COSEWIC
Assessment and Status Report

on the

False-foxglove Sun Moth
Pyrrhia aurantiago

in Canada

ENDANGERED
2018

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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False-foxglove Sun Moth — Photo by Mary Gartshore (with permission).

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COSEWIC
Assessment Summary

Assessment Summary – April 2018

Common name
False-foxglove Sun Moth

Scientific name
Pyrrhia aurantiago

Status
Endangered

Reason for designation
This rare moth is extant at three locations in Canada, all within the oak-dominated savannas and open woodlands of southern Ontario. It is estimated that 99% of this habitat type has been lost in Ontario. The larvae depend on Smooth Yellow False Foxglove and Fern-leaved Yellow False Foxglove, both of which are species at risk in Canada. Canadian subpopulations of this moth are mostly in protected areas where the primary threats are over-browsing of the larval host plants by native White-tailed Deer and the effects of competition from invasive plants on the host plants.

Occurrence
Ontario

Status history
Designated Endangered in April 2018.

COSEWIC
Executive Summary

False-foxglove Sun Moth
Pyrrhia aurantiago

Wildlife Species Description and Significance

False-foxglove Sun Moth is an owlet moth (family Noctuidae). Adults are approximately 30 mm long with a wingspan of 25 – 33 mm. The forewing is dark orange at the base and purple on the outer third, separated by a dark, jagged band. The hind wing is yellowish at the base, grading into dull red or pink on the outer third. The thorax and abdomen are covered with orange hairs. Younger larvae are whitish to yellowish and unmarked. Mature larvae are an overall dark brown with paler stripes on the sides and back and blackish patches on the head.

Distribution

Globally, False-foxglove Sun Moth ranges from southern Maine, west through southern Ontario and southern Wisconsin, south to eastern Texas and central Florida. In Canada, the species ranges in southwestern Ontario from eastern Lake Erie, west to Lake Huron, and south to Windsor. There are five known subpopulations of the moth. The subpopulations in the Pinery area, at Turkey Point, and the Ojibway Prairie Complex at Windsor are considered extant and the occurrences at London and Delhi are considered extirpated.

Habitat

False-foxglove Sun Moth inhabits oak-dominated savannas and open woodlands where its larval host plants, Smooth Yellow False Foxglove (*Aureolaria flava*) and Fern-leaved Yellow False Foxglove (*Aureolaria pedicularia*), co-occur. Habitats include dry sandy or loamy soils near the Great Lakes. These host plants are also species at risk in Canada.

Biology

False-foxglove Sun Moth typically has a single generation per year. In late summer, females lay eggs on the flowers of host plants and the larvae burrow into the seed capsules, and feed on the seeds until the fall. Sometime from late September to October larvae find a suitable place in the soil beneath the host plants to seek winter diapause. The larvae emerge the following spring and may feed further before pupation. Adults emerge the following summer, or may remain as pupae for two or three years before emerging. Adults are active in August and September, are nocturnal and feed on nectar.

Population Sizes and Trends

Population size and trends of False-foxglove Sun Moth are poorly understood, due mainly to the lack of specimens observed and/or collected. The species has probably declined in Canada due to the decline of both its host plants and associated habitat. About 99% of savanna habitat has been lost in southern Ontario and the species is apparently extirpated at two of the five historical sites. The number of occupied sites appears to be stable over the last 10 years.

Threats and Limiting Factors

The three extant Canadian subpopulations are within protected areas where the primary threats are over-browsing of the larval host plants by native White-tailed Deer; and ecosystem modifications from invasive plant competition and subsequent displacement of the host plants. Historically, False-foxglove Sun Moth was threatened by loss of oak savanna habitat.

Protection, Status and Ranks

All extant populations of False-foxglove Sun Moth in Canada are in provincial or municipal parks. The species is not protected under the federal *Species at Risk Act* or Ontario's *Endangered Species Act*. The global conservation status rank for False-foxglove Sun Moth is vulnerable (G3) and the provincial conservation status rank is critically imperilled (S1) in Ontario.

TECHNICAL SUMMARY

Pyrrhia aurantiago

False-foxglove Sun Moth

Héliotin orangé

Range of occurrence in Canada: Ontario

Demographic Information

Generation time	1 to 3 years. Life cycle can be completed in a single year; individuals can spend 2 -3 years as pupae.
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Insufficient data
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Insufficient data
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Insufficient data
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Insufficient data
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Insufficient data
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. No b. Yes, partially c. No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	10,124 km²
Index of area of occupancy (IAO)(2x2 grid value).	12 km²

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. Unknown b. Probably
Number of “locations”*	3; Windsor site may be extirpated because it was last recorded in 1982
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. Observed decline in habitat quality due to White-tailed Deer herbivory and non-native plants outcompeting host plants.
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
Pinery, Turkey Point and Windsor (extant sites)	Unknown
Total	Unknown

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Insufficient data

* 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? Yes, High Impact calculated. Threats call completed January 23, 2017 (see Table 5).

1.1 Housing & urban areas (medium impact)
1.2 Commercial & industrial areas (medium impact)
1.3 Tourism & recreation areas (low impact)
6.1 Recreational activities (low impact)
6.3 Work & other activities (low impact)
7.3 Other ecosystem modifications (low impact)
8.2 Problematic native species/diseases (medium impact)

What additional limiting factors are relevant?

- Low abundance
- Possibly short adult lifespan

Host plants are also species at risk.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Status not ranked in Michigan; see Table 6 for status ranks elsewhere within its range
Is immigration known or possible?	Not likely. Dispersal capability and status of nearest subpopulations in Michigan are unknown.
Would immigrants be adapted to survive in Canada?	Yes, likely.
Is there sufficient habitat for immigrants in Canada?	Unknown.
Are conditions deteriorating in Canada?	Yes, from browsing by White-tailed Deer and competition to host plants from invasive non-native plants.
Are conditions for the source population deteriorating?	Unknown
Is the Canadian population considered to be a sink?	Not likely.
Is rescue from outside populations likely?	Not likely.

Data Sensitive Species

Is this a data sensitive species? No.

Status History:

COSEWIC: Designated Endangered in April 2018.

Status and Reasons for Designation:

Status:	**Alpha-numeric codes:**
Endangered	B2ab(iii,v)

Reasons for designation:
This rare moth is extant at three locations in Canada, all within the oak-dominated savannas and open woodlands of southern Ontario. It is estimated that 99% of this habitat type has been lost in Ontario. The larvae depend on Smooth Yellow False Foxglove and Fern-leaved Yellow False Foxglove, both of which are species at risk in Canada. Canadian subpopulations of this moth are mostly in protected areas where the primary threats are over-browsing of the larval host plants by native White-tailed Deer and the effects of competition from invasive plants on the host plants.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable.
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Endangered, B2ab(iii,v), because IAO is less than the threshold (12 km²) and it occurs at less than 5 locations. There is a continuing decline in (iii) area, extent and/or quality of habitat due to White-tailed Deer herbivory and competition from invasive plants on the host plants; and (v) number of mature individuals is inferred to have declined based on browsing by White-tailed Deer on the flower heads, which is where the larvae are situated.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable.
Criterion D (Very Small or Restricted Population): Not applicable.
Criterion E (Quantitative Analysis): Not applicable.

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 (2018)

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

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

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

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

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

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

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Phylum: Arthropoda - arthropods

Class: Insecta - insects

Order: Lepidoptera - butterflies and moths

Superfamily: Noctuoidea Latreille, 1809

Family: Noctuidae Latreille, 1809 - owlet or cutworm moths

Subfamily: Heliothinae Boisduval, 1828 - sun or flower moths

Genus: *Pyrrhia* Hübner

Species: *Pyrrhia aurantiago* (Guenée 1852)

Moths of North America (MONA) Catalogue No.: 11065 (Hodges *et al*. 1983).

Synonyms: Originally described as *Xanthia aurantiago* Guenée 1852, the species was renamed *Rhodoecia aurantiago* (Guenée 1852) and generally known by that name until the genus *Rhodoecia* was synonymized under the genus *Pyrrhia* (Pogue 2008). Other synonyms include *Pyrrhia illiterata* Grote 1874, *Orthosia differta* Morrison 1875, *Heliothis illinoiensis* French 1879, and *Orthosia aurantiago* (Grote 1880) (Pogue *et al.* 2010).

No subspecies have been named although Forbes (1954) distinguished two races; a northern race in New York State and a smaller race in Florida.

English common name(s): False-foxglove Sun Moth (Natureserve 2018), Orange Sallow Moth, Orange Sallow (Covell 1984), False Foxglove Sun Moth (Wagner *et al.* 2011), Aureolaria Seed Borer (Natureserve 2018).

