_extant_dwc-a&v=1.6 doi:10.15468/hnhrg3
- Queensland Museum: Queensland Museum provider for OZCAM doi:10.15468/lotsye
- North Carolina Museum of Natural Sciences Invertebrates Collection doi:10.15468/jzqd4x
- California Academy of Sciences: CAS Invertebrate Zoology (IZ) doi:10.15468/tiac99
- 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
- Museo Argentino de Ciencias Naturales: Colección Nacional de Invertebrados - Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia' doi:10.15468/uuz636