Species Status Assessment Report

for the

Bog Buck Moth
(*Hemileuca maia menyanthevora)*
***(= H. iroquois*)**

Photo by J. Jaycox, NYNHP

December 2020
U.S. Fish and Wildlife Service
Cortland, NY

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Executive Summary

For many years, the U.S. Fish and Wildlife Service (Service) has recognized the need to investigate the current population status and trends of the bog buck moth (*Hemileuca maia menyanthevora*)(=*H. iroquois*) and the relative effects of both positive and negative influences on the species' viability. We identified the bog buck moth as a Category 2 candidate species for listing in the November 21, 1991, Annual Candidate Notice of Review (56 FR 58804). More recently, we prioritized a status review for the species according to the Service's 2016 Methodology for Prioritizing Status Reviews and added the species to the Endangered Species Program's National Listing Work Plan (Work Plan). We used the Species Status Assessment framework to assess the species needs and status currently and into the future. Based on this process, we intend to make a decision on the bog buck moth's listing status in Fiscal Year 2021.

The bog buck moth is a fairly large-bodied, day-flying moth limited in occurrence to a few locations near Lake Ontario in New York and in Ontario, Canada. The bog buck moth's life cycle is similar to other *Hemileuca* species and generally completed within 1 year. Nonfeeding adults emerge in the fall. After mating, female buck moths lay one large cluster of eggs on sturdy stems of a variety of plant species. The eggs overwinter until the following spring when they hatch into larvae that initially rely primarily on the host plant *Menyanthes trifoliata* (commonly referred to as bogbean, bog buckbean, or buckbean). Pupation occurs by mid-July, and takes place below the surface, and then the pupal stage lasts about 2 months.

The bog buck moth is restricted to open, calcareous, low shrub fens containing large amounts of buckbean. The sites in New York are considered medium fens. Medium fens are fed by waters that are moderately mineralized with pH values generally ranging from 4.5 to 6.5. The buckbean is intolerant of shade and is not found under shrubs. In addition to requiring buckbean and supplemental host plants for larval feeding, the species also requires plants with sturdy upright stems for oviposition.

The primary factors currently influencing bog buck moth population health are inherent factors (e.g., narrow habitat niche) and several external factors resulting in loss or alteration of habitat or directly influencing demographic rates. In chapter 4 we describe how these factors influence the current condition of the species. In chapter 5 we discuss plausible future scenarios for these or additional factors, the anticipated response of the impacted populations, and the species viability.

The current rangewide status of the bog buck moth is poor. In Canada, there are two known extant populations, which are potentially healthy populations. In the United States, there is one known extant population, which is in poor condition (there are also a population that is extirpated and a population that is presumed extirpated). We anticipate a continued declining status in the remaining population in the United States due to ongoing and increasing threats, primarily reduced habitat availability and flooding combined with natural boom and bust cycles. We also anticipate similar declines in the Canadian populations. It is unlikely that bog buck moths will disperse and shift their range in response to these habitat changes.

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CHAPTER 1. INTRODUCTION

1.1 Background

The U.S. Fish and Wildlife Service (Service) is responsible for identifying species that may be in need of protection under the Endangered Species Act, as amended (ESA). The Service has recognized the need to investigate the current population status and trends of the bog buck moth (*Hemileuca maia menyanthevora*)(=*H. iroquois*) and the relative effects of both positive and negative influences on the species' viability for many years. We identified the bog buck moth (*Hemileuca* sp.) as a Category 2 candidate species for listing in the November 21, 1991, Annual Candidate Notice of Review (56 FR 58804). In the February 28, 1996, Annual Candidate Notice of Review (61 FR 7596), we announced our discontinuation of the designation of Category 2 species as candidates, which removed the species from the candidate list. We finalized our decision to discontinue the practice of maintaining a list of Category 2 species on December 5, 1996 (61 FR 64481).

At our discretion, we prioritized a status review for the species according to the Service's 2016 Methodology for Prioritizing Status Reviews and added the species to the Endangered Species Program's National Listing Work Plan (Work Plan). The Work Plan is updated annually to reflect the need to respond to new petitions, updated information on the included species, and the Service's budget and staffing resources. Based on this process, we intend to make a decision on the bog buck moth's listing status in Fiscal Year 2021.

1.2 Analytical Framework

The Species Status Assessment (SSA) report, the product of conducting a SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the ESA.

This SSA report for the bog buck moth is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered and if so, whether or not to propose designating critical habitat. The process and this SSA report do not represent a decision by the Service whether or not to list a species under the ESA. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the bog buck moth. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and a decision will be announced in the ***Federal Register***.

Using the SSA framework (figure 1.1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Smith *et al*. 2018, entire). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe.

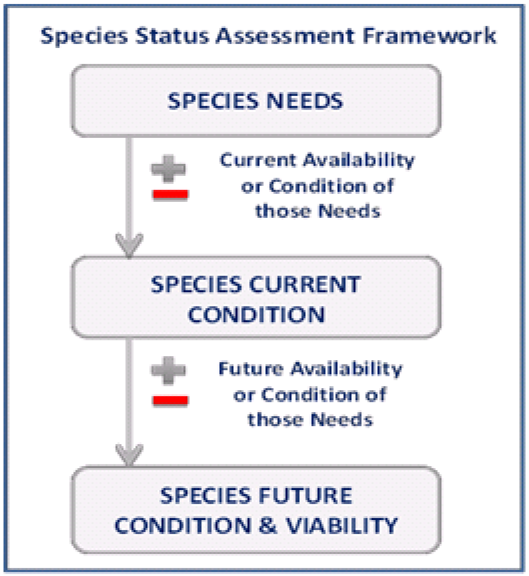

Figure 1.1. Species Status Assessment Framework.

Resiliency, redundancy, and representation (together, the 3Rs), are defined as follows:

<u>Resiliency</u> is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford *et al.* 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate -- survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations.

<u>Redundancy</u> is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083).

We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments-- referred to as adaptive capacity--is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra *et al.* 2015, p. 1269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Nicotra *et al.* 2015, p. 1270; Beever *et al.* 2016, p. 132). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Zackay 2007, p. 1; Crandall *et al.* 2000, p. 290-291; Sgro *et al.* 2011, p. 327).

We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess (1) natural levels and patterns of gene flow, (2) degree of ecological diversity occupied, and (3) effective population size. In our species status assessments, we assess all three facets to the best of our ability based on available data.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation. We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures.

CHAPTER 2. SPECIES BIOLOGY AND RESOURCE NEEDS

In this chapter we provide basic biological information about the bog buck moth, including its taxonomy, morphological description, and known life history traits. We then outline the resource needs for individuals, populations, and the species as whole. This is not an exhaustive review of the species natural history; rather, it provides the ecological basis for the SSA analyses.

2.1 Taxonomy

The bog buck moth is a silk moth (family = Saturniidae) in the buck moth genus (*Hemileuca*). The bog buck moth was first identified as a variant of the *maia* species group within *Hemileuca* in 1977 by John Cryan and Robert Dirig from four sites (2 populations) along the southeast shore of Lake Ontario in Oswego County, NY, but was not formally named at that time (Legge *et al.* 1996, p. 86; Pryor 1998, p. 126; Cryan and Dirig 2020, p. 3). Four additional sites (2 populations) were discovered in 1977 in eastern Ontario (COSEWIC 2009, p. 7). Multiple common names have been used since then (e.g., bogbean buckmoth, Cryan's buckmoth, fen buck moth).

For many years, the bog buck moth's taxonomic status has been confusing and uncertain. Tuskes *et al.* (1996, p. 111) included the bog buck moth as part of the *Hemileuca maia* complex, which is a broadly distributed group of closely related taxa including *H. maia, H. lucina, H. nevadensis*, among others. Tuskes *et al.* (1996, pp. 120-121) further refined the description of populations of buck moths in the Great Lakes region, including the bog buck moth, as the *H. maia complex of Great Lakes Region Populations*. Kruse (1998, p. 109) included *H. maia* and *H. nevadensis* as part of the Great Lakes complex; however using genomewide single nucleotide polymorphisms (SNPs), Dupuis *et al.* (2018, p. 6) and Dupuis *et al.* (2020, p. 3) show that *H. nevadensis* is restricted to the west (figure 2.1). The Annotated Taxonomic Checklist of the Lepidoptera of North America (Pohl *et al.* 2016, p. 735) included the Great Lakes populations of buck moths as part of *H. maia* (based on Tuskes *et al.* 1996), pending species-level taxonomic classification.

Recently, Dupuis *et al.* (2018, pp. 5-7) and Dupuis *et al.* (2020, pp. 2-3) used SNPs and found unambiguous results supporting the conclusion that both Ontario and Oswego County, NY populations are part of the bog buck moth lineage that is divergent from *Hemileuca lucina*, *H. peigleri*, *H. slosseri*, and all other *H. maia*. They also found clear differentiation between the group formed by the Ontario and Oswego County, NY populations and the group formed by Wisconsin and Michigan populations (Dupuis *et al.* 2020, p. 3).

In 2020, Pavulaan (2020, entire) was first to formally describe the bog buck moth as *Hemileuca maia menyanthevora* and stated that it may actually represent a full species. Pavulaan (2020, pp. 8-14) considered host plant use and morphology for the designation and included the Oswego County, NY, Marquette and Ozaukee County, WI, and Ontario fens as part of the range. All specimens that Pavulaan used for describing morphology were from one location in Oswego County, NY, and he relied on host plant use discussed in Kruse (1998, entire) for inclusion of the two Wisconsin sites (Pavulaan pers. comm.). Cryan and Dirig (2020, pp. 26-31) subsequently named the bog buck moth as *H. iroquois* and included just the Oswego County, NY and Ontario populations. The official scientific name has to follow the rule of publication priority under the International Code of Zoological Nomenclature; therefore the official name of the bog buck moth is *H. maia menyanthavora* with the junior synonym of *H. iroquois*.

Based upon the strong evidence provided by Dupuis *et al.* (2018, entire and 2020, entire), we consider the current range of *Hemileuca maia menyanthevora* as Oswego County, NY and Ontario. The historical range also included Jefferson Couny, NY (see below). We find this evidence markedly more persuasive than host plant information that Pavulaan (2020, entire; pers. comm.) relied upon when he included the Wisconsin sites in the absence of specimens from those sites. The Oswego County, NY and Ontario range is consistent with the range described when the Service originally considered the bog buck moth (*Hemileuca* sp.) as a Category 2 Candidate in 1991 (56 FR 58804). It is also consistent with the range described by NatureServe (2020, pp. 1-4), COSEWIC (2009, pp. 5,7), and Cryan and Dirig (2020, entire).

In summary, this SSA provides the status of *Hemileuca maia menyanthevora* with the current range of Oswego County, NY and Ontario, Canada, and our use of the common name “bog buck moth” refers to that taxon. Appendix A provides a complete summary and evaluation of the literature pertinent to the taxonomy of the bog buck moth, and further details our conclusion that the bog buck moth is a valid taxon for consideration for listing under the ESA.