French common name(s): Héliotin orangé

Morphological Description

Adults:

False-foxglove Sun Moth adults are approximately 30 mm long with a wingspan of 25 - 33 mm. The forewing is dark orange at the base with a band of pale to dark purple on the outer third, separated by a dark, jagged band (Figure 1). Irregular purplish or black spots and blotches cover the forewing (Forbes 1954; Covell 1984). The wings of newly emerged adults may be covered with reddish scales, which obscure the markings until they wear off (Schweitzer *et al.* 2011). The hindwing is yellowish at the base, grading into dull red or pink on the outer third (Forbes 1954). The thorax and abdomen are covered with orange hairs.

False-foxglove Sun Moth is similar to Bordered Sallow (*Pyrrhia adela*) (also occurring in Ontario), which has a smooth band (rather than jagged band) on the forewing (Schweitzer *et al.* 2011).

Figure 1. Adult False-foxglove Sun Moth collected at Pinery August 5 2016 (posed). Photo by Mary Gartshore (with permission).

Larvae:

Mature larvae are dark brown overall with paler stripes on the sides and back and blackish patches on the head (Forbes 1954; Wagner *et al.* 2011). The body is hairless and up to 30 mm long and 6 mm wide (Crumb 1956), but covered with small, spine-tipped granules (Forbes 1954; Wagner *et al*. 2011). Younger larvae are pale to yellowish and unmarked.

Eggs and pupae:

The eggs and pupae are undescribed and have not been observed in Canada.

Population Spatial Structure and Variability

No population structure or genetic studies have been completed on False-foxglove Sun Moth in Canada or elsewhere. Individuals of the Florida subpopulations of False-foxglove Sun Moth are thought to be smaller than those from the Midwest United States (Slotten pers. comm. 2016) but no genetic or morphological studies have been completed.

False-foxglove Sun Moth has a patchy distribution and is rare throughout its North American range. Its pattern of distribution is closely tied to the scattered occurrences of its host plants and their habitat (Schweitzer *et al.* 2011). Canadian subpopulations of False-foxglove Sun Moth are probably isolated from each other and from United States subpopulations due to distribution of suitable habitat and extirpation of intervening subpopulations.

Designatable Units

False-foxglove Sun Moth occurs as a single designatable unit in Canada. All occurrences are in the Great Lakes Plains National Ecological Area (COSEWIC 2015a) and there are no data on discreteness, genetic structure, or evolutionary significance among subpopulations and no subspecies are recognized.

Special Significance

Canadian occurrences of False-foxglove Sun Moth mark the northern edge of the species' global range, and are isolated from the nearest known extant subpopulations in the United States by over 200 km. False-foxglove Sun Moth inhabits Dry Black Oak Tallgrass Savanna, a globally rare community type (NHIC 2016). Both of the larval host plants are declining and rare in Ontario (Oldham and Brinker 2009; COSEWIC 2018).

DISTRIBUTION

Global Range

The range of False-foxglove Sun Moth extends from southern Maine, west through southern Ontario and southern Wisconsin; south to eastern Texas and central Florida (Figure 2) (Schweitzer *et al.* 2011), overlapping the range of its three major host plant species, Fern-leaved Yellow False Foxglove (*A. pedicularia*), Smooth Yellow False Foxglove (*Aureolaria flava*), and Large-flower False Foxglove (*A. grandiflora*).

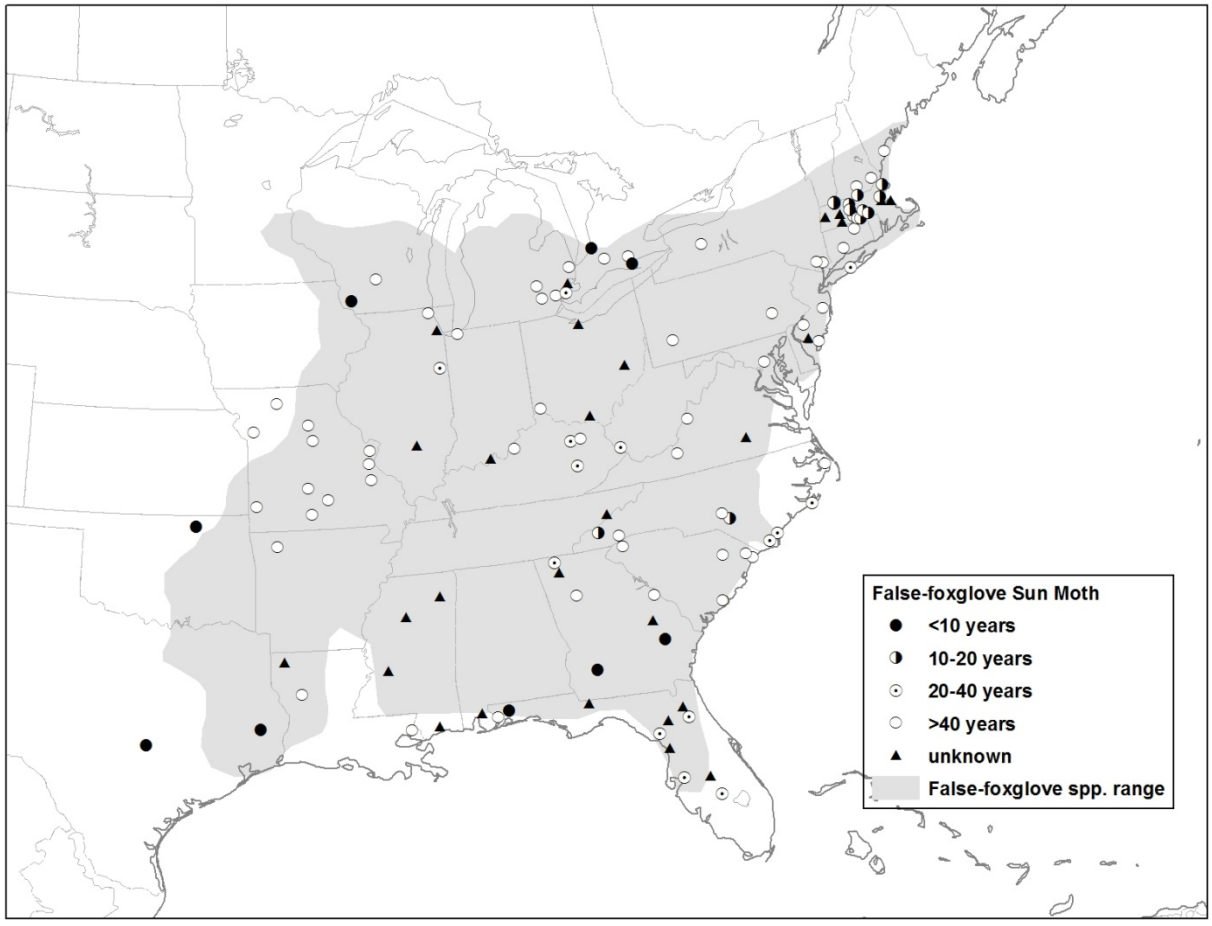

Figure 2. Map showing all known North American records of False-foxglove Sun Moth (Table 1). Shaded area is the composite range of the three main larval host plants: *Aureolaria flava*, *A. pedicularia*, and *A. grandiflora* from Pennell (1935).

False-foxglove Sun Moth is apparently rare and patchily distributed throughout most of its range (Schweitzer *et al.* 2011) but considered less rare at the northeastern and southern parts of its range in Massachusetts (Schweitzer *et al.* 2011) and north central Florida (Slotten pers. comm. 2016). There are historical (>40 years old) but no known recent records from Arkansas, Connecticut, Maine, Maryland, Michigan, Missouri, New Hampshire, New York (mainland), Pennsylvania, and South Carolina (Schweitzer *et al.* 2011 and references listed in Table 1).

Table 1. Canadian records of False-foxglove Sun Moth.

Sub-population Number	Collection / observation date	Site Name	Collector	Specimen accession number and/or notes	Source
1	1982, August 19	Windsor	J. Pilkington	NOC14579	Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario.
2	1936, August 2	Grand Bend	Hudson-Wood	CNC LEP 00064372	Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario.
2	2015, September 12	“Port Franks” (i.e. Pinery)	K. Stead	Adult	Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario.
2	2015, August 7	Pinery	K. Stead	2 adults	Schmidt *et al.* 2016.
2	2016, August 4	Pinery	K. Stead	Adult	K. Stead pers. comm. 2016
3	2015, September 28	Turkey Point	C. Jones; R. Craig	Late instar larva in leaf litter at base of *Aureolaria pedicularia*	C. Jones pers. comm. 2016
4	c. 1900	London	H.S. Saunders	Not available.	Royal Ontario Museum, Toronto, Ontario.
5	1971, August 20	Delhi	Cheng & Hanlon	CNC LEP 00064371	Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario.