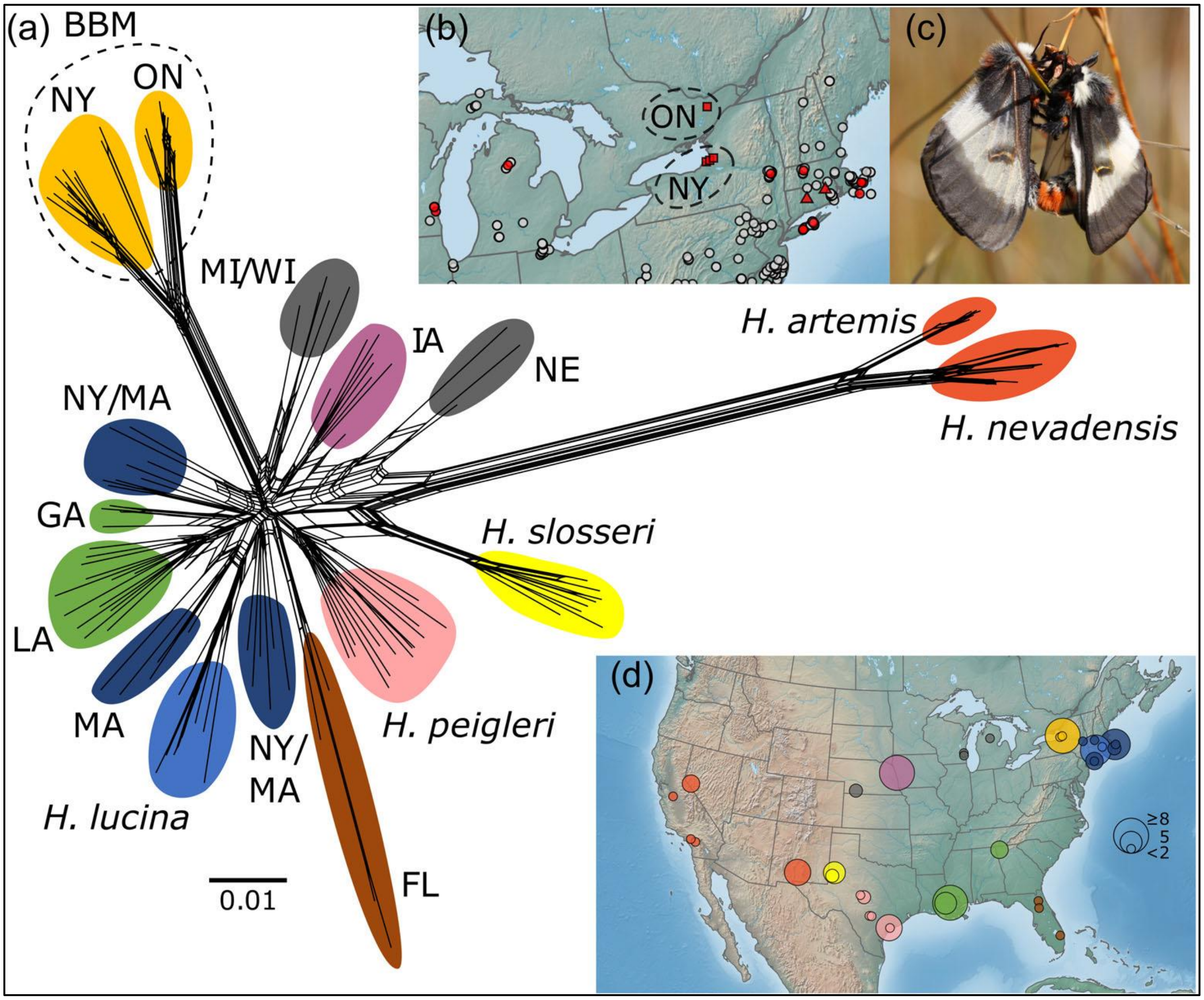

Figure 2.1. Neighbornet phylogenetic network generated with SplitsTree (a), specimen samples and *H. maia* occurrence data around the range of the bog buck moth (BBM) (c), photograph of mating BBMs (b), and sampling localities from Dupuis *et al.* (2018) to which Ontario BBM samples were integrated (d). In (a) and (d), colors match those used in the study by Dupuis *et al.* (2018) and state/province abbreviations are used to differentiate *H. maia* groupings. In (b), red shapes indicate sampling localities for ddRAD data (circles: *H. maia*, squares: BBM, triangles: *H. lucina*), and grey dots represent GBIF records matching *H. maia* or *H. maia maia* (accessed 10 December 2019). In (d), circle size indicates sample size per locality (for interpretation of colors in this figure, we refer readers to the web version of this paper). For comparison between Ontario BBM to New York BBM, our New York samples were collected at three localities: Oswego Inland, Lakeside 2 and Lakeside 5. [Color figure can be viewed at wileyonlinelibrary.com](Dupuis *et al.* 2020, p. 3, Figure 1).

2.2 Morphological Description

Bog buck moth adults have black bodies and black/gray translucent wings with wide, white wing bands and an eyespot (COSEWIC 2009, p. 5; NatureServe 2015, p. 4) (figure 2.2). Bog buck moths have forewing lengths of 22 to 36 millimeters (mm) (0.9 to 1.4 inches [in]) (Tuskes *et al.* 1996, p. 121; Pavulaan 2020, p. 9). Males and females are generally similar in appearance with the following exceptions. Similar to all saturniids, males have highly branched, feather-like antennae with receptors that respond to female pheromones (Tuskes *et al.* 1996, p. 14). Males also have a red-tipped abdomens (figure 2.2) and females are slightly larger than males (COSEWIC 2009, p. 5). Adults are larger than other *Hemileuca maia* and have similar highly translucent wings as *H. lucina*. White wing bands are much larger than other *H. maia* (Cryan and Dirig 2020, p. 26; Pavulaan 2020, p. 9).

Figure 2.2. Male bog buck moth, J. Jaycox 2004 (Bonanno and White 2011, p. 2).

Late instar larvae are dark with reddish-orange branched urticating (stinging) spines dorsally (figure 2.3), and a reddish-brown head capsule and prolegs (COSEWIC 2009, p. 6). Initially egg rings are light green (Cryan and Dirig 2020, p. 26) and fade to light brown or tan (K. Sime, pers comm). Mature larvae are usually predominantly black with small white dots and lack a yellow pattern (COSEWIC 2009, p. 6; NatureServe 2015, p. 4; Cryan and Dirig 2020, p. 26) (figure 2.3). Additional details are provided by Pavulaan (2020, p. 9) and Cryan and Dirig (2020, pp. 26-27).

Figure 2.3. Sixth instar bog buck moth larvae, K. Sime (Sime 2019, p. 20).

2.4 Life History – Individual Needs

2.4.1 Life Cycle and Longevity

The life cycle of a bog buck moth is similar to other *Hemileuca* species and generally completed within 1 year (figure 2.4, table 2.1) (Tuskes *et al.* 1996, p. 103). Nonfeeding adults emerge in the fall. After mating, female buck moths lay one large cluster of eggs on sturdy stems of a variety of plant species (table 2.2). The eggs overwinter until the following spring when they hatch into larvae. While early instar larvae rely primarily on the host plant *Menyanthes trifoliata* (commonly referred to as bogbean, bog buckbean, or buckbean) (Stanton 2000, p. 2), eggs are never laid on these plants as they die back each year rendering them unavailable for overwintering. Pupation occurs by mid-July and the pupal stage lasts about 2 months. While not specifically documented for bog buck moth, in other *Hemileuca* species (including *H. maia maia*), individual pupae may remain dormant until the following fall or possibly the fall after that (Cryan and Dirig 1977, p. 10; Tuskes *et al.* 1996, pp. 103, 114). See below for more details on each life stage.

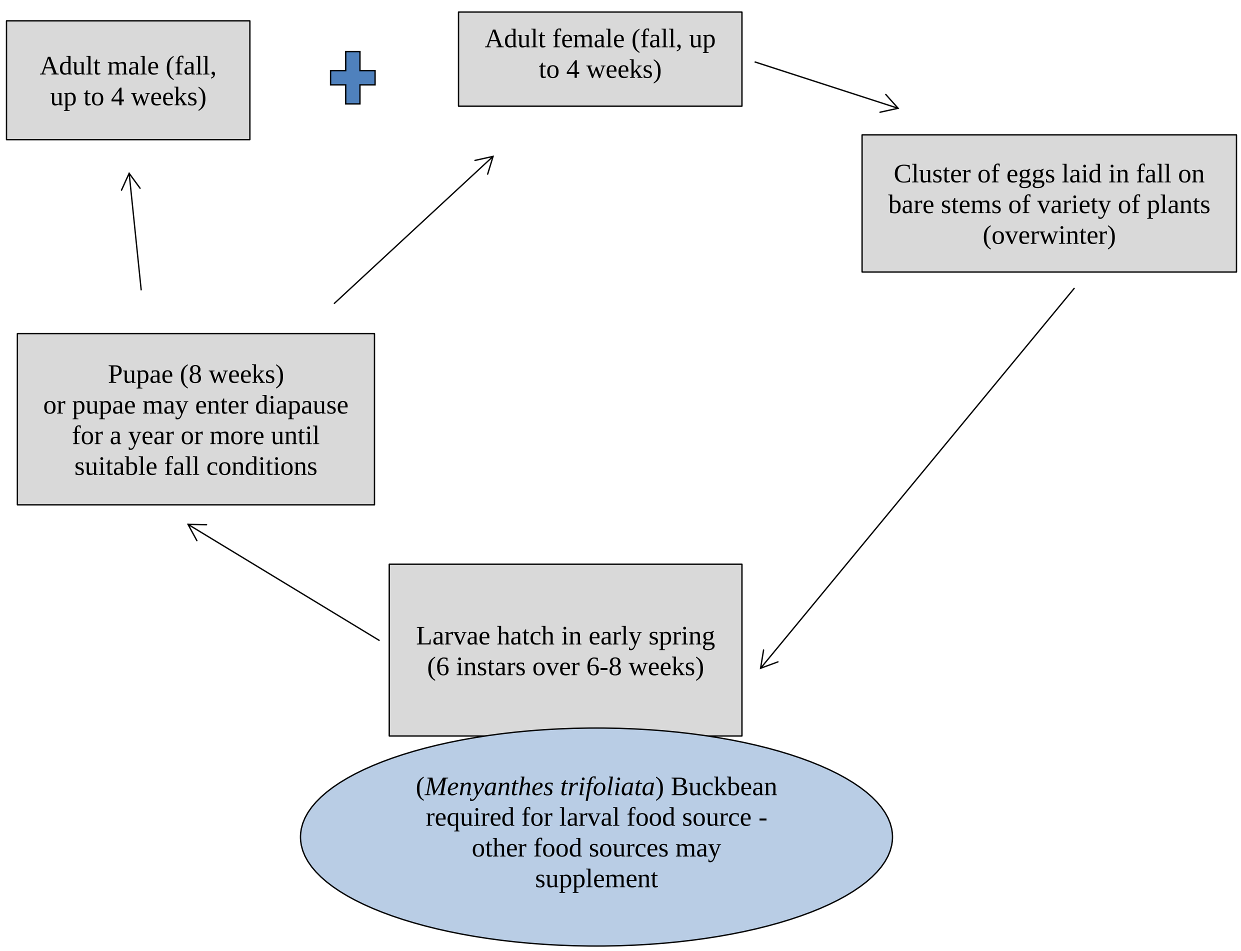

Figure 2.4. Bog buck moth life cycle.

Table 2.1. Bog buck moth life history timeline.

Life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult									X	X		
Egg	X	X	X	X	X	X			X	X	X	X
Larvae					X	X	X					
Pupae	X[1]	X	X	X	X	X	X	X	X	X	X	X

The bog buck moth is univoltine (single adult flight period). The flight period lasts 4 weeks, generally from mid-September to October (Pryor 1998, p. 134; Stanton 2000, p. 15; C. Schmidt, pers. comm.). While the flight period within a population can last up to 1 month, individual adults survive for less than 2 weeks with 9 and 12 days being the oldest females and males observed in New York (Stanton 1998, pp. 20, 26). Based on experience with other *Hemileuca*

[1] Lighter gray denotes uncertainty that pupae can overwinter

species, the life span probably averages 3 to 4 days for males and, once mated, 2 to 3 days for females (M. Collins, pers. comm.). Adults do not feed (Tuskes *et al.* 1996, p. 9; Stanton 2004, p. 3).

Adults are diurnal (fly during the day) avoiding cooler fall night temperatures (Tuskes *et al.* 1996, p. 12; Pryor 1998, p. 133). They appear to have some basic requirements that allow for suitable flying conditions. Bog buck moths fly when temperatures are generally above 20 degrees Celsius (°C) (68 degrees Fahrenheit [°F]) and when winds are less than 24 kilometers per hour (kmph) (15 miles per hour [mph]) (Stanton 1998, pp. 19-20, 29). Pryor (1998, p. 131) observed no flights when temperatures were below 12 °C (53.6 °F), during rainstorms, or during high winds. Flights may occur throughout the day with peak male flights concentrated between 11 a.m. and 2 p.m. and some female flights after that (Pryor 1998, p. 133). Males and females differ in flight patterns with males flying large, circular paths and females making short, direct, frequent flights (Pryor 1998, p. 133). Adult males fly for longer periods as well, covering the open area of the fen for approximately 10 minutes compared to females flying short distances lasting a matter of seconds (Pryor 1998, p. 133). Stanton (2004, p. 7) similarly observed males to freely fly throughout the entire suitable habitat within the Lakeside 2 (NY) site with movements of up to 0.5 kilometer (km) (0.3 miles [mi]). Mate-finding is apparently based on pheromones rather than visual cues (Pryor 1998, p. 133). Adult males typically fly 1 meter (m) (3.3 feet [ft]) above the ground (Pryor 1998, p. 134) searching for females. Females remain hidden and emit attractant pheromones luring males to their location (Pryor 1998, p. 133; Stanton 2000, p. 2).