Canadian Range

The Canadian range of False-foxglove Sun Moth is restricted to southwestern Ontario from eastern Lake Erie, west to Lake Huron, and south to Windsor. The species is specific to savanna habitats of the Carolinian Zone in southern Ontario where the larval host plants, Smooth Yellow False Foxglove and Fern-leaved Yellow False Foxglove co-occur (Figure 3; Table 1). There are five subpopulations of False-foxglove Moth in Canada, three are considered extant (Windsor; Pinery; and Turkey Point) and two are considered extirpated (London and Delhi). The extirpated records are >40 years and >100 years old respectively and the host plants have apparently disappeared or declined to only a few individual plants at these sites (COSEWIC 2018). Approximately 1% of the global range of False-foxglove Sun Moth is in Canada.

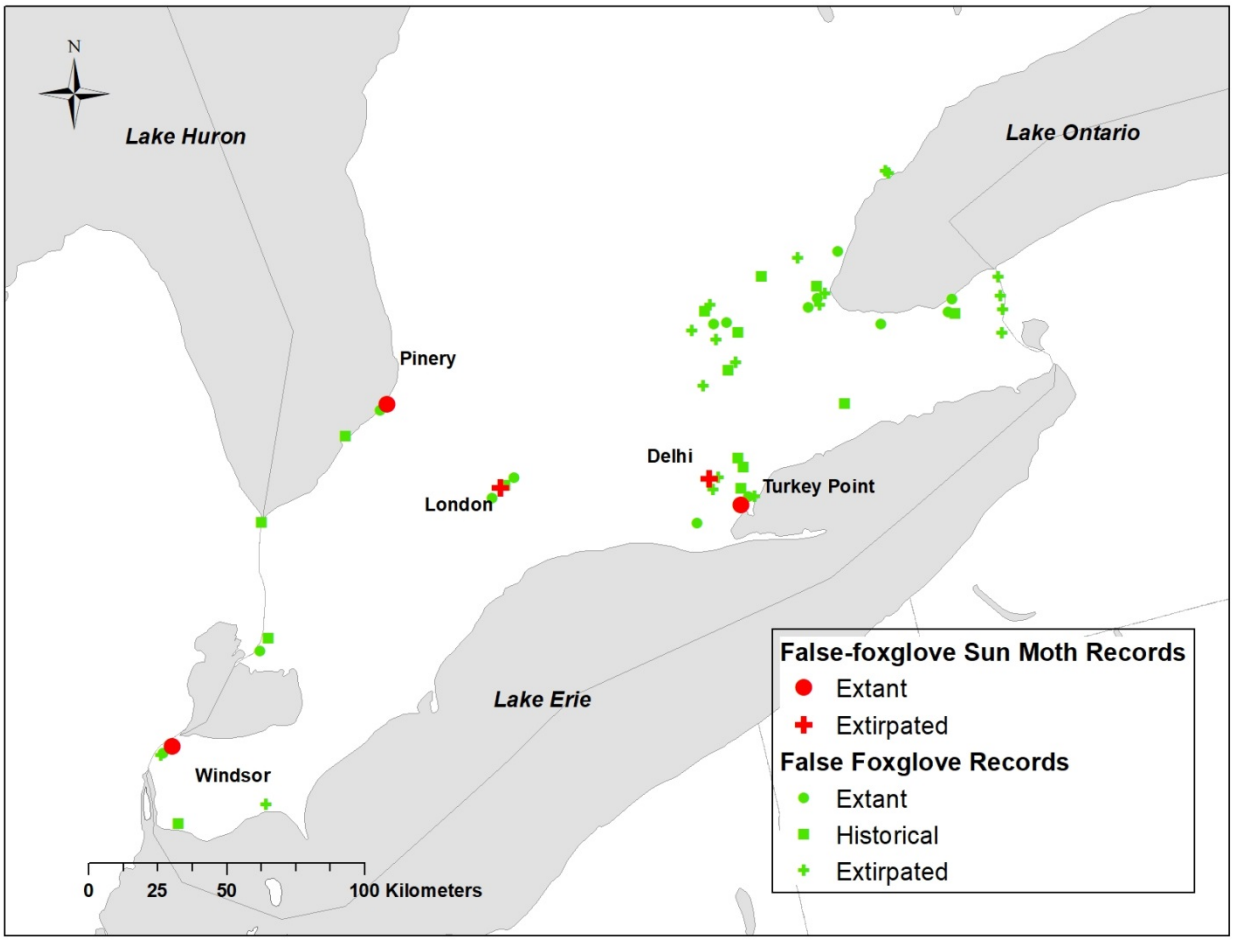

Figure 3. Canadian range of False-foxglove Sun Moth from circa 1900 – 2016 (Table 1 and 2). There are nine adult records and one larval record. Occurrences before 2015 are taken from collection labels and lack precise coordinates. These records were mapped at the approximate site (for example “Delhi”). False Foxglove (*Aureolaria flava* and *A. pedicularia*) records are from COSEWIC (2018).

Extent of Occurrence and Area of Occupancy

The extent of occurrence (EOO) of False-foxglove Sun Moth in Canada is 10,124 km^2. The EOO was calculated by a minimum convex polygon and encompasses the three extant subpopulations at Windsor; Pinery; and Turkey Point (Figure 4). The index of area of occupancy (IAO) is 12 km^2 (3 grid squares based on a 2 km x 2 km grid).

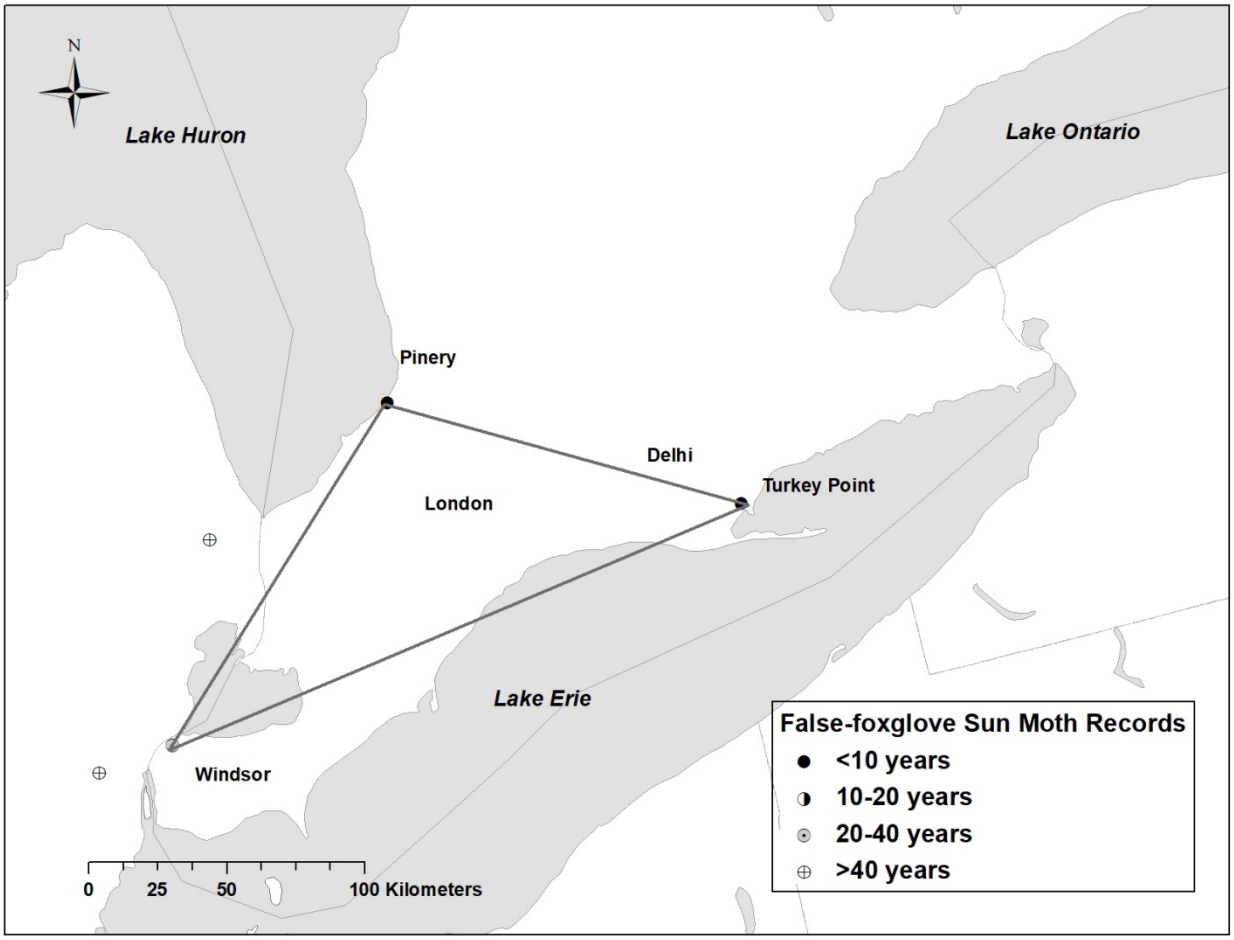

Figure 4. False-foxglove Sun Moth extent of occurrence (EOO) in Canada (see Table 1 for details).

Search Effort

Canadian records of False-foxglove Sun Moth date from about 1900 to 2016 (Table 1). There are nine adult records and one larval record.

False-foxglove Sun Moth is nocturnal and adults are sampled using general moth survey methods (e.g., black lights, mercury vapour lights, and baits). Most adults were collected by ultra-violet light trapping. Visual surveys for late instar larvae on the host plants may be the most efficient survey method (Wagner *et al*. 2011). Searching for bore holes in the seed capsule of the host plants in September to October is considered equally as effective as searching for mature larvae feeding on the outside of the seed capsules (Chaloux 2015). Adults are also apparently attracted to bait (Schweitzer *et al.* 2011).

Recent searches for False-foxglove Sun Moth are summarized in Table 2. Prior to 2015 there had been no targeted surveys for False-foxglove Sun Moth. Details of historical search efforts are unknown but most or all collections before 2015 probably come from non-targeted moth surveys and incidental observations.

Table 2. Search effort for False-foxglove Sun Moth during 2015 and 2016 surveys specifically in preparation of this status report. Searches for larval feeding damage on seed capsules of Fern-leaved Yellow False Foxglove were undertaken at Turkey Point on September 21, 2016 (Heagy pers. comm. 2016). Larval searches were also conducted during searches for the host plants in August 2016 (Heagy pers. comm. 2016). Rob Craig (RC), Mary Gartshore (MG), Allan Harris (AGH), Audrey Heagy (AH), Jessica Linton (JL), Jeremy deWaard (JD) and Colin Jones (CJ) completed surveys.

Date	Location	Search Effort (person-minutes)	False-foxglove Sun Moth Detected	Weather	Observer
2014, May – September	Pinery Provincial Park, Turkey Point Provincial Park Ojibway Prairie	One malaise trap set in each of these parks for the duration of the flight period	No	Variable	JD
2015, September 28	Turkey Point Provincial Park	180 minutes; visual searches for larval feeding damage	No	Not recorded.	RC, CJ
2015, September 29	Pinery Provincial Park	220 minutes; visual searches for larval feeding damage	No	Not recorded.	RC, CJ
2015, September 30	Pinery Provincial Park	220 minutes; visual searches for larval feeding damage	No	Not recorded.	RC, CJ
2016, August 12	Turkey Point Provincial Park	Mercury vapour lights 21:00 - 23:15; two black lights all night	No	24°C, very high humidity. Short downpour at dawn.	MG
2016, August	Windsor, Pinery, Turkey Point, and the Royal Botanical Gardens	Larval surveys conducted concurrently with plant surveys (Heagy pers. comm. 2016)	No	Larval surveys	MG, AH
2016, September 20	Turkey Point Provincial Park	200 minutes; visual searches for larval feeding damage	No	16°C, calm, clear	AGH, AH
2016, September 21	Ojibway Park	85 minutes; visual searches for larval feeding damage	No	22°C, sunny, calm	AGH
2016, September 21	Tallgrass Prairie Heritage Park	50 minutes; visual searches for larval feeding damage	No	22°C, sunny, calm	AGH
2016, September 21	Ojibway Prairie Provincial Nature Reserve	70 minutes; visual searches for larval feeding damage	No	25°C, cloudy, calm	AGH
2016, September 22	Pinery Provincial Park: west	105 minutes; visual searches for larval feeding damage	No	25°C, partly cloudy, calm	AGH
2016, September 22	Pinery Provincial Park: east side	90 minutes; visual searches for larval feeding damage	No	25°C, partly cloudy, calm	AGH

Date	Location	Search Effort (person-minutes)	False-foxglove Sun Moth Detected	Weather	Observer
2016, September 22	Pinery Provincial Park: road	20 minutes; visual searches for larval feeding damage	No	25°C, partly cloudy, calm	AGH
2016, September 22	Pinery Provincial Park: bridge	30 minutes; visual searches for larval feeding damage	No	25°C, partly cloudy, calm	AGH
2016, September 23	Royal Botanical Gardens: Hendrie Valley	270 minutes; visual searches for larval feeding damage	No	15°C, drizzle, breezy	AGH
2016, September 23	Royal Botanical Gardens: Sassafras Point	200 minutes; visual searches for larval feeding damage	No	15°C, drizzle, breezy	AGH
2016, October 1	Pinery Provincial Park	40 minutes; visual searches for larval feeding damage	No	Larval surveys	CJ; JL
Total larval survey search effort		**1780 minutes**			

The species was first collected in Canada at London, Ontario around 1900: the collection label has no date but Saunders was active from the late 1800s to the early 1900s (Hubley pers. comm. 2016). The host plant is virtually extirpated from the London area; only a single plant of Smooth Yellow False Foxglove was observed during 2016 surveys (COSEWIC 2018) and False-foxglove Sun Moth is probably also extirpated from the London area.

Two specimens of False-foxglove Sun Moth in the Royal Ontario Museum collected north of Lake Ontario at “Kendel” and “Port Hope” were actually Bordered Sallow (Schmidt pers. comm. 2017) and therefore these sites are no longer considered valid.

The two records from “Delhi” are presumably from the Delhi Research Station (Gartshore pers. comm. 2016) where monitoring of insect agricultural pests was conducted during the 1970s (exact dates and methods are unknown) (Walker 1983). The moth has not been recorded for over 40 years and the host plant apparently no longer occurs within 25 km or more of the station (Heagy pers. comm. 2016). False-foxglove Sun Moth is probably extirpated at Delhi.

There is a single record of False-foxglove Sun Moth from Windsor in 1982. The exact locale is unknown but the collector (J.E. Pilkington) collected in the Ojibway Prairie Complex (where Smooth Yellow False Foxglove is present) between 1972 and 1985 (Paiero *et al.* 2010). The Ojibway Prairie Complex is made up of five protected areas (Ojibway Prairie Nature Reserve, Ojibway Park, Tallgrass Prairie Heritage Park, Spring Garden Natural Area, and the Black Oak Heritage Park) encompassing 320 ha of prairie and savanna (Bakowsky and Riley 1992). Surveys conducted in 2016 did not find the moth but the habitat and host plant are present and the moth may persist here.

Surveys within the historical range of the host plants have taken place annually at High Park, Toronto (e.g., Yukich 2014) and at Walsingham (Gartshore pers. comm. 2016).

Collections from the Pinery area date from 1937 to 2016, with a 78 year gap between the first and second records (Table 1). References to the “Pinery” encompass the area from Grand Bend at the north end of Pinery Provincial Park to Port Franks at the south end. The Karner Blue Sanctuary includes 15 ha of oak savanna at Port Franks (Lambton Wildlife Inc. 2017). There is a 1926 specimen of Fern-leaved False Foxglove at Ipperwash (roughly 5 km southwest of the park) but the status of that occurrence is unknown and treated as “historical” (COSEWIC 2018). Coordinates of the 1937 collection of False-foxglove Sun Moth (labelled as “Grand Bend”) are unknown, but recent records are from a Black Oak – White Oak savanna at the north end of the park and extending to private land outside the park (Stead pers. comm. 2016). Mercury-vapour and black-light trapping has been conducted annually since 1993 near Pinery, including most nights during estimated flight season, although precise estimates of survey effort are unavailable (Stead pers. comm. 2016). Traps were placed in or near Fern-leaved Yellow False Foxglove (Stead pers. comm. 2016). Only 4 adults have been recorded which indicates a lack of propensity for coming to light and/or a low density of the moth (Table 1). Pinery Provincial Park includes about 1,250 ha of oak-pine savanna (Bakowsky and Riley 1992).

False foxglove habitat was searched for larvae at Turkey Point on September 28, 2015 (Figure 6) and a single late instar larva was observed in the leaf litter beneath a plant (Jones pers. comm. 2016). Similar searches were undertaken at Pinery Provincial Park and adjacent areas on September 29 and 30, 2015; and again in September 2016, but no larvae were observed (Jones pers. comm. 2016; Linton pers. comm. 2018). In 2014 malaise traps were established for four months within Pinery Provincial Park, Turkey Point Provincial Park and Ojibway Prairie, yet no False-foxglove Sun Moths were recorded (deWaard pers. comm. 2018). Malaise traps are not the ideal collection method for moths, but they did cover the entire known flight period and moths have been collected via this method.