Female saturniids typically mate with the first male to reach them (Tuskes *et al.* 1996, p. 16). Female bog buck moths mate once and deposit eggs in rings of 33 to 257 eggs (Pryor 1998, p. 129; Stanton 1998, p. 8) around bare sections of rigid, vertical plant stems (Stanton 2000, p. 11) (figure 2.5). Unlike other *Hemileuca* species (Tuskes *et al.* 1996, p. 103), bog buck moths do not lay eggs on their primary larval host plants (Legge *et al.* 1996, p. 88; Stanton 2000, pp. 2, 11). In fact, Pryor (1998, p. 136) found egg rings more than 20 m (65 ft) from the nearest buckbean plant and Stanton (2000, p. 16) observed females ovipositing as far as 500 m (0.3 mi) from the nearest buckbean. The bog buck moth is documented to use a wide variety of plants for oviposition sites. For example, in New York, Pryor (1998, p. 128) and Stanton (2000, pp. 10-11) observed eggs on 9 and 15 different plant species, respectively (table 2.2). Plants must have stems of adequate diameter that are sturdy enough and stay upright to persist above the water until spring. Stanton (1998, p. 11) observed host stem diameters of 1.3 to 8.2 mm (0.05 to 0.3 in). While eggs may survive temporary submersion, they will not survive long-term flooding. For example, Stanton (1998, p. 9) observed eggs survive after high water submerged 50 percent of egg masses for 2 weeks at South Pond. However, this was not the case in 2017 or 2019 which were long-term flooding events (many months of high water). In 2017, Dr. Sime observed water mold infection on some of the unhatched egg masses she found at Lakeside 5 (Sime, pers. comm., cited within Bonanno 2017, p. 3).

Figure 2.5. Bog buck moth egg ring at Lakeside 5, K. Sime (Sime 2019, p. 7).

Table 2.2. Documented bog buck moth larval host plants and oviposition plants.

Species	Documented as larval host plant	Documented as oviposition plant
Acer rubrum		Pryor 1998, p. 128; Stanton 2000, p. 10
Alnus incana ssp. *rugosa*	Pryor 1998, p. 130; Stanton 2000, p. 13	Pryor 1998, p. 128; Stanton 2000, p. 10
Anchistea virginica		Pryor 1998, p. 128
Andromeda polifolia L.		Sime 2019, p. 9
Aronia melanocarpa	Pryor 1998, p. 130; Stanton 2000, p. 13	Sime 2019, p. 9
Aster umbellatus		Stanton 2000, p. 10
Aster spp.		COSEWIC 2009, p. 13
Betula pumila	COSEWIC 2009, p. 13	COSEWIC 2009, p. 13
Carex sp.	Pryor 1998, p. 130; Stanton 2000, p. 13	Pryor 1998, p. 128
Chamaedaphne calyculata	Pryor 1998, p. 130; Stanton 2000, p. 13	Pryor 1998, p. 128; Stanton 2000, p. 10
Cladium mariscoides		Stanton 2000, p. 10
Cornus sericea		Pryor 1998, p. 129; Stanton 2000, p. 10
Frangula alnus		Sime 2019, p. 9
Ilex verticillata	Pryor 1998, p. 130; Stanton 2000, p. 13	
Larix laricina		Stanton 2000, p.10
Menyanthes trifoliata	Pryor 1998, p. 130; Stanton 2000, p. 13; COSEWIC 2009, p. 13	
Muhlenbergia glomerata		COSEWIC 2009, p. 13
Myrica gale		Pryor 1998, p. 128; Stanton 2000, p. 10; COSEWIC 2009, p. 13

Species	Documented as larval host plant	Documented as oviposition plant
Nymphaea odorata	Stanton 2000, p. 13	
Osmunda regalis		Stanton 2000, p. 10
Phragmites australis ssp. *americanus*		Gradish and Tonge 2011, p. 6
Quercus sp.	Pryor 1998, p. 130; Stanton	
Rhamnus alnifolia	Stanton 2000, p. 13	Stanton 2000, p. 10
Salix bebbiana	COSEWIC 2009, p. 13	
Salix pedicellaris	Pryor 1998, p. 130; Stanton 2000, p. 13	Pryor 1998, p. 128; Stanton 2000, p. 10
Salix petioloaris	COSEWIC 2009, p. 13	
Sarracenia purpurea L.		Sime 2019, p. 9
Scirpus sp.		COSEWIC 2009, p. 13
Solidago sp.		Stanton 2000, p. 10; COSEWIC 2009, p. 13
Spirea alba	Pryor 1998, p. 130; Stanton 2000, p. 13; COSEWIC 2009, p. 13	Pryor 1998, p. 129; Stanton 2000, p. 10
Typha angustifolia L.		Sime 2019, p. 9
Vaccinium macrocarpon	Pryor 1998, p. 130; Stanton 2000, p. 13	Stanton 2000, p. 10
Woodwardia virginica		Stanton 2000, p. 10

The herbaceous buckbean dies back late summer and is not available for oviposition (Pryor 1998, p. 137; Stanton 2000, p. 11) or to help cue alternative nearby egg-laying locations. Pryor (1998, p. 137) suggests possible chemical ovipositional cues may be left by prior eggs or larvae. Bog buck moths overwinter in the egg stage like most *Hemileuca* species (Tuskes *et al.* 1996, pp. 103, 121; Cryan and Dirig 2020, p. 27).

The overwintering egg stage allows larvae to emerge and begin feeding early in the spring when host plant quality is greatest (Tuskes *et al.* 1996, p. 12). In NY, bog buck moth larvae hatch between mid-May and mid-June (Pryor 1998, p. 130). Larval mortality appears high in the first week and finding larval food resources early is important (Stanton 2000, p. 14). Early instar larvae feed primarily on buckbean leaves (Legge *et al.* 1996, p. 88; Tuskes *et al.* 1996, p. 121; Pryor 1998, p. 130) unless the leaves are not yet available due to early spring site conditions. For example, at a site in New York, the earliest hatching larvae fed on cranberry (*Vaccinium macrocarpon)* until buckbean leafed out on or about May 24th, and by June 14th, 72 percent of larvae were observed feeding on buckbean (Pryor 1998, p. 130). While buckbean is essential for early stages of larval growth, Pryor (1998, p. 130) observed late instar larvae feeding less on buckbean (25 percent) and more on *V. macrocarpon* (54 percent) and *Carex spp*. (16 percent). Stanton (2000, p. 13) observed bog buck moth entirely feeding on buckbean for the first three instars and a preference for buckbean as later instars but with frequent observations of alternative hosts. Table 2.2 includes a list of larval host plants. Overall, buckbean is essential but other foodplants may be important, particularly in later larval stages. In Ontario, larvae regularly must feed on plants other than buckbean simply because buckbean is not abundant enough to provide enough foliage as larvae mature. And while larvae must start out on buckbean, other plants form the majority of the diet later on (C. Schmidt, pers. comm.).

Larvae are the "feeding" stage of the bog buck moth and must accumulate sufficient fat stores to serve the nonfeeding adult for breeding and any dispersal (Tuskes *et al.* 1996, p. 18). Larvae pass through six instars and must move several times to find food as they grow with larval groups often splintering when traveling between food resources Stanton (2000, p. 14). Similar to other buck moths, larvae are gregarious in early instars (figure 2.6) and the number of larvae per group declines as the larvae grow (Pryor 1998, p. 130; Stanton 1998, p. 18-19; Stanton 2000, p. 14). Pryor (1998, p. 130) reported the mean number of larvae per group declined from 23 to 7 from June 2 to 14, respectively. Similarly, Stanton (2000, p. 14) reported that by the fourth instar most groups contain fewer than three individuals.

Figure 2.6. Cluster of first and second bog buck moth instar larvae from the Oswego Inland Site, K. Sime (Sime 2019, p. 20).

Stamp and Bowers (1990, entire) examined the effects of diet, group size, and temperature on growth rates of captive third-instar larvae of the closely related *Hemileuca lucina*. At 20 °C (68 °F) (average daytime temperatures in a cool, overcast spring in Massachusetts), growth rates and body mass gains were lowest regardless of diet or group size (Stamp and Bowers 1990, p. 1035). At temperatures of 30 °C (86 °F) (temperatures larvae may obtain by basking), growth rates doubled with the highest rates associated with larger groups eating a diet of new leaves (Stamp and Bowers 1990, p. 1036). Each increase of 5 °C (9 °F) shortened the duration of the instar by 2.3 days (Stamp and Bowers 1990, p. 1035). Shorter instar duration reduces the period of risk for caterpillar parasitism and predation. To obtain warmer temperatures and eat new leaves, bog buck moth larvae would need to forage on the outer edges of plants; however, this also exposes larvae to the greatest risk of predation. At sites with higher predator densities, larvae likely experience slower growth rates, prolonged development, and reduced body mass (Stamp and Bowers 1990, p. 1037) because they would be forced to forage closer to the center of plants where it is cooler and older leaves are present.

By the sixth instar, larvae burrow into peat mat or leaf litter in July to pupate (Pryor 1998, p. 131; Stanton 2000, p. 2) and stay in the pupal stage for about 2 months. They do not enclose themselves in cocoons, but may spin a loose silk web to pull leaf matter around themselves (Stanton 1998, p. 26). As mentioned above, pupae usually develop into adults in late summer with cooling fall rains, but some pupae of other *Hemileuca* species (including *H. maia maia*) have been documented to remain dormant for a year or more if there is a late summer drought (Cryan and Dirig 1977, p. 10; Tuskes *et al.* 1996, pp. 103, 114). Because adults live for less than 2 weeks, synchronous emergence is essential to allow for successful reproduction (Tuskes *et al.* 1996, p. 12).

2.4.2 Habitat Needs

The bog buck moth is restricted to open, calcareous, low shrub fens containing large amounts of buckbean (COSEWIC 2009, p. 10) (see figure 2.7 for example habitat photograph). Fens are classified along a gradient that ranges from rich fens to poor fens based on their water chemistry and plant community structure. Rich fens receive more mineral-rich groundwater than poor fens, which results in higher conductivity, pH, and calcium and magnesium ion concentrations (Vitt and Chee 1990, p. 97). The sites in New York are considered medium fens (New York Natural Heritage Program [NYNHP] 2020a, p. 3). Medium fens are fed by waters that are moderately mineralized with pH values generally ranging from 4.5 to 6.5 (Olivero 2001, p. 15). Medium fens often occur as a narrow transition zone between a stream or lake and either a swamp or an upland community (Olivero 2001, p. 15). The dominant species in medium fens are usually wooly-fruit sedge (*Carex lasiocarpa*) and sweet-gale (*Myrica gale*), with a variety of characteristic shrubs and herbs generally less than 5 m (16.4 ft) in height (NYNHP 2020b, pp. 5-11). Bog rosemary (*Andromeda glaucophylla),* leatherleaf (*Chamaedaphne calyculata*), cranberry, spatulate-leaved sundew (*Drosera intermedia*), three-way sedge (*Dulichium arundinaceum* var. *arundinaceum*), and green arrow arum (*Peltandra virginica)* are only characteristic of medium fens, compared to any of the other calcareous fens found in New York (Olivero 2001, p. 14).

In Ontario the bog buck moth is found in calcareous fens with buckbean. The fens are either low shrub dominated by sweet gale (*Myrica gale*), bog birch (*Betula pumila*), bog willow (*Salix pedicellaris*) and other willows, but with patches of open fen dominated by sedges and water Horsetail (*Equisetum fluviatile*) or primarily open fens dominated by sedges such as wire sedge (*Carex lasiocarpa*), twig rush (*Cladium mariscoides*) and American common reed (*Phragmites australis* ssp. *americanus*) surrounded by conifer swamp (COSEWIC 2009, p. 10).

Figure 2.7. Bog buck moth habitat at Lakeside 5, 5/24/2011 K. Sime (Sime 2019, p. 5).

The buckbean has a much larger distribution than the bog buck moth and is considered a circumpolar species (occurring between 40 °North latitude and the Arctic Circle in North America, Europe and Asia). The buckbean is intolerant of shade (Hewett 1964, p. 729) and is not found under shrubs (Bonanno 2014, p. 6). Hewett (1964, p. 731) suggests there may be a minimum water temperature (perhaps around 10 °C [50 °F]) before buckbean spring growth begins.

While buckbean and supplemental hosts are necessary for larval feeding, plants with sturdy upright stems are necessary for oviposition sites (table 2.2). Bog buck moth egg rings are laid fairly low to the ground on these stems. For example, Pryor (1998, p. 128) observed an average height of 11.4 to 27.0 centimeters (cm) (4.5 to 10.6 in) above the substrate in New York. Pryor (1998, p. 137) suggests egg deposition that is low to the ground may improve overwinter survival if eggs are covered with snow by protecting eggs from freezing temperatures or ingestion during deer or rabbit browse of stems. Larvae feed and find shelter on a variety of host plants with the primary host plant being buckbean. Pupae bury in substrate (e.g., sphagnum) approximately 4 cm (1.6 in) below the surface (Pryor 1998, p. 131). Upon eclosion, adult bog buck moths climb up nearby vegetation to harden their wings (Pryor 1998, p. 131). Adults cling to vegetation during rain, on cold days, and during high winds (Pryor 1998, p. 131).

Bog buck moths depend on shifting mosaics of early successional fen habitat created by regular disturbance (such as periodic flooding) (Cryan and Dirig 2020, p. 28). Without disturbances, similar to other early successional habitats, vegetation succession will occur; however in fens with intact hydrology, this succession occurs very slowly. Succession may be sped up with nutrient inputs or changes to hydrology (see chapter 3).

2.4.3 Movements and Dispersal

The bog buck moth is sedentary (nonmigratory) and therefore present within suitable habitat year-round. Schweitzer considered movements of 0.5 km (0.3 mi) within suitable habitat as common (NatureServe 2015, p. 5). NatureServe (2015, p. 5) previously suggested that populations may be separated by areas of unsuitable habitat greater than 2 km (1.24 mi) or areas of suitable habitat greater than 10 km (6.2 mi); however, some infrequent dispersal events may occur at slightly longer distances between unsuitable patches. NatureServe (2020, p. 5) currently states that bog buck moth "Should be capable of flying several to many kilometers, but seldom leaves habitat. In NY probably some movement between certain sites that are close together." COSEWIC (2009, p. 15) suggests that isolation of populations is increased by the short–lived adult stage (not much time for adults to fly far). In addition, they seem to have no inclination or ability to fly long distances. Adult females that do make short flights are laden with hundreds of eggs.

In New York, Pryor (1998, p. 138) did not observe any bog buck moth dispersal events but suggested the potential for an adult bog buck moth to disperse with strong winds or powered flight if surrounding vegetation do not impede them. Stanton (2004, p. 7) captured 3 males on sticky traps in unsuitable habitat located between the Lakeside 1 and Lakeside 2 sites in New York supporting some movement outside of suitable habitat but well within the 2 km (1.24 mi) discussed above. We conclude that most movements are likely to be limited to the highly localized fen habitat but that infrequent male dispersal events of a few kilometers is possible.

2.4.4 Summary of Individual Needs

Bog buck moth needs are summarized in table 2.3. In general, individual bog buck moths are habitat specialists preferring medium fens and require specific host plants such as buckbean. Adults have localized movements.

Table 2.3. Summary of bog buck moth life history information by life stage.

Life Stage	Life history information
Adults	• Flight period for 1 month with individual adults living less than 2 weeks • Require appropriate flying weather of warm fall days with no rain and low winds • Males fly throughout suitable habitat in search of females • Females have limited flights and lure males using pheromones • Females require perennial plants with bare sections of sturdy small stems above substrate, near buckbean for oviposition
Eggs	• Require perennial plants with bare sections of sturdy small stems above substrate, near buckbean for shelter • Snow cover may protect eggs from freezing or desiccation
Larvae	• Gregarious in early instars and not in late instars • Require buckbean and other plants for shelter • Feed primarily on leaves of buckbean • Also feed on leaves of other plants if limited buckbean or in later instars • We assume bog buck moth are similar to other *Hemileuca* larvae with faster growth rates and shorter instars when larve are able to bask to warm themselves and eat new leaves
Pupae	• Larvae move into leaf litter or substrate before pupating • They do not use cocoons, but may spin loose silk web • May remain in pupal state for one year if fall conditions are unsuitable for adult flight
All	• Habitat specialists • Residents (nonmigratory)

2.5 Population Needs

In this section, we describe the ecology needs of a healthy population (i.e., what a population requires to sustain itself over time). Healthy or resilient populations are those that are able to respond to and recover from stochastic events (e.g., flooding, storms) and normal year-to-year environmental variation (e.g., temperature, rainfall). Simply said, healthy populations are those able to sustain themselves through good and bad years. To be resilient, populations must: (1) have healthy demography and (2) occupy areas with suitable habitat conditions for all life stages and seasons.

2.5.1 Healthy Demography

For bog buck moths, healthy demography includes sufficient population size to survive boom and bust cycles and population structure that includes connectivity among subpopulations.

Sufficient number of bog buck moths to survive bust portion of boom and bust cycles

There are no models available to suggest minimum viable population size for the bog buck moth and only limited population size estimates from specific sites and years are available across the range. For example, Stanton (1998, p. 20) estimated a number of adult males at Lakeside 2, and his highest estimate was 3,035 (SE = 463) on September 24, 1997. Since population estimates are not widely available, at the New York sites researchers have conducted standardized adult male transect surveys (Stanton 2000, pp. 18-22; Stanton 2004, entire) as population indices of abundance since 1998. Stanton (2004, pp. 5, 7, 10) (figure 2.8) found that population transect counts are correlated with estimated population size from mark-release recapture studies and can be used as an indicator of abundance and permit comparisons among years and sites but cannot be used to extrapolate actual population size.

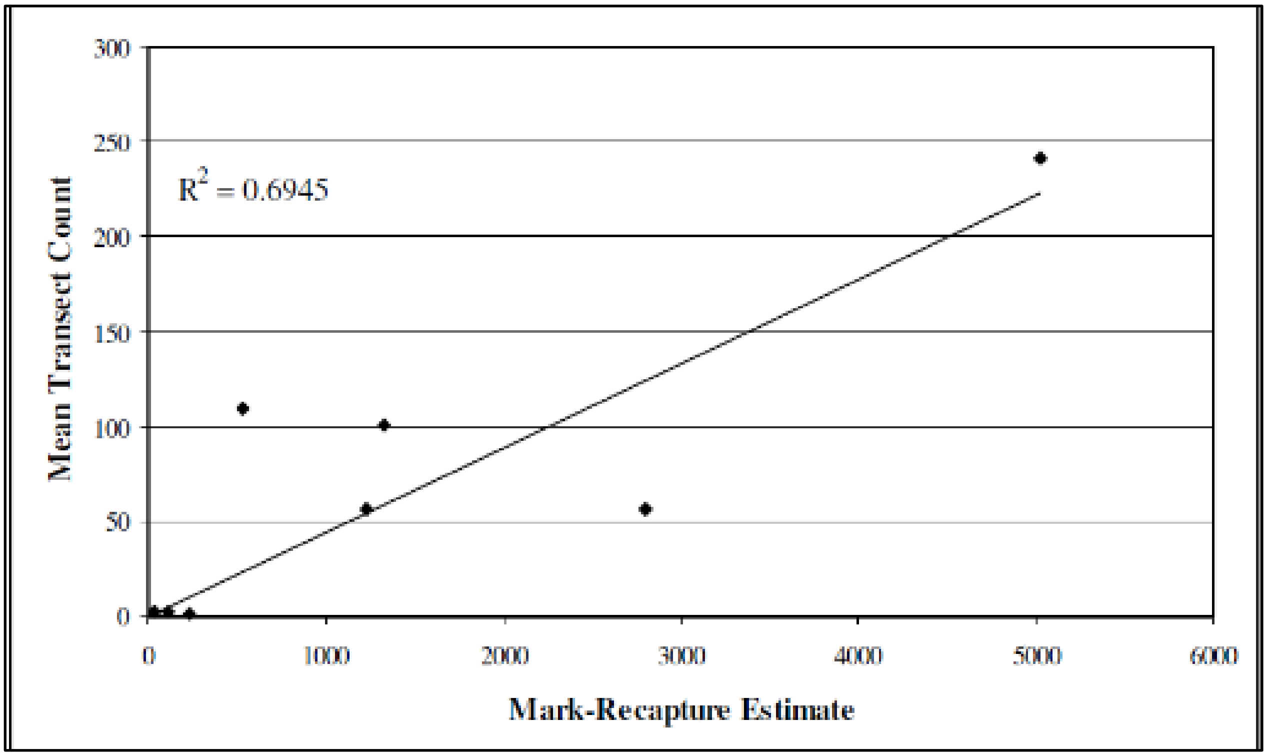

Figure 2.8. Comparison of mark-recapture and transect population estimates of male bog buck moths at Lakeside 2 Fen (p<0.01) (Stanton 2004, p. 7, figure 4).

Bog buck moth transect counts vary widely from year to year. Other *Hemileuca* species are known to undergo cyclic changes with "outbreak proportion" during favorable years while disease, predation, or parasitoids can lead to crashes (Tuskes *et al.* 1996, p. 10). Therefore, we do not expect that suitable habitat patches will be occupied (or moths will be detected) each year. Typical for most invertebrate species, the bog buck moth may be following a strategy of "hide and seek" with its predators and pathogens and needs to have open habitat to move to when mortality loads are too high (D. Rubinoff, pers. comm.). While boom-bust cycles are expected, sites with repeated years of low counts are at risk of extirpation. To withstand these fluctuations, populations should be large enough to withstand the demographic and genetic consequences of these stochastic events and have multiple suitable habitat patches available. Populations should also have a stable to increasing long-term trend that captures the boom and bust cycles[2]. When peak transect counts have fallen into single digits, the result has usually been disappearance within a few years (S. Bonanno, pers. comm.).

While we generally lack detailed information on other life stages, large numbers of eggs appear necessary to allow for losses in the egg, larvae, and pupal stage (Stanton 1998, p. 16-18, figure 8) (figure 2.9). Threats to the various life stages are discussed in chapter 4.

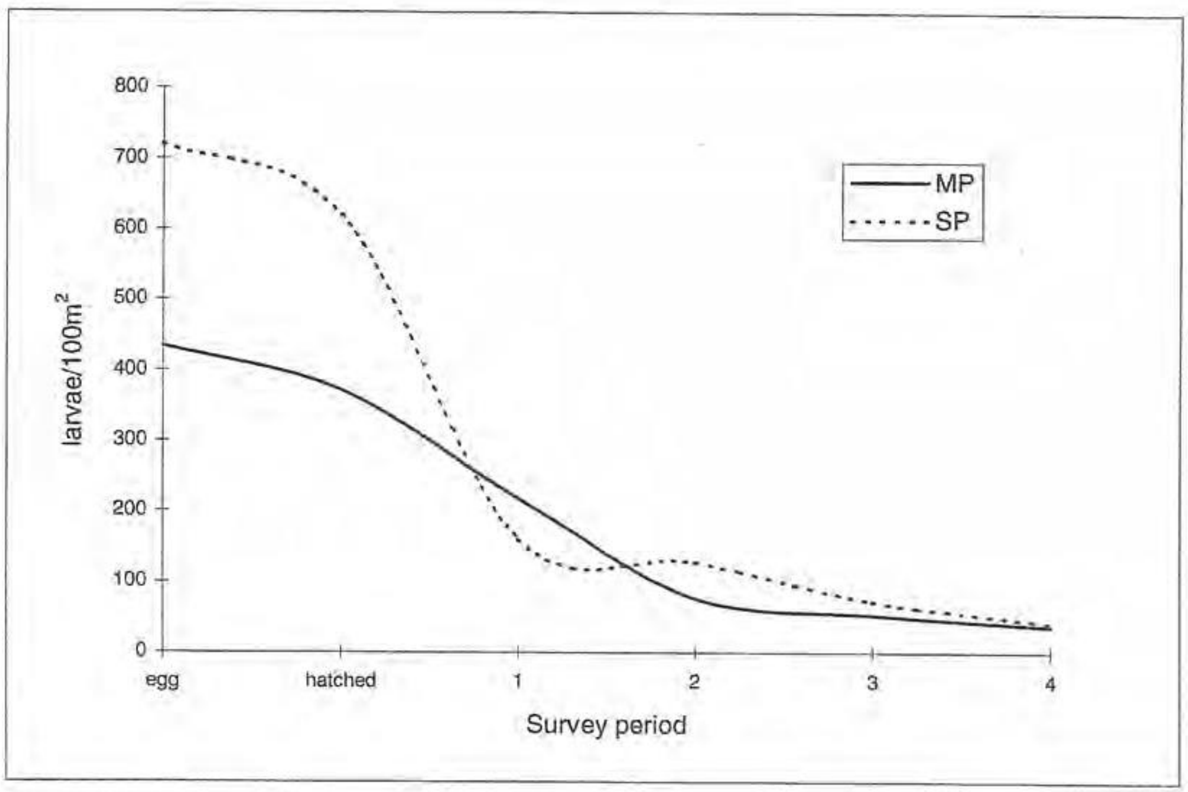

Figure 2.9. Bog buck moth egg and larvae survival at the Oswego Inland (MP) and Lakeside 2 (SP) sites (Stanton 1998, p. 18, figure 8).

Population Structure

Bog buck moth populations consist of sedentary (nonmigratory) populations of multiple males and females. These populations occupy patches of specialized suitable habitat required for all life stages throughout the year. Most likely, bog buck moth populations function as metapopulations with asynchronous boom and bust cycles of subpopulations. Multiple patches (and subpopulations) should provide opportunities for recolonization of subpopulations within a metapopulation should one subpopulation be reduced to zero (i.e., extirpated). However, as

[2] Boom and bust portions of cycles should be captured when looking at trends over 10 years based on several New York subpopulations.

discussed, females do not move far and may need to be blown by the wind into adjacent suitable habitat.