Searches for larval feeding damage on seed capsules of Fern-leaved Yellow False Foxglove were undertaken at Turkey Point on September 21, 2016 (Heagy pers. comm. 2016). Larval searches were also conducted during searches for the host plants in August 2016 at Windsor, Pinery, Turkey Point, and the Royal Botanical Gardens (Heagy pers. comm. 2016). No False-foxglove Sun Moth larvae were observed.

On August 12, 2016, two mercury vapour lights on sheets were deployed from 21:00 to 23:15 and two black lights set all night at Turkey Point Provincial Park in a targetted effort to find False-foxglove Sun Moth adults (Gartshore pers. comm. 2016). No False-foxglove Sun Moth adults were collected.

Surveys were conducted on September 20 – 23, 2016 (Harris pers. comm. 2016), coinciding with the period when the late instar larvae are feeding on the exterior of the seed capsules and most easily observed. Searches of false foxglove plants were conducted at Turkey Point (3.3 person-hours), Windsor (3.4 person-hours), and the Pinery area (4.2 person-hours). Potential sites with Fern-leaved Yellow False Foxglove at Hendrie Valley and Cootes Paradise at the Royal Botanical Gardens in Hamilton were also searched (7.8 person-hours). No False-foxglove Sun Moth larvae were observed (Harris pers. comm. 2016). When combined with other search effort (Table 2) there are more than 29 hours of recent search effort.

Walpole Island is a locality where the host plant is present but surveys for False-foxglove Sun Moth have not been completed.

There are seven extant Canadian subpopulations of Smooth Yellow False Foxglove and four extant subpopulations of Fern-leaved Yellow False Foxglove where False-foxglove Sun Moth has not been recorded (COSEWIC 2018). Most of these subpopulations have had no known search effort for the moth. The largest subpopulation of host plants where moth surveys have not been completed is at Walpole Island where there is an inferred 50-200 individuals of Smooth Yellow False Foxglove (COSEWIC 2018).

HABITAT

Habitat Requirements

False-foxglove Sun Moth is associated with its larval host plants, Fern-leaved Yellow False Foxglove or Smooth Yellow False Foxglove, which inhabit dry sandy or rocky oak dominated savannas and open woodlands (Figures 5 and 6) (Schweitzer *et al.* 2011). Both host plants are parasitic on the roots of oaks. Fern-leaved Yellow False Foxglove is an annual that parasitizes Black Oak (*Quercus velutina*) but may also use other woody plants, at least in the southern part of its range (Voss and Reznicek 2012). Smooth Yellow False Foxglove is perennial and parasitizes White Oak (*Quercus alba*) (Voss and Reznicek 2012).

Figure 5. False-foxglove Sun Moth habitat at the Pinery area, September 2016. Photo A. Harris.

Figure 6. False-foxglove Sun Moth habitat at Turkey Point Provincial Park, September 2016. Photo by A. Harris.

At Turkey Point, False-foxglove Sun Moth was observed at a stand of Fern-leaved Yellow False Foxglove in a Black Oak savanna on loamy fine sand. The habitat of Fern-leaved Yellow False Foxglove is similar in the Pinery area, where Black Oak savanna occurs on old dune ridges (Bakowsky 1994). The precise location of the Windsor collection in 1982 is unknown but is probably at the Ojibway Prairie complex. Smooth Yellow False Foxglove occurs in Black Oak woodland and savanna on fine lacustrine sands over clay (COSEWIC 2018).

Habitats of the older Canadian subpopulations are unknown. In New York and Massachusetts, False-foxglove Sun Moth has also been collected on powerline corridors, edges of old fields, and roadsides where oaks and the host plants occur (Nelson 2012; Chaloux 2015).

Fern-leaved Yellow False Foxglove and Smooth Yellow False Foxglove are often at sites that burn frequently and may benefit from regular fire (Schweitzer *et al.* 2011).

Habitat Trends

Over 99% of prairie and savanna habitat in southern Ontario was lost to agriculture and other development since European settlement (Bakowsky and Riley 1992). Fire suppression also contributes to the habitat changes. Savanna typically occurs within a matrix of woodland and prairie; the area of savanna in Ontario at European contact is unknown.

Savanna habitats were formerly more extensive within the known range of False-foxglove Sun Moth at the Pinery area, Windsor, and Norfolk County (encompassing Turkey Point and Delhi) (Bakowsky and Reilly 1992). Savanna has virtually disappeared at historical sites of False-foxglove Sun Moth at London, Ontario.

The host plant subpopulations are believed to have declined significantly over the past century in Ontario (Oldham and Brinker 2009). At least four subpopulations of Smooth Yellow False Foxglove and 10 subpopulations of Fern-leaved Yellow False Foxglove have become extirpated since the 1970s (COSEWIC 2018). At least three of the seven extant subpopulations of Smooth Yellow False Foxglove have declined in the last 20 years (COSEWIC 2018).

Most of the remaining habitat is in protected areas where it is managed through prescribed burning to maintain savanna vegetation and has probably been relatively stable for the last 10 years (MacKenzie pers. comm. 2017; COSEWIC 2018). However, increasing White-tailed Deer (*Odocoileus virginanus*) populations and invasive plants continue to alter habitat (see Threats and Limiting Factors).

The impacts of climate change on savanna vegetation are unclear and trends are difficult to predict in Ontario where most savanna is in protected areas and is actively managed with prescribed burning.

BIOLOGY

False-foxglove Sun Moth is only known in Canada from eight adults and a single larva and most of the biology presented here is extrapolated from what is known from subpopulations in the United States, especially details summarized in Schweitzer *et al.* (2011).

Life Cycle and Reproduction

False-foxglove Sun Moth likely has one generation per year. In Canada, adults fly from late July to mid-September (Table 1), but as late as late October in the southern part of its range in the United States (Forbes 1954; Schweitzer *et al.* 2011; Brou 2016). Adults are nocturnal and visit flowers for nectar (Schweitzer *et al.* 2011).

Females probably lay eggs on the flowers of the host plant(s) (Schweitzer *et al.* 2011) which include Fern-leaved Yellow False Foxglove (Figure 7) and Smooth Yellow False Foxglove (Figure 8). Largeflower Yellow False Foxglove (*Aureolaria grandiflora*) and Mullein Foxglove (*Dasistoma macrophylla*) are also used in the United States but do not occur in Canada (Schweitzer *et al.* 2011). *Agalinis* and *Gerardia* have also been named as host plants but are apparently misinterpretations of the nomenclature changes of *Aureolaria* (Schweitzer *et al.* 2011). Captive larvae will also accept species of Butter-and-eggs (*Linaria vulgaris*) and Snapdragons (*Antirrhinum majus*) (both species were formerly in the family Scrophulariaceae but now are assigned to family Plantaginaceae) (Wyatt 1938).

Figure 7. Fern-leaved Yellow False Foxglove seed capsules at the Pinery area, September 2016. Photo by A. Harris.

Figure 8. Smooth Yellow False Foxglove at Windsor with White-tailed Deer feeding damage, September 2016. Photo by A. Harris.

Young larvae bore into the ovary of the host plant, seal the opening with silk, and feed on the seeds and flower parts in the developing seed capsule (Wyatt 1938). Larvae reside in the capsule until they become too large, and then move outside the capsule. Older larvae remain on the host plant and feed by chewing through seed capsules and eating the seeds. Larvae are also nocturnal (Schweitzer *et al.* 2011). After feeding for several weeks, larvae move to the ground to pupate. In New York State, larvae have been found from early September until late October (Chaloux 2015), and some larvae are observed into November (Schweitzer *et al.* 2011). The only known occurrence of a larva in Canada was observed on the ground underneath the host plant on September 28, 2015 and was probably about to pupate (Jones pers. comm. 2016).

In the fall, larvae burrow under the leaf litter or into the soil, pupate, and overwinter in underground cells. Adults may emerge the following year or may remain in the pupal stage for two or three years (Schweitzer *et al.* 2011; Wyatt 1938). Schweitzer *et al.* (2011) reared 27 pupae, none of which overwintered more than one year, but Wyatt (1938) had pupae collected on the same date in 1935 overwinter for one, two, and three years, despite being apparently kept in similar conditions. The larvae in Wyatt's study were collected in the Chicago area, at roughly the same latitude as the Canadian subpopulations. The size of the larvae when they pupate may influence the duration of the pupal stage. Smaller larvae of *Schinia* (also in the subfamily Heliothinae) are more likely to spend more than one winter as a pupa than are larger larvae of the same species (Schweitzer *et al.* 2011).

Physiology and Adaptability

False-foxglove Sun Moth has a specialized life history. The larvae feed exclusively on two species of *Aureolaria* in Canada, which are also hemi-parasitic and restricted to oak savanna habitat. In captivity, larvae have been successfully raised on plants in the family Scrophulariaceae (Wyatt 1938), but are not known to do so in the wild. The species is therefore not highly adaptable.