While we discuss the historical and current condition of populations in chapter 4, we introduce the names of bog buck moth populations and subpopulations here. The **White Lake** Population is located in Ontario and comprises two sites (White Lake North and White Lake South). **Richmond Fen** Population is also located in Ontario and comprises two sites (Richmond Fen North and Richmond Fen South). The **Lakeside** Population occurs along the eastern shore of Lake Ontario in Oswego County, NY and comprises five sites (Lakeside 1 through 5). To the southwest, the **Oswego Inland Site** Population occurs in Oswego County, NY and is a single site with two fen openings with metapopulation dynamics operating at a smaller scale.

2.5.2 Habitat Quality

Habitat is considered suitable for the bog buck moth when there is sufficient habitat available for all life stages. There should be relatively abundant host plants (greater than 4 percent buckbean [Stanton 2000, p. 23]), relatively abundant sturdy perennial stems for oviposition, and safe pupation sites. Additional details are discussed above (section 2.4.2).

2.5.3 Manageable Threats

Another consideration when describing the needs of resilient populations is the concept of ensuring that any threats acting upon the populations are not causing (or anticipated to cause) reductions in demography or habitat. This is not a separate item in table 2.4 as a threat is not a conservation need. However, managing ongoing threats is a conservation need for the bog buck moth. This is similar to other conservation-reliant species that often need continued habitat management or continued responses to ongoing threats. In addition, multiple threats can be acting upon all of the factors. Threats and conservation actions are discussed further in chapter 3 and appendix D.

2.5.4 Key Uncertainties/Assumptions

Population Dynamics

As stated above, we do not fully understand the causes of bog buck moth boom and bust cycles; however, we assume the reasons are similar as that for other buck moths, including responses to changes in disease, parasitoids, and predation.

Habitat Size

Larger wetlands should provide more suitable habitat for larger populations. In addition, if parts of a wetland are impacted by a stressor but the wetland is large enough, there may be some suitable habitat remaining. However, if all areas of a large wetland are equally vulnerable to a parasitoid explosion, then smaller, scattered wetlands are a better defense. We did not rank populations using this factor given the significant amount of uncertainty about whether it influences population health.

Pupal Stage

We do not have any information about whether bog buck moths use the strategy of overwintering as pupae if fall conditions are not appropriate for adult flights. However, we assume that this is a possibility given that closely related species have been documented using this strategy.

2.5.5 Summary of Population Needs

In general, bog buck moth populations would be considered healthy if they have multiple connected patches of high quality habitat and sufficient numbers of buck moths to survive boom and bust cycles. Bog buck moth population needs are summarized in table 2.4.

Table 2.4. Population needs for the bog buck moth[3].

Requirement for Population Resiliency	Metric
Healthy population	• Both sexes present. • Sufficient survival of all life stages. • Sufficient number of bog buck moths to survive bust portion of boom and bust cycles. • Stable to increasing trend over last 10 years (10 generations). • Connectivity via multiple occupied suitable habitat patches within metapopulation

Habitat to support healthy populations	• Sufficient habitat size.
	• Sufficient habitat quality
	  o Sufficient buckbean plants (>4% areal coverage).
	  o Relatively abundant oviposition sites.
	  o Suitable pupation sites.
	• Hydrology and ecological processes supportive of suitable habitat

2.6 Species Needs

2.6.1 3 Rs (Resiliency, Redundancy, Representation)

For the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild over time. The bog buck moth needs multiple healthy (resilient) populations (table 2.4). Resiliency is the ability of a population to recover from harsh years and stochastic events. To be resilient, the bog buck moth must have populations that are able to sustain themselves through good and bad years. The more populations, and the wider the

[3] The third factor in describing resilient populations is the concept of ensuring that any threats acting upon the populations are manageable or not causing reductions in demography or habitat needs. This is not a separate item in table 2.4 as having the threat is not the conservation need but managing the threats may be.

distribution of those populations (redundancy), the less likely that the species as a whole will be negatively impacted if an area of the species' range is negatively affected by a catastrophic event, and the more likely that natural gene flow and ecological processes will be maintained (Wolf *et al.* 2015, pp. 205–206). Species that are well distributed across their historical range are less susceptible to the risk of extinction as a result of a catastrophic event than species confined to smaller areas of their historical range.

Furthermore, diverse and widespread populations of bog buck moth may contribute to the adaptive diversity (representation) of the species if redundant populations are adapting to different conditions. In considering what may be important to capture in terms of representation for the bog buck moth, we identified two primary means of defining bog buck moth diversity: genetic differences and potential adaptation to variation in climatic conditions across latitudinal gradients.

Gene flow is influenced by the degree of connectivity and landscape permeability (Lankau *et al.* 2011, p. 320). Gene flow may be somewhat limited among bog buck moth populations due to their rare and patchy distributions and sedentary (nonmigratory) behavior. According to amplified fragment-length polymorphism data, the Oswego Inland Site, NY population is genetically distinct from the nearest of the Lake Ontario shore NY populations (about 30 km [18.6 mi] away), though the data indicate that there is or was probably some limited migration between them (Buckner *et al.* 2014, pp. 510-512). In addition, as discussed in section 2.1, while Dupuis *et al.* (2020, pp. 2-3) found an unambiguously close relationship between the bog buck moth specimens from Ontario and the populations in Oswego County, NY, they also found that both of these populations formed distinct sister clusters (figure 2.1). They suggest that it is possible that, historically, bog buck moth populations were more widespread along the wetlands around Lake Ontario, forming a connection that has since been broken (Dupuis *et al.* 2020, p. 4). Maintaining populations in both Canada and New York is important to conserve this genetic diversity.

The bog buck moth has a fairly narrow distribution; however, Lake Ontario influences local climatic conditions and at more northern latitudes, the Canadian populations experience colder winters. In Ottawa, Canada average monthly temperatures range from 5.4 to 21.6 °F (–14.8 to –5.8 °C) in January to 60 to 79.7 °F (15.5 to 26.5 °C) in July[4], and average snowfall is 88 in (2.23 m). In Oswego, NY (directly on Lake Ontario) temperatures range from 18 to 30°F (–7.8 to –1.1 °C) in January to 63 to 79 °F (17.2 to 26.1 °C) in July, and average snowfall is 141 in (3.58 m)[5]. Stanton (1998, p. 26) observed earlier adult male flights by 3 to 5 days at the Oswego Inland Site compared to Lakeside 2 and suggested this was likely due to the climate tempering effects of Lake Ontario on the Lakeside 2 site. Maintaining populations across historical latitudinal and climatic gradients increases the likelihood that the species will retain the potential for adaptation over time. Local adaptation to temperature, precipitation, host plants, and community interactions have all been identified for butterflies (Aardema *et al.* 2011, pp. 295–297).

[4] https://www.weather-ca.com/en/canada/ottawa-climate#temperature. Accessed 7.14.2020.
[5] https://www.usclimatedata.com/climate/oswego/new-york/united-states/usny1078. Accessed 7.14.2020.

2.6.2 Summary of Species Needs

In summary, the bog buck moth requires multiple resilient populations spread across its geographical extent to maintain its ecological and genetic diversity (table 2.5). Information to date suggests that bog buck moths are genetically structured across their range. Given the above, we believe the breadth of adaptive diversity can be captured by two representative units, Canadian and United States.

Table 2.5. Ecological requirements for species-level viability.

<table>
<tr><th>3Rs</th><th>Requisites</th><th>Metric</th></tr>
<tr><td>Resiliency (able to withstand stochastic events)</td><td>Healthy populations</td><td>Populations with:
• Both sexes present
• Sufficient survival of all life stages
• Sufficient number of bog buck moths to survive bust portion of boom and bust cycles
• Stable to increasing trend over last 10 years (10 generations)
• Multiple occupied suitable habitat patches within metapopulation
• Sufficient habitat size
• Sufficient habitat quality
• Intact hydrology and ecological processes</td></tr>
<tr><td>Representation (to maintain evolutionary capacity)</td><td>Maintain adaptive diversity</td><td>Healthy populations distributed across areas of unique adaptive diversity (e.g., across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.</td></tr>
<tr><td rowspan="2">Redundancy (to withstand catastrophic events)</td><td>Sufficient distribution of healthy populations</td><td>Sufficient distribution to guard against catastrophic events significantly compromising species adaptive diversity.</td></tr>
<tr><td>Sufficient number of healthy populations</td><td>Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.</td></tr>
</table>

CHAPTER 3. FACTORS INFLUENCING VIABILITY

In this chapter we describe multiple factors (positive and negative) that affect bog buck moths at the individual and population levels. We considered a wide range of factors (table 3.1) and focus our discussion on those that are known or are likely to have population-level impacts. The number and location of populations affected and degree of influence of these factors determine their impact on the species as a whole, across the species' range, and within any unique environmental settings or genetic lineages.

Table 3.1. Factors influencing bog buck moth viability at the individual and population levels.

Factor	**Individual**	**Population**
Inherent factors	X	X
Habitat alteration *from:* Temperature changes Water levels Invasive plants and succession Nutrient input	X	X
Flooding	X	X
Parasitoids	X	X
Predation	X	?
Disease	X	?
Pesticides	?	?
Conservation actions	?	?

The primary factors currently influencing bog buck moth population health are inherent factors (e.g., narrow habitat niche) and several external factors resulting in loss or alteration of habitat or directly influencing demographic rates (figures 3.1). In chapter 4 we describe how these factors influence the current condition of the species. In chapter 5 we discuss plausible future scenarios for these or additional factors, the anticipated response of the impacted populations and the species viability.

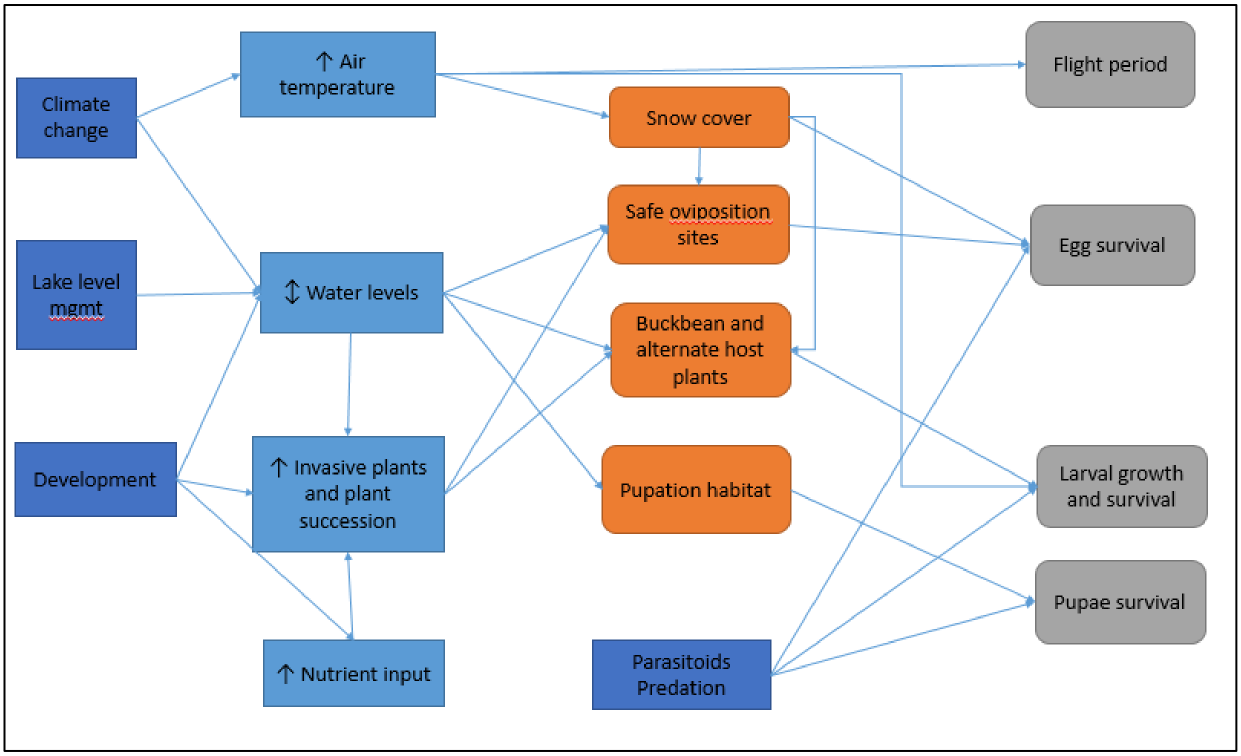

Figure 3.1. Primary extrinsic factors influencing bog buck moth population health (resiliency).

3.1 Inherent Factors

The main reason for the uneven distribution of extinction risk among species is likely to be that the intrinsic ecological traits of a species determine how well it is able to withstand the threats to which it is exposed (Cardillo *et al.* 2004, p. 0910; Mattila *et al.* 2008, p. 1). Bog buck moths exhibit several inherent traits that influence population viability, including its specialized habitat requirements and limited dispersal ability (Gradish and Tonge 2011, p. 6). In addition, bog buck moth populations undergo extreme swings (boom and bust cycles) and several sites currently have smaller population sizes than previously documented and are not rebounding.

As discussed in chapter 2, bog buck moths are limited to highly specific habitat of open, calcareous, low shrub fens containing large amounts of buckbean (COSEWIC 2009, p. 10). While there are additional fens meeting these conditions in Canada and New York, none have signs of bog buck moth use. Also as discussed in chapter 2, expected dispersal distances for adult males are just a few kilometers. Due to its limited dispersal capacity and behavior, and lack of finding bog buck moths at any other sites to date, it is unlikely that the bog buck moth will move from its current fen locations to any additional known suitable areas naturally (Gradish and Tonge 2011, p. 6). Females fly little and solely within their fens. Any new bog buck moth colonies (or recolonization of extirpated sites) would require wind-aided dispersal or human-aided relocation of gravid females. While Stanton (2000, p. 16) recaptured females up to 500 m (0.3 mi) away from a previous capture, these females were examined and always found barren (post-oviposition). Although they are probably capable of flying several kilometers, the distance between the Ontario and New York populations stands at approximately 170 km (106 mi), a distance that is highly unlikely for dispersal to occur. Thus, it is unlikely that adults from New York would recolonize any Ontario site lost due to extirpations or vice versa (COSEWIC 2009, p. 19). A general consequence of habitat specialization and limited dispersal capacity, either in isolation or combined with these threats, is the potential loss of genetic diversity within populations of the species (Gradish and Tonge 2011, p. 6). Genetic exchange between Canadian and U.S. populations probably does not currently occur and is probably impossible even between the two Canadian populations located ~50 km (31 mi) apart (COSEWIC 2009, p. 18).

Species that experience marked population fluctuations, particularly those where populations "crash" periodically, are particularly vulnerable to extreme weather events and or climate variability during crashes (Foden *et al.* 2018, p. 10). As discussed in chapter 2, bog buck moth populations are documented to undergo considerable fluctuations. When they are at the smaller end (crash or bust) of the cycle, small population size puts sites at greater risk of extirpation from stochastic events (e.g., periodic flooding, summer drought).

In addition, smaller populations of any wildlife species may have reduced genetic diversity and low genetic diversity is documented within the bog buck moth (Dupuis *et al.* 2020, pp. 3-4). Genetic drift[6] occurs in all species, but is more likely to negatively affect populations that have a smaller effective population size[7] and populations that are geographically spread and isolated from one another.

Foden *et al.* (2018, entire) describe methods for assessing species vulnerability to effects of climate change including seven attributes associated with a given species' sensitivity to climate change. For at least six of these attributes, the bog buck moth appears highly sensitive given its: specialized habitat requirements, dependence on appropriate climatic conditions for various life stages, dependence upon a specific host plant, rarity of populations, and existing exposure to other threats. Similar methods have previously been employed by NatureServe looking at the likelihood of exposure to changes and sensitivity to those changes (Young *et al.* 2015, entire) and using a slightly earlier version of the 2015 NatureServe guidelines, New York populations of the bog buck moth were ranked as "extremely vulnerable" to climate change (Schlesinger *et al.* 2011, p. 42). Extremely vulnerable species are those defined as having abundance and/or range extent within the geographical area assessed as extremely likely to substantially decrease or disappear by 2050 (Schlesinger *et al.* 2011, p. 3). Factors that led to this assessment ranking included low dispersal ability of adult females, species dependence on a seasonal hydrologic regime, dependence on a specific geology, susceptibility to mortality with flooding during some life stages, and reliance on bog buckbean as a food requirement during the larval stage.

3.2 Habitat Alteration

In addition to the inherent factors discussed above, the primary factor influencing bog buck moth population health is availability of quality habitat for all life stages. As discussed in above and in chapter 2, bog buck moths are found in medium fens. Medium fens are listed as S2S3 (imperiled or vulnerable) in New York ([NYNHP 2020b, p. 2). Threats to medium fens include

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[6] The variation in the relative frequency of different genotypes in a small population, owing to the chance disappearance of particular genes as individuals die or do not reproduce.
[7] The number of individuals in a population who contribute offspring to the next generation.

development, recreational overuse, habitat alteration in the adjacent landscape, and hydrological change (NYNHP 2020b, p. 3). Fens are especially sensitive to relatively small changes in hydrology (van Diggelen *et al.* 2006, p. 159). The NYNHP (2020, p. 3) found that several medium fens in New York are threatened by invasive species, such as purple loosestrife (*Lythrum salicaria*), reed grass (*Phragmites australis*), and buckthorn (*Rhamnus* spp.) (NYNHP 2020, p. 3). These identified threats have or are occurring at fens used by the bog buck moth. Gradish and Tonge (2011, p. 6) described the biggest threat to the bog buck moth as habitat change. For the purposes of this report we organized habitat alteration by the primary sources of changes in water levels and changes in vegetation. We also include brief discussions on other possible sources.

3.2.1 Change in Water Levels

Water level changes can directly kill individuals (e.g., flooding of pupae) or result in changes in habitat suitability and availability. Flooding can result in reductions in suitable oviposition sites, larval food sources and shelter, or pupation sites (figure 3.2).

Water level management – Canadian populations

In Canada, the most significant threat to the buck moth is habitat degradation either due to alteration of water regime within the species' habitat or the invasion of habitat by nonnative plant species (COSEWIC 2009, p. 18; Environment Canada 2015, p. 7). Both the northern and southern White Lake subpopulations are influenced by manipulation of the White Lake outlet dam in the town of White Lake (C. Schmidt, pers. comm), and large fluctuations may cause mortality (COSEWIC 2009, p. 18). Environment Canada (2015, p. 7) suggests that alteration of the water regime can be mitigated or avoided through appropriate water management policies, actions, and land stewardship techniques; however, there were no clear prescriptive actions provided. The Strategy for the Bogbean Buckmoth in Ontario (Ontario Recovery Strategy) includes recovery actions to understand the specific hydrology of Richmond Fen wetlands and the White Lake wetlands and to work with stakeholders to mitigate impacts from land use change, particularly water level manipulation at White Lake (Gradish and Tonge 2011, pp. 12-13). We have no information to suggest these actions have been initiated to date, and Ontario's 5-year review of the bog buck moth (OMNR 2017, pp. 11-17) does not mention anything about these specific actions. However, through regulation, Ontario formally designated "habitat"[8] for the bog buck moth[9] in 2014 (Environment Canada 2015, p. 9). Environment Canada then adopted the description of bog buck moth "habitat" as "critical habitat" in the federal recovery strategy (Environment Canada 2015, p. 10). The designation includes a list of activities which alter the fen's water regime as those likely to destroy critical habitat for the buck moth

[8] "habitat" means, (a) with respect to a species of animal, plant or other organism for which a regulation made under clause 56(1)(a) is in force, the area prescribed by that regulation as the habitat of the species, or (b) with respect to any other species of animal, plant or other organism, an area on which the species depends, directly or indirectly, to carry on its life processes, including life processes such as reproduction, rearing, hibernation, migration or feeding, and includes places in the area described in clause (a) or (b), whichever is applicable, that are used by members of the species as dens, nests, hibernacula or other residences; ("habitat")

[9] Ontario Regulation 242/08, section 24.1.1.1 https://www.ontario.ca/laws/regulation/080242#BK54 accessed 7.13.2020

(Environment Canada 2015, p. 17) (appendix B). See section 3.5.1 for more information about Ontario and Canadian laws and regulations.

Water level management – United States populations

Water level management resulted in the extirpation of a Jefferson County, NY population in the 1970s (Bonanno and White 2011, p. 9) by flooding the fen habitat and creating a freshwater marsh. The site is currently being maintained by NYS Office of Parks, Recreation and Historic Preservation as a marsh for flood control, septic system management, and New York State-listed endangered black tern (*Chlidonias niger)* habitat (S. Bonanno, pers. comm.).

The Lakeside population is currently influenced by water levels associated with management of Lake Ontario through regulation of the Moses-Saunders hydroelectric dam and precipitation events. The St. Lawrence River is located at the northeast end of Lake Ontario and is the natural outlet for the Great Lakes. Approximately 160 km (100 mi) downstream from Lake Ontario are the structures used to control the flow from Lake Ontario, most of which is used by the Moses-Saunders powerhouses (IJC 2014, p. 4). The International Joint Commission (IJC) and its International Lake Ontario-St. Lawrence River Board oversee management of these flows. The IJC is guided by the Boundary Waters Treaty, signed by Canada and the United States in 1909. The treaty provides general principles, rather than detailed prescriptions, for preventing and resolving disputes over waters shared between the two countries and for settling other transboundary issues.

The Lake Ontario water level changes in response to the difference between the supply it receives and its outflow. The supply is uncontrolled, and the use of the Moses-Saunders Power Dam to change outflow provides some control over Lake Ontario water levels but there are limits to the amount of water that can be released (IJC 2014, p. 5). Most of the episodic changes in Great Lakes water levels over the past century are attributable to corresponding changes in annual precipitation (Gronewold and Stow 2014, p. 1084). Prior to the construction of the dams on the St. Lawrence River, recorded lake levels of Lake Ontario from 1860 to 1960 show a pattern of variation with highs and lows captured within each decade or so (Wilcox *et al.* 2008, p. 302). The historical range of monthly average water levels was more than 1.8 m (6 ft) between low and high levels and the IJC recommended regulating within a narrow 1.2-m (4-ft) target from April to November (IJC 2014, p. 8). This has resulted in compressing the range of Lake Ontario water levels to 0.7 m (2.3 ft) from 1.5 m (5 ft) (Wilcox *et al.* 2008, p. 302) (figures 3.2, 3.3). The IJC (2014, p. 43) found that regulation of Lake Ontario has restricted the natural fluctuation of its water levels, both in terms of reducing its extremes and year-to-year variability.

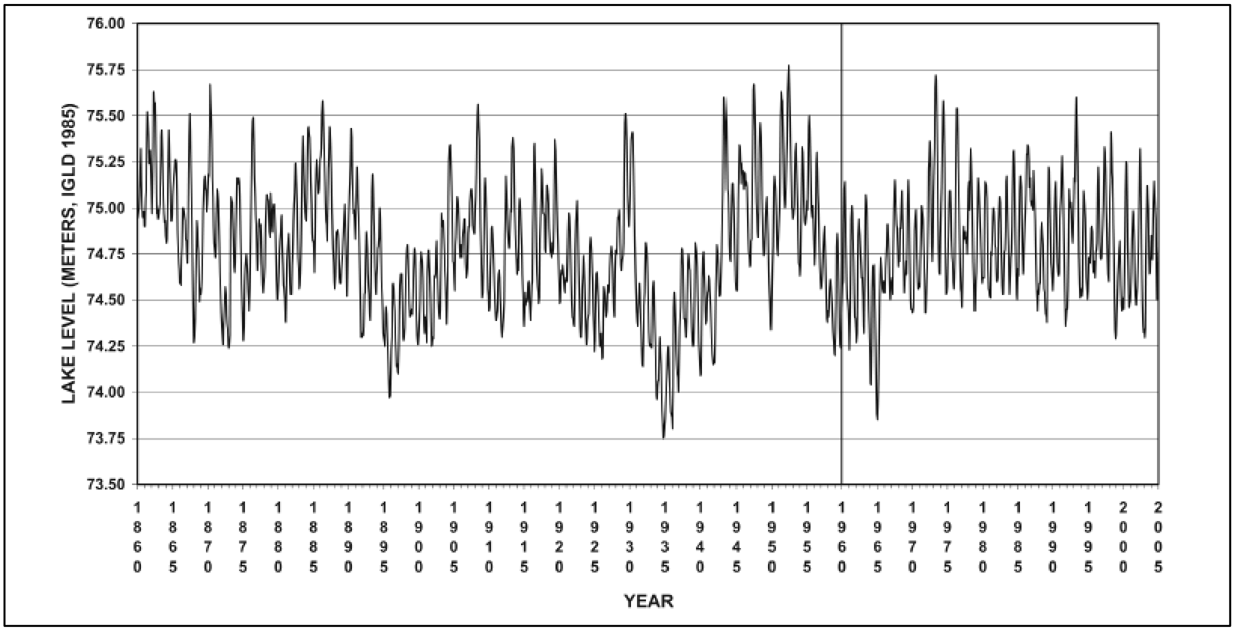

Figure 3.2. Hydrograph of Lake Ontario (1860 to 2005). Vertical line denotes initiation of regulation in 1960 (Wilcox *et al.* 2008, p. 302, figure 1).