Dispersal and Migration

The dispersal capability of False-foxglove Sun Moth is unknown. As a species inhabiting savanna where fires frequently burn, dispersal between habitat patches may occur regularly due to the dynamic nature of their habitat. False-foxglove Sun Moth is non-migratory.

Interspecific Interactions

Larvae of Dark-spotted Palthis Moth (*Palthis angulalis*) (Lepidoptera; Erebidae) are a potential competitor for the larval host plant of False-foxglove Sun Moth. Dark-spotted Palthis Moth larvae had eaten the contents of about 2% of Fern-leaved Yellow False Foxglove seed capsules at Turkey Point and up to 40% of capsules in some patches within the Pinery area in September 2016 (Harris pers. comm. 2016). Another species of moth larvae *Endothenia hebesana* (Family Tortricidae; Schmidt pers. comm. 2016) had infested the seed capsules of about 60% of Fern-leaved Yellow False Foxglove at the Royal Botanical Gardens at Hamilton, Ontario. *Endothenia hebesana* is a widespread generalist seed predator (Bodeux 2006). Baltimore Checkerspot (*Euphydryas phaeton*) also uses *Aureolaria* as a larval host plant (Schweitzer *et al.* 2011).

Parasites of False-foxglove Sun Moth are probably similar to those of other Lepidoptera and include wasps (Hymenoptera) of various families and tachinid flies (Tachinidae) (Young 1997). Predators probably include insects, spiders, shrews, bats, and birds (Young 1997).

White-tailed Deer browse heavily on Smooth Yellow False Foxglove and at least moderately on Fern-leaved Yellow False Foxglove (see Threats and Limiting Factors).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

False-foxglove Sun Moth is infrequently captured at lights even where there has been intensive effort spanning several decades (e.g. surveys by Brou 2016; Stead pers. comm. 2016), suggesting that the species occurs at low density, at irregular intervals, or is not readily attracted to light traps. Survey techniques are discussed in Search Effort.

Abundance

No abundance estimates are available for False-foxglove Sun Moth. The species is apparently rare in Canada where there are only nine confirmed records (eight adults and one larva) between c.1900 and 2016. Only four adults were found in the Pinery area between 1993 and 2016 despite sampling effort most nights in the flight season (Stead pers. comm. 2016).

The host plant subpopulations at Windsor, Pinery and Turkey Point are not necessarily indicative of moth populations; however, it is assumed larger host plant abundance would likely support a larger moth subpopulation. Additional research is needed to clarify this assumption. Table 3 gives host plant subpopulation abundance estimates (COSEWIC 2018).

Table 3. Host plant subpopulation abundance at extant False-foxglove Sun Moth sites.

Site Name	Fern-leaved Yellow False Foxglove Subpopulation	Yellow False Foxglove Subpopulation
Windsor		286 – 1036 plants
Pinery Complex	3500 – 5000	None
Turkey Point	3000 – 5000	None
Total	7500 – 10,000 plants	286 – 1036 plants

Table 4. Source of False-foxglove Sun Moth records (see Figure 2).

Jurisdiction	Source
United States	Schweitzer *et al.* 2011
Alabama	Hill pers. comm. 2016
Arkansas	Arkansas Lepidoptera Survey 2016
Arkansas	Osborne pers. comm. 2016
Florida	Kons and Borth 2006; Slotten pers. comm. 2016
Georgia	Adams pers. comm. 2016
Illinois	Wyatt 1938; Mahoney pers. comm. 2016; Wiker pers. comm. 2016
Indiana	Wiker pers. comm. 2016

Kentucky	Laudermilk pers. comm. 2016
Louisiana	Brou 2016; Hill pers. comm. 2016
Maine	Brower 1984; deMaynadier pers. comm. 2016
Massachusetts	Nelson 2012
Michigan	Moore 1955
Mississippi	Hill pers. comm. 2016
Missouri	Buback pers. comm. 2016
New Hampshire	Stanwood pers. comm. 2016
New Jersey	Weintraub pers. comm. 2016
New York	Forbes 1954; Chaloux 2015; Conrad pers. comm. 2016; Weintraub pers. comm. 2016
North Carolina	Hall pers. comm. 2016; Snyder 2016; Sullivan pers. comm. 2016
Ohio	Rings *et al.* 1992; Weintraub pers. comm. 2016
Ontario	Hubley pers. comm. 2016; Lonsdale pers. comm. 2016
Pennsylvania	Leppo pers. comm. 2016
Virginia	Roble pers. comm. 2016
West Virginia	Olcott pers. comm. 2016
Wisconsin	Kons *et al.* 2007; Watson pers. comm. 2016

Fluctuations and Trends

No information on subpopulation trends or fluctuations is available for False-foxglove Sun Moth in Canada, but subpopulations probably declined over the last century as the habitat and host plants declined. The short term trend is less clear because most remaining habitat of known occurrences is in protected areas and managed to protect savanna vegetation.

Other species in the subfamily Heliothinae include the Corn Earworm (*Helicoverpa zea*) and Tobacco Budworm (*Heliothis virescens*), which are agricultural pests that occasionally increase to high abundance (Wagner *et al.* 2011).

Subpopulations of False-foxglove Sun Moth have likely declined in the northeastern United States (Somes pers. comm. 2016; Weintraub pers. comm. 2016).

Rescue Effect

The potential for rescue from subpopulations in the United States is unknown although unlikely. The Pinery area and Turkey Point subpopulations are found at the northern edge of the range of the host plants and isolated by over 100 km from the nearest extant occurrence in the United States, although historical occurrences at London and Delhi were formerly between the Pinery area and Turkey Point. Windsor is about 30 km from the nearest known Michigan occurrence but all known Michigan records are over 60 years old and the present status of the Michigan subpopulations is unknown.

THREATS AND LIMITING FACTORS

Threats

Native White-tailed Deer browsing (e.g., consumption of larvae feeding on flower heads) and competition to host plants by invasive plants are probably the greatest threats to False-foxglove Sun Moth and their host plants both inside and outside protected areas. Residential and commercial developments are threats to the host plant subpopulations in the Pinery area that are outside of Pinery Provincial Park.

Potential threats are described using the International Union for the Conservation of Nature - Conservation Measures Partnership (IUCN- CMP) threats calculator categories (see Salafsky *et al*. 2008; Master *et al*. 2009; Open Standards 2017). The overall calculated threat impact is High (Table 5). Threats are listed in the numerical order in which they occur in Table 5.

Table 5. Threats Assessment Calculator results for False-foxglove Sun Moth (*Pyrrhia aurantiago*) in Canada.

The threat classification below is based on the International Union of Conservation Networks (IUCN) and Conservation Measures Partnership (CMP) unified threats classification system. For a detailed description of the threat classification system, see the Open Standards website (Open Standards 2017). Threats may be observed, inferred, or projected to occur in the near term. Threats are characterized here in terms of scope, severity, and timing. Threat "impact" is calculated from scope and severity. For details, see Salafsky *et al*. (2008) and Master *et a*l. (2009). Only discussed and scored threats are included in the table below.

Species Scientific and English Common Name	*Pyrrhia aurantiago* - False-foxglove Sun Moth			
Date of threats teleconference	False-foxglove Sun Moth threats call January 23, 2016. Threat information updated after conference call for Smooth Yellow False Foxglove and Fern-leaved Yellow False Foxglove on March 4, 2017			
Assessors	Al Harris (status report writer), Jenny Heron and Paul Grant (Arthropods SSC co-chairs), John Klymko, Jessica Linton, Rob Longair, Chris Schmidt (Arthropods SSC members), Colin Jones (COSEWIC member for Ontario and Arthropods SSC member), Alistair Mackenzie (Ontario Parks) and Angèle Cyr (COSEWIC Secretariat)			
			Level 1 Threat Impact Counts	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	0	0
	C	Medium	2	2
	D	Low	2	2
	Calculated Overall Threat Impact:		High	High

Threat	Impact (calculated)	Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & commercial development	C	Medium	Restricted (11-30%)	Serious (31-70%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
1.1	Housing & urban areas	C	Medium	Restricted (11-30%)	Serious (31-70%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.
1.2	Commercial & industrial areas	C	Medium	Restricted (11-30%)	Serious (31-70%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.
1.3	Tourism & recreation areas	D	Low	Restricted (11-30%)	Slight (1-10%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.
2	Agriculture & aquaculture		Unknown	Restricted (11-30%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
2.1	Annual & perennial non-timber crops						Not applicable. Historical threat. Approximately 99% of Ontario's historical prairie and savanna were cleared, presumably mainly for agriculture (Bakowsky and Riley 1994). The proportion of False-foxglove Sun Moth habitat destroyed is unknown but probably significant. There has been no agricultural development in the extant sites in protected areas in the last 10 years nor is there likely any in the next 10 years.
2.2	Wood & pulp plantations						Not applicable. Historical plantings of pine trees in savannas at the Pinery area and Turkey Point may have damaged false foxglove habitat but planting no longer takes place and cutting and prescribed burning are restoring the habitat (MacKenzie pers. comm. 2017).
2.3	Livestock farming & ranching		Unknown	Restricted (11-30%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Horse pastures may be a permitted use in the area adjacent to Pinery Provincial Park, but records of the moth do not presently exist at these sites.
3	Energy production & mining		Unknown	Restricted (11-30%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
3.2	Mining & quarrying		Unknown	Restricted (11-30%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	There is one active sand pit and another closed pit adjacent to Pinery Provincial Park that may have destroyed False-foxglove Sun Moth habitat (MacKenzie pers. comm. 2017). Some lots in this area are zoned as "Extractive", where sand quarrying is permitted (Municipality of Lambton Shores 2017).