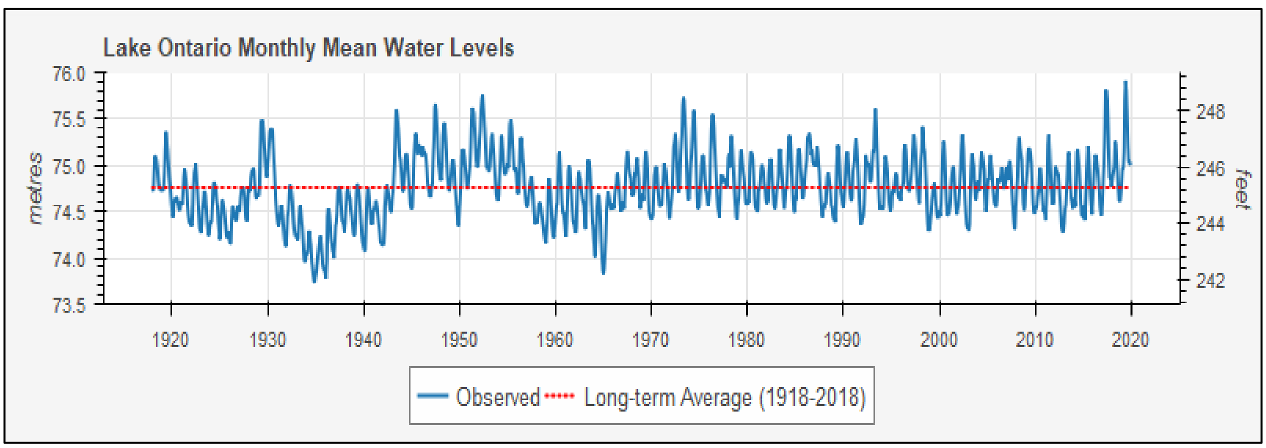

Figure 3.3. Hydrograph of Lake Ontario (1918 to 2018) (International Lake Ontario - St. Lawrence River Board [ILOSLRB 2019, p. 6, figure 4]).

The existing shoreline vegetation of the Great Lakes depends on regular fluctuation in water levels (Keddy and Reznicek 1986, p. 35). Fluctuating water levels increase the area of shoreline vegetation and the diversity of vegetation types and plant species (Keddy and Reznicek 1986, p. 35). High lake levels periodically eliminate dense-canopy emergent plants, and low lake levels allow less competitive understory species to grow (Keddy and Reznicek 1986, entire; Wilcox *et al.* 2008, p. 301).

Stabilization of Lake Ontario water levels after the construction of the Moses-Saunders Power Dam may have subsequently increased cattail (*Typha spp.*) dominance (Rippke *et al.* 2010, p.

814). Specifically, lack of low lake levels shifted the competitive advantage to the taller cattails resulting in loss of large expanses of sedge/grass meadows[10] (Wilcox *et al.* 2008, p. 316). The IJC (2014, p. 43) found that the compressed lake level range has allowed trees and shrubs to grow closer to the water, and cattails and other emergent plants that tolerate persistent flooding to expand their range up the shoreline, reducing the sedge meadow plants that occurred in between. Increased cattails have been documented at Lakeside bog buck moth subpopulations including Lakeside 3 and Lakeside 4 (S. Bonanno, pers. comm; Sime 2019, p. 38). These changes in vegetation from *Carex spp.*, sweet-gale, herbs, and shrubs to cattail marsh result in overall habitat loss through permanent reductions in the amount of suitable oviposition sites, larval food sources, and pupal habitat.

In addition to the construction of the Moses-Saunders Power Dam, there are other sources of increased cattail marsh expansion along the Lake Ontario shoreline. Based on analyses of pollen from core samples, this succession was likely initially related to European settlement and associated land use changes with increased land-clearing and agriculture (Rippke *et al.* 2010, p. 814). Another factor that may have caused changes in cattail dominance in this area is the arrival of *Typha angustifolia*, concurrent with the increase in agriculture (Rippke *et al.* 2010, p. 813). *Typha angustifolia* may have been present in North America prior to European settlement, but was not widespread and mostly found in New England (Shih and Finkelstein 2008, pp. 11-12). There is evidence that *T. angustifolia* came from Europe (Ciotir *et al.* 2013, pp. 1382-1387) and is thought to have migrated into the Great Lakes region along canals, railroads, and roadside ditches in the late 1800s, breeding with *T. latifolia* as it moved west, resulting in the hybrid *T. x glauca* (Grace and Harrison 1986, p. 370; Rippke *et al.* 2010, p. 813). All three *Typha* display invasive tendencies in disturbed wetlands (Shih and Finkelstein 2008, p. 14). Increased *T. x glauca* was observed at bog buck moth sites along Lake Ontario after new residential development took place (S. Bonanno pers comm.).

As of December 2016, a new plan (Plan 2014 [IJC 2014, entire]) was implemented to regulate Lake Ontario-St. Lawrence River water levels and flows. The objective of Plan 2014 is "to maintain beneficial uses for the key water-using interests while returning the Lake Ontario-St. Lawrence River system to a more natural hydrological regime, thereby helping to restore coastal and riverine ecosystems" (IJC 2014, p. 20). Plan 2014 is intended to allow for more frequent low and more frequent high Lake Ontario water levels that would expand meadow areas periodically (IJC 2014, pp. 43-44) by setting back succession.

In addition to changes in vegetation discussed above, water levels can directly impact survival of bog buck moth in various life stages. The Lakeside population includes sites that have been described as physically "protected wetlands" located behind sandbars and connected to Lake Ontario by intermittent or indirect surface water openings or ground water (Vaccaro *et al.* 2009, p. 1038). Water levels in these sites are greatly influenced by precipitation and highly variable depending on their unique connection to Lake Ontario (Vaccaro *et al.* 2009, p. 1045). Barrier beaches along Lake Ontario restrict flow out of the wetlands, causing water levels to rise sharply

[10] While Wilcox did not sample coastal fens, he did sample less complicated systems of sedge/grass meadows. Sedge meadows and medium fens are similar ecological communities in the category of "open peatland" which are peatlands with less than 50 percent canopy cover of trees (Edinger *et al.* 2014, p. 55). The medium fens that bog buckmoths use will similarly benefit from reduced cattails and increased sedges.

in response to local precipitation events in the "protected wetlands" (Vaccaro *et al.* 2009, p. 1045). These sharp rises can result in flooding events. Though flood events may be related to water level management, they are more strongly connected to precipitation events (Gronewold and Stow 2014, p. 1084) and are further discussed below in the "compounding effects from climate change" subsection.

In addition to the larger scale water level management of Lake Ontario, more localized water level management may influence bog buck moth sites. Water levels may be influenced by impoundments (human or beaver) or roads that restrict flow into or out of the fens. Restriction of flow into fens results in drying of sites and increases in shrubs. Taller shrubs shade out buckbean reducing optimal larval host plants.

One example of localized water level influences is the impact of a road at Lakeside 1 and Lakeside 2. Historically connected, these two sites have become isolated from one another, due in part to the construction of a road in the mid-1950s (Bonanno 2006, p. 8). In addition, the Lakeside 1 fen may have become isolated from its groundwater source to some extent, by an impoundment south of a road (Bonanno 2006, p. 8). Despite new culverts installed across the road resulting in improved water flow from Lakeside 1 to Lakeside 2, beaver are maintaining the impoundment south of Lakeside 1 resulting in the drying of the fen (Bonanno 2014, p. 5). Fen habitat contracted from 6 to 2 ha (15 to 5 ac) at the Lakeside 1 and 32.4 to 24.7 ha (80 to 61 ac) at Lakeside 2 from 1998 to 2001 (Olivero 2001, p. 10). This was corroborated with personal observations by Bonanno (2014, p. 6), who found that vegetation in Lakeside 1 was succeeding to a black spruce-tamarack bog forest with deep sphagnum, taller shrubs, and scarce buckbean. At Lakeside 2, Bonanno (2014, p. 5; 2015, p. 7; 2016, p. 8) noted succession to the point where significant habitat restoration would be needed.

The kind of rapid vegetation succession observed at both Lakeside 1 and Lakeside 2 has been observed at other fens (not bog buck moth sites) in the United States. At a site in Ohio, woody plant cover increased almost 1 percent per year from 1938 to 1997 even with attempts at management (Barry *et al.* 2008, p. 401). They suggested one reason for an increase in woody plants in managed fens is that intensity of control efforts can be limited by funding (Barry *et al.* 2008, p. 401).

Water levels on Lake Ontario have no direct effect on the Oswego Inland Site population, and we are unaware of any smaller scale water level management at this site; however, temperature, precipitation, and evaporation potential will impact hydrology (Stanton 2004, p. 11) (see "compounding effects of climate change" section below).

Compounding effects of climate change

While there are many possible effects to bog buck moths from climate change, here we focus on observed changes in precipitation to date resulting in increased flooding risk. We discuss additional predicted changes in chapter 5.

As discussed above, Lake Ontario water levels naturally fluctuate within and among years; however, record high water levels have recently occurred resulting in impacts to bog buck moth sites. Between 1951 and 2017, the total precipitation with the Great Lakes Basin increased by approximately 14 percent with heavy precipitation events increasing by 35 percent (Great Lakes Integrated Sciences + Assessments [GLISA] 2019[11], entire). After 15 years of below-average water levels on Lake Superior and Lake Michigan-Huron, water levels of the upper Great Lakes started rising in 2013, and have been well above-average for several years (ILOSLRB 2020, p. 7). With all of the Great Lakes above or near record-highs, this represented an unprecedented volume of water in the Great Lakes system that is funnelled into Lake Ontario and out the St. Lawrence River (ILOSLRB 2020, p. 7) resulting in the Lakeside population fens being vulnerable to flooding for an extended period of time. Flooding that negatively impacts bog buck moths can be described as longer duration flooding, as long-term flooding of bog buck moth fens submerges vegetation and makes the site unsuitable for most life stages and may directly kill individuals. However, periodic flooding that is shorter in duration helps maintain habitat suitability.

Two high water events across the entire Great Lakes basin caused by above-normal precipitation (record-breaking January to May 2017 and high precipitation in November 2018 through May 2019) compounded the already high water levels (ILOSLRB 2020, pp. 6-9) in the Great Lakes basin. These events took place while bog buck moths were in the egg stage (see table 2.1 for life history timing). Bonanno (2015, p. 7) noted that Lakeside 3 and Lakeside 4 are subject to the greatest amount of hydrologic variability of all New York sites given their proximity to a creek. Flooding was documented at Lakeside 3 after the 2019 event (Bonanno 2019, pp. 5-6) and at Lakeside 5 after both the 2017 and 2019 events (Bonanno 2017, pp. 3, 7; 2019, p. 3). As discussed in section 2.4, bog buck moth eggs can tolerate short-term submersion but are not viable after long-term flooding events. In 2017, all of Lakeside 5 was flooded to depths approaching 2 ft (0.6 m) above normal, but the duration of the flooding apparently varied between the two sections of the fen, with a high water mark still clearly visible in September in the west fen and more subtle markings in the east fen (Bonanno 2017, pp. 3, 7). The east fen opening had a good bog buck moth flight after this while the west fen crashed. These openings are separated by a wide band of dense shrubby growth, and this area may have served as a refugium for the population during the flooding event (Bonanno 2017, p.7).

Summary

In summary, water levels may be influenced by human activity, wildlife, or precipitation events and the resulting changes in water levels influence bog buck moth populations directly or alter their habitat. Changes in water levels are a factor for multiple subpopulations in the United States and Canada.

3.2.2 Change in Vegetation

Both invasive species and succession can reduce the amount of available suitable oviposition plants and/or larval host plants (figure 3.2). Invasive species and later successional plants directly compete for space and nutrients or shade out bog buckbean. Stanton (2004, p. 11)

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[11] http://glisa.umich.edu/media/files/GLISA%202%20Pager%202019.pdf. Accessed 6.30.2020.

suggests that changes in the quality or quantity of bog buckbean is a potential cause of documented declines in bog buck moths in New York.

Invasive Species

We evaluated the relative threats posed by invasive understory species and determined that *Typha spp.*, common reed (*Phragmites australis*), and glossy buckthorn (*Frangula alnus*) are currently the primary species that could affect population level dynamics of the bog buck moth. Impacts from increased *Typha spp.* are described in section 3.2.1. Common reed is abundant across the northern hemisphere including most of the United States and the southern portions of Canada (Galowitsch *et al.* 1999, pp. 739-741). Native fen plants like *Myrica gale* are reduced with the presence of common reed (Richburg *et al.* 2001, p. 253).