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4	Transportation & service corridors		Not Calculated (outside assessment timeframe)	Restricted (11-30%)	Unknown	Low (Possibly in the long term, >10 yrs/3 gen)	
4.1	Roads & railroads		Not Calculated (outside assessment timeframe)	Restricted (11-30%)	Unknown	Low (Possibly in the long term, >10 yrs/3 gen)	Not applicable. Historical threat. Transportation and service corridors may have historically threatened False-foxglove Sun Moth habitat. Although the Turkey Point site is fewer than 100 m from a road the effects of the road have no known impacts on False-foxglove Sun Moth habitat or its host plant. An access road allowance between Pinery Provincial Park and adjacent private property is unlikely to be developed (MacKenzie pers. comm. 2017).
4.2	Utility & service lines		Not a Threat	Restricted (11-30%)	Neutral or Potential Benefit	Unknown	False-foxglove Sun Moth inhabits powerline corridors, in New York where clearing trees and shrubs maintain an open habitat for the larval host plants (Nelson 2012; Chaloux 2015). False-foxglove Sun Moth larva recorded at Turkey Point in 2015 was on a transmission line right-of-way (Jones pers. comm. 2016).
5	Biological resource use		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
5.1	Hunting & collecting terrestrial animals		Negligible	Restricted (11-30%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	False-foxglove Sun Moth is unlikely to be collected unsustainably. Collecting animals is prohibited within the parks without a permit therefore scope is limited to area adjacent to Pinery Provincial Park.
5.2	Gathering terrestrial plants		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Collecting False-foxglove Sun Moth or its host plants is probably not a threat to Canadian populations, given that most are within protected areas where collecting cannot be done without a research permit from the Ontario Ministry of Natural Resources and Forestry. Few park visitors walk off the trails where most false foxglove plants are found (MacKenzie pers. comm. 2017). Both species of false-foxglove have large, showy flowers and may be vulnerable to being picked by people outside the park.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.3	Logging & wood harvesting		Not a Threat	Restricted (11-30%)	Neutral or Potential Benefit	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Remote possibility in area adjacent to Pinery Provincial Park.
6	Human intrusions & disturbance	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	
6.1	Recreational activities	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	See text in report.
6.3	Work & other activities	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	See text in report.
7	Natural system modifications	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	
7.1	Fire & fire suppression		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Pinery, Windsor, Turkey Point have had prescribed burns to maintain savanna habitat. Excessive burning is harmful to some prairie insects. Could be positive for plant but excessive burning might be detrimental for insects.
7.3	Other ecosystem modifications	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Pine planting in savanna habitat occurred historically in Pinery and Turkey Point but no longer occurs. Threats from invasive non-native plant encroachment, and oak (and therefore host plant decline) consumption by European Gypsy Moth are scored under this category
8	Invasive & other problematic species & genes	B	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	
8.1	Invasive non-native/alien species/ diseases	B					See text of report. Scored under 7.3 Other ecosystem modifications.
8.2	Problematic native species/ diseases	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	See text in report.
9	Pollution						
9.3	Agricultural & forestry effluents						Potential application of pesticide to control introduction of European Gypsy Moth (*Lymantria dispar*), and subsequent impacts the introduced moth has to the oak tree that the host plant depends upon. This is not currently considered applicable. This would be scored under 7.3.
11	Climate change & severe weather		Unknown	Pervasive (71-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
11.1	Habitat shifting & alteration		Unknown	Pervasive (71-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.2	Droughts		Unknown	Pervasive (71-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.
11.3	Temperature extremes		Unknown	Pervasive (71-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	See text in report.

IUCN Threat 1. Residential or Commercial Development (Medium impact)

1.1 Housing & urban areas (Medium impact)

The privately owned part of the oak savanna bordering the Pinery Provincial Park has an occurrence of Fern-leaved Yellow False Foxglove and is potentially at risk of residential or other development (MacKenzie pers comm. 2017). Parts of this area are zoned Future Development, Industrial, Institutional, and Commercial in the municipality's official plan (Municipality of Lambton Shores 2017). Historical residential development adjacent to the Turkey Point, Pinery, and Windsor occurrences probably destroyed False-foxglove Sun Moth habitat but the extent is unknown. There has been little or no residential development adjacent to the extant sites (in protected areas) in the last 10 years.

1.2 Commercial and industrial areas (Medium impact)

Parts of the area adjacent to the Pinery Provincial Park are zoned for industrial and commercial uses in the municipality's official plan (Municipality of Lambton Shores 2017) and potentially available for development. This area has an occurrence of Fern-leaved Yellow False Foxglove.

1.3 Tourism and recreation areas (Low impact)

Campground development at Turkey Point Provincial Park is a potential threat (COSEWIC 2018) but is unlikely to occur within the Pinery area (MacKenzie pers comm. 2017).

IUCN Threat 6. Human Intrusions and Disturbance (Low impact)

6.1 Recreational activities (Low impact)

Most remaining False-foxglove Sun Moth habitat is in provincial parks and other protected areas where it is not subjected to excessive traffic by hikers and other users. Host plants in Pinery Provincial Park and Turkey Point Provincial Park are well off the trails or on trails not used in summer months, and the recreational impact to these sites is considered low. There has been a recent trend of fewer people leaving the trails due to the increased incidence of Black-legged Tick (*Ixodes scapularis*), a host of Lyme disease, in the parks (MacKenzie pers. comm. 2017). All-terrain vehicle (ATV) use occurs on road right-of-way adjacent to the Pinery Provincial Park and occasionally illegally extends into the park.

IUCN Threat 7. Natural system modifications (Low impact)

7.1 Fire and fire suppression (Unknown impact)

False-foxglove Sun Moth habitat at the Pinery area (Bakowsky 1994), Turkey Point (COSEWIC 2009), and Windsor (Paiero *et al.* 2010) has been subjected to regular prescribed burning. Fire maintains savanna habitat by reducing the incursion of trees, shrubs, and invasive plants (Kline 1997). False foxglove species benefit from fire by reducing competition from other plants and by providing a suitable seed bed. Fern-leaved Yellow False Foxglove is particularly associated with fire, possibly because as an annual species it depends on disturbance to successfully reproduce (Schweitzer *et al.* 2011).

Excessive burning can reduce subpopulations of some prairie Lepidoptera (Swengel *et al.* 2010). Prescribed burns are often more frequent, more severe, more extensive (sometimes burning the entire habitat patch), and occur outside of the natural wildfire season compared to natural fire. False-foxglove Sun Moth pupae overwinter underground where they receive some protection from light burns in winter through early summer (Schweitzer *et al.* 2011) but larvae are vulnerable to fires in August to October. Since the 1990s, prescribed burns in parks have made efforts to burn smaller areas at low intensity in an effort to maintain refuges for insects (MacKenzie pers comm. 2017). Prescribed burns at parks in southern Ontario are becoming more difficult to implement with increasingly unpredictable weather and increased resistance from the public (MacKenzie pers. comm. 2017). False-foxglove Sun Moth has evolved with fire and fire could be a beneficial; the overall impact on subpopulations is unknown.

7.3 Other ecosystem modifications (Low impact)

Numerous cumulative threats contribute to changes in habitat for False-foxglove Sun Moth. Invasive plants can degrade savanna habitat by competing with false foxgloves for space and nutrients. The Windsor sites are threatened by Black Locust (*Robinia pseudoacacia*), Common Reed (*Phragmites australis* ssp. *australis*), and Garlic Mustard (*Alliaria petiolata*) (Cedar pers. comm. 2016). Savanna habitats at the Pinery area and Turkey Point do not presently have problematic levels of invasive plant species but the Pinery area has seen significant increases in Autumn Olive (*Elaegnus umbellata*), buckthorn (*Rhamnus* spp.) and Garlic Mustard (*Alliaria petiolata*) in the last ten years (MacKenzie pers. comm. 2017). Areas adjacent to the Pinery area are not subject to prescribed burning (see 7.1) and may be more vulnerable to invasive species than areas in the parks.

<u>IUCN Threat 8. Invasive and other problematic species and genes (Medium impact)</u>

8.1 Invasive non-native/alien species

This threat is discussed in this subheading but scored under 7.3 Other ecosystem modifications because the threat is considered proximal (the threat is to the host plants).

8.2 Problematic native species (Medium impact)

Excessive browsing by native White-tailed Deer is perhaps the greatest threat to False-foxglove Sun Moth in much of its range (Schweitzer *et al.* 2011). Since the 1970s White-tailed Deer subpopulations have increased over much of eastern North America, and False-foxglove Sun Moth is most likely to be found in well-hunted areas in North Carolina and New Jersey where deer subpopulations were suppressed (Schweitzer *et al*. 2011). Deer subpopulations in the Pinery area increased from about 35 in 1957, to 480 animals in 1980, and 880 in 1992 (Bakowsky 1994). Excessive browsing caused suppression of favoured plant species and increased abundance of invasive plants (Bakowsky 1994). Deer culls at the Pinery area commenced in the 1990s and successfully reduced the population to about 30 animals in 2016 (Bakowsky 1994; MacKenzie pers. comm. 2017). Continued culls will be required to maintain low deer numbers because deer are not culled outside of the park, and act as a source and continuing threat to the host plant subpopulations in the park. Culls have also occurred at Long Point, near Turkey Point (MacKenzie pers. comm. 2017) but no culls have been implemented at Windsor (Cedar pers. comm. 2016).

All Smooth Yellow False Foxglove sites in southern Ontario observed in 2016 showed damage from deer browsing (COSEWIC 2018). Fern-leaved Yellow False Foxglove plants are also browsed but apparently less intensively (COSEWIC 2018). Smooth Yellow False Foxglove at Windsor had been heavily browsed by White-tailed Deer in September 2016 (Harris pers. comm. 2016). Most plants had at least some damage and some were browsed with less than a few centimetres of the plant remaining. Deer eat most of the flowers from Smooth Yellow False Foxglove at Windsor before they set seed (Cedar pers. comm. 2016). Young False-foxglove Sun Moth larvae are probably eaten with the flower and older larvae are deprived of food when the flowers and young seed pods are browsed (Schweitzer *et al.* 2011). Repeated browsing by deer can kill Smooth Yellow False Foxglove (Schweitzer *et al.* 2011). Fern-leaved Yellow False Foxglove may be somewhat less palatable to deer and not eaten when deer subpopulations are low and alternate food is abundant (Heagy pers. comm 2016). Plants at the Pinery area and Turkey Point showed little sign of browsing in September 2016 but Fern-leaved Yellow False Foxgloves had been heavily browed by deer at the Royal Botanical Gardens (Harris pers. comm. 2016).

IUCN Threat 11. Climate Change and severe weather (Unknown impact)

The impacts of climate change on False-foxglove Sun Moth and their habitat is unknown. Potential impacts include altered phenology disrupting the timing of adult emergence and other critical stages, reduced survival of overwintering larvae, and altered fire regimes and vegetation dynamics. The impacts of climate change on savanna vegetation are difficult to predict in Ontario where most savanna is in protected areas and is actively managed with prescribed burning. The broad geographical distribution of False-foxglove Sun Moth suggests that it tolerates a wider range of climatic conditions including warmer temperatures than currently experienced in Canada. The host plants may be less susceptible to drought than their competition because they are parasitic and receive nutrients from host plant. Occasional droughts could therefore benefit false foxglove plants.

Increased frequency of early or late season frosts could kill false foxglove flowers or feeding False-foxglove Sun Moth larvae.

Limiting Factors

The limiting factors for False Foxglove Sun Moth are speculative but are likely related to the limited availability and scattered distribution of savanna habitat and the host plants. The species apparently occurs as small and localized subpopulations in isolated habitat patches. There is likely little or no interbreeding or genetic mixing between subpopulations. Local extinctions due to inbreeding depression are possible.

Number of Locations

Three subpopulations of False-foxglove Sun Moth are considered extant in Canada (Windsor, Pinery and Turkey Point). Threats vary in nature and intensity and each subpopulation represents one location based on the threat of consumption of the host plant (and feeding/developing larvae) by White-tailed Deer and the ongoing ecosystem modifications (e.g., changes to habitat) at each site. Walpole Island is a potential fourth location where the host plant is present but surveys for False-foxglove Sun Moth have not been completed.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

False-foxglove Sun Moth and its host plants are not listed under the federal *Species at Risk Act* or Ontario's *Endangered Species Act*.

Non-Legal Status and Ranks

Table 6. Global, national and subnational conservation status ranks for False-foxglove Sun Moth.

	Conservation Status Rank	Reference
Global	vulnerable to probably secure (G3G4)	Natureserve 2018
Canada	NNR (status not ranked)	Natureserve 2018
United States	NNR (status not ranked)	Natureserve 2018
Jurisdiction subnational ranks		
Ontario	critically imperilled (S1)	Jones pers. comm. 2016
Maine and Pennsylvania	historical (SH)	Natureserve 2018
Connecticut	imperilled (S2)	Natureserve 2018
Indiana	critically imperilled to imperilled (S1S2)	Natureserve 2018
North Carolina and Virginia	critically imperilled to vulnerable (S1S3)	Natureserve 2018
Massachusetts	vulnerable to probably secure (S2S3)	Natureserve 2018
Arkansas, Maryland, Michigan, and Wisconsin	Not ranked (SNR)	Natureserve 2018
New Hampshire, New Jersey, New York	Unknown (SU)	Natureserve 2018
Illinois	Occurred historically but no rank provided by NatureServe (2018)	Wyatt 1936

	Conservation Status Rank	Reference
Florida, Georgia, Kentucky, Mississippi, Missouri, Ohio, Oklahoma, South Carolina, Texas, Louisiana, West Virginia	Records from these states but no rank provided by NatureServe (2018)	Brou 2016; Schweitzer *et al.* 2011

At the state level, False-foxglove Sun Moth is listed in Massachusetts as Special Concern (Nelson 2012). Both Smooth Yellow False Foxglove and Fern-leaved Yellow False Foxglove host plant species are ranked S2 (imperilled) in Ontario and N2 (imperilled) in Canada (NatureServe 2018).

Habitat Protection and Ownership

False-foxglove Sun Moth is recorded from Turkey Point Provincial Park. The collections of False-foxglove Sun Moth in 2015 and 2016 at the Pinery area were on private land near the boundary of Pinery Provincial Park. The oak savanna habitat and population of Fern-leaved Yellow False Foxglove extend into the park. The exact locality of the Windsor occurrence is unknown but a subpopulation of Smooth Yellow False Foxglove is within Ojibway Park and Tallgrass Prairie Park, both owned and managed by the City of Windsor, and Ojibway Prairie Provincial Nature Reserve.

A permit is required to collect insects and plants in the Ojibway Prairie complex and would likely require protective measures to ensure False-foxglove Sun Moth and its host plants are not unintentionally damaged.

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Allan Harris is a biologist with over 25 years' experience in northern Ontario. He has a B.Sc. in Wildlife Biology from the University of Guelph and an M.Sc. in Biology from Lakehead University. After spending seven years as a biologist with Ontario Ministry of Natural Resources, he co-founded Northern Bioscience, an ecological consulting company based in Thunder Bay, Ontario. Al has authored or coauthored dozens of scientific papers, technical reports, and popular articles, including COSEWIC status reports for the Monarch, Gold-edged Gem, Nuttall's Sheep Moth, Lake Huron Grasshopper, Riverine Clubtail, Laura's Clubtail, Rapids Clubtail, Gibson's Big Sand Tiger Beetle, Northern Barrens Tiger Beetle, Powesheik Skipperling, Mormon Metalmark, Weidemeyer's Admiral, Bogbean Buckmoth, Hop-tree Borer, Georgia Basin Bog Spider, Broad-banded Forestsnail, Nahanni Aster, Crooked-stem Aster, Bluehearts, Drooping Trillium and Small-flowered Lipocarpha. Al also authored the Ontario provincial status report for woodland caribou, and has authored or coauthored national and provincial recovery strategies for vascular plants and birds.

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COLLECTIONS EXAMINED

The following collections were searched for specimens of False-foxglove Sun Moth:

Arkansas Tech University (On-line search)

Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, ON (Owen Lonsdale)

Carnegie Museum of Natural History, Pittsburgh, Pennsylvania (John E. Rawlins)

Drexel University Academy of Natural Sciences, Philadelphia, Pennsylvania (J. D. Weintraub)

Illinois Natural History Survey, Champaign, Illinois (Jim Wiker)

Mississippi Entomological Museum, Starkville, Mississippi (JoVonn Hill)

Royal Ontario Museum, Toronto, ON. (Brad Hubley).