Glossy buckthorn is a shrub of Eurasian origin that is aggressive in bogs and fens. Drier portions or less frequently inundated sections of wetlands with available hummock surfaces are more readily invaded (Berg *et al.* 2016, p. 1370). Glossy buckthorn displaces or shades out native fen plant species (Fiedler and Landis 2012, pp. 41, 44, 51). Bog buckbean typically does not grow well in shade (Hewett 1964, p. 730); although it can be found in shaded areas of some fens (E. Helquist, pers. comm). Glossy buckthorn transpiration in mid-summer has been shown to lower the water table (Godwin 1943, p. 81) resulting in faster decomposition rates and reduction of hummocks in sites (Fiedler and Landis 2012, pp. 41, 44, 51). Sites with glossy buckthorn also have lower soil pH, although it is unclear whether buckthorn invaded these areas more frequently or created this change (Fiedler and Landis 2012, p. 51).

As stated above (section 3.2.1), in Canada, the most significant threat to bog buck moth populations includes habitat degradation from cattails, common reed, and glossy buckthorn (COSEWIC 2009, p. 18; Gradish and Tonge 2011, pp. 6-7; Environment Canada 2015, p. 7). These plants occur in or adjacent to all Ontario sites and pose an ongoing and future threat of habitat reduction. Environment Canada (2015, p. 7) found that while invasive plant species have been found within or near all four sites where the buck moth is known to occur in Ontario, the risk posed by these species can be assessed regularly through targeted monitoring and, to the extent feasible, invasive plant control employed as appropriate and necessary to help mitigate this threat. Invasive vegetation control would likely require long-term management.

These species are also documented at the U.S. sites. For example, glossy buckthorn makes up a significant portion of the shrubby component at Lakeside 5 and is present at Oswego Inland Site (Bonanno 2006, p. 7; 2013, p. 2). Cattail had been expanding at Oswego Inland Site and Bonanno (2013, p. 2) noted the only obvious change in potential drivers of vegetation was the large expansion of a subdivision along the lakeshore. *Typha angustifolia* encroachment at Oswego Inland Site has been managed sporadically prior to 2016, and annually from 2016 to 2020 (E. Helquist, pers. comm). Other invasive species management projects have also been undertaken at Oswego Inland Site and Lakeside 5; however, invasive plants remain at these sites. In addition, several clones of both the introduced and the native phragmites occur near bog buck moth habitat at Lakeside 3 (Bonanno 2004, p. 9).

Succession

There may be multiple sources of vegetation succession, including natural succession from early successional to late successional plant species, as well as human-induced or accelerated succession from sources such as increased nutrient input (enrichment) and altered wetland hydrology (discussed in section 3.2.1). Here we provide some additional details about nutrient input.

Fens are characterized by a very low supply of N and P (Bedford and Godwin 2003, p. 614) and many fens in New York are degraded by altered hydrology or by nitrate moving in ground water, by phosphate adsorbed to sediment in run-off, or by altered water chemistry caused by development within fen watersheds (Drexler and Bedford 2002, p. 278; Bedford and Godwin 2003, p. 617). Drexler and Bedford (2002, pp. 276-278) observed that nutrient loading of a fen in New York (not a bog buck moth site) resulted in reductions in species richness of both vascular plants and bryophytes and increases in monotypic stands of *Calamagrostis canadensis*, *Carex lacustris*, *Epilobium hirsutum*, and *Typha latifolia*, especially in an area adjacent to a farm field. Dense cover reduces fen biodiversity through direct space competition, or by reducing seedling growth from decreased available light and increased litter layer (Jensen and Meyer 2001, pp. 173-179).

Increased nutrient inputs have been documented at both the Lakeside and Oswego Inland Site populations. For Lakeside, Lakeside 3 and Lakeside 4 are adjacent to an RV campground that may contribute to nutrient enrichment encouraging growth and size of *Phragmites australis*. Lakeside 2 is also subject to surface water inputs from the adjacent pond, Lakeside 1 is surrounded by seasonal camps and an RV campground, and Lakeside 5 is abutted by a very large RV campground. Oswego Inland Site has seen recent residential development along the lake shoreline.

Succession and associated declines in native fen plants has been documented at multiple bog buck moth subpopulations and is discussed in section 3.2.1.

Summary

Changes in fen vegetation associated with invasive plant species and succession can affect entire populations and are a factor for all populations in the United States and Canada. As discussed above, bog buck moth habitat along Lake Ontario has likely been maintained through periodic disturbance associated with water level changes. Other bog buck moth sites have likely been maintained through natural water level changes and the natural continued high water table of fens. However, if the hydrology of a site is altered resulting in a sustained lowered water table, enhanced vegetative succession occurs. The addition of nutrients helps invasive species outcompete native fen vegetation. Both invasive plants and native shrubs shade out native fen plants including the bog buckbean. Repeated vegetation management is likely needed to continue to set back the seral stage and reduce invasive species.

3.3 Parasitoids

Parasitoids are small insects whose immature stages develop within or attached to their host insects. Parasitoids eventually kill their hosts as compared to parasites that typically feed upon hosts without killing them. Most of the known saturniid parasitoids are wasps (Chalcidoidea and Ichneumonoidea) and flies (Tachinidae) (Tuskes *et al.* 1996, p. 24). Most saturniids are attacked during the larval stage, and late instar larvae often suffer heavy losses (Tuskes *et al.* 1996, pp. 25-27). We provide information about saturniids in general and bog buck moths specifically when available, below.

3.3.1 Egg Parasitoids

Stanton (2000, p. 4) reported that nearly all of the bog buck moth egg masses found at Lakeside 1 since 1996 were parasitized by the wasp *Anastatus furnissi* (Burks). For example, in 1997, Stanton (1999, p. 9) observed mortality of 84 percent of egg masses from Lakeside 1 was due to wasp parasitoids. In June 1999, Stanton (2000, p. 12) collected 80 bog buck moth egg masses from Lakeside 2 after the larvae had hatched to assess wasp parasitism. They reported that *A. furnissi* emerged from 36 egg masses (45 percent) which was an increase from 8.7 percent in 1997 (Stanton 1988, p. 9; Stanton 2000, p. 12). Stanton (2000, p. 13) suggested the wasp was the primary mortality factor at Lakeside 2 and Lakeside 1 and possibly Lakeside 5. It has also been documented at Oswego Inland Site (Sime 2019, p. 15). The parasitism rates do not appear to be density-dependent as parasitism levels have been consistent at Lakeside 5 and Oswego Inland Site fens at 25 to 30 percent of egg clusters affected/year since 2009, while bog buck moth populations have undergone dramatic fluctuations in that time period (Sime 2019, p. 15).

3.3.2 Larval Parasitoids

Larval parasitoids are common in *Hemileuca* species (Tuskes *et al*. 1996, p. 103), although there is no documentation of larval parasitoids on bog buck moth to date. Parasitoids can include native and nonnative species, such as the native ichneumonid wasp *Hyposter fugitivus* (Say) and tachinid fly *Leschenaultia fulvipes* (Bigot), and the introduced tachinid fly *Compsilura concinnata* (Meigen).

The accidental introduction of gypsy moths (*Lymantria dispar*) into the United States in 1869 in Massachusetts (USDA 2010, p. 1-2) may impact bog buck moths as measures are taken to control the moth (see USDA 2012, entire for description of various measures). It is now widely established in the Northeast, Great Lakes, and Ontario (USDA 2010, p. B-1) (figure 3.4). In the early 1900s, the United States Department of Agriculture (USDA) began introducing predators and parasitoids of the gypsy moth (from its native range, including *Compsilura concinnata*, a tachinid fly with a very broad host range (Elkinton and Boettner 2012, p. 278).

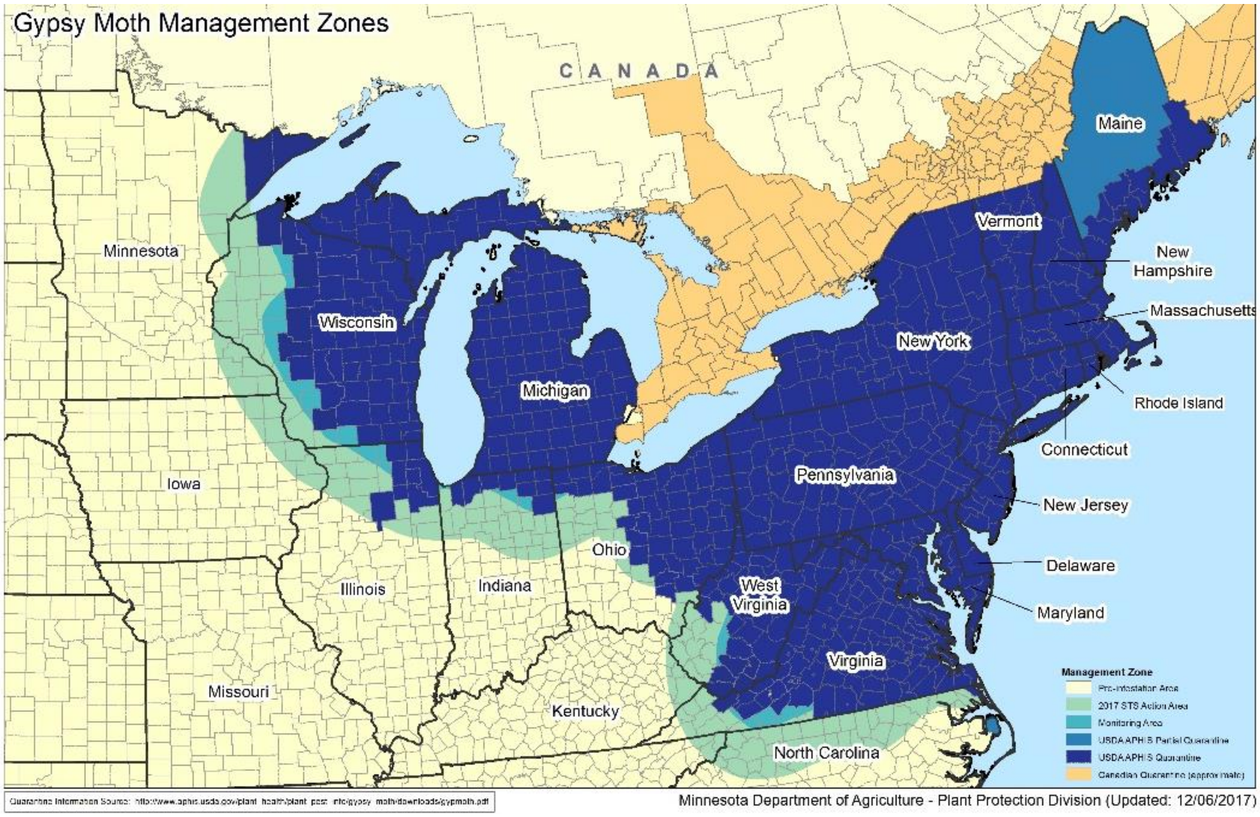

Figure 3.4. North American European gypsy moth (*Lymantria dispar*) management zones. White areas are pre-management zones. Blues are United States monitoring and quarantine zones. Orange is Canadian quarantine zone.
(https://apps.fs.usda.gov/nicportal/gmdigest/map/2018GypsyMothManagementZones_highres.jpg accessed 8/10/2020)

COSEWIC (2009, p. 14) states that "No parasitism of bog buck moth has been reported at Canadian sites, although *C. concinnata* is likely present (M. Wood, pers. comm.)." Parasitism is assumed to be occurring at the Canadian populations (COSEWIC 2009, p. 17). Similarly, while not documented at the bog buck moth sites in the United States, we find they are likely to be susceptible to parasitism from *Compsilura concinnata* and other parasitoids and may be related to observed boom/bust cycles. Bonanno (2016, p. 5) reported the 2016 crash of adult bog buck moths at Oswego Inland Site after abundant larvae of all sizes were observed in May and June and suggested looking further into larval or pupal parasitoids as a possible cause.

If bog buck moths are not killed by predators (see 3.4.1 below) or parasitoids, larval behavior may still be affected by their presence. Early instar larvae tend to stay together and defend themselves while late instar larvae escape leading to increased subdivision of clusters (Cornell *et al.* 1987, p. 387). As discussed in chapter 2, at sites with higher predator or parasitoid densities, larvae likely experience slower growth rates, prolonged development, and reduced body mass (Stamp and Bowers 1990, p. 1037) because they would be forced to forage closer to the center of plants where it is cooler and older leaves are present.

3.4 Other Stressors Considered

3.4.1 Predation

Eggs are susceptible to predation by small mammals and invertebrates and may incidentally be ingested by white-tailed deer (*Odocoileus virginianus*) and rabbits (*Sylvilagus floridanus*) that consume host plant stems (Pryor 1998, p. 136). Pryor (1998, p. 136) and Stanton (1988, p. 9) also observed egg predation from mites.

All *Hemileuca* larvae have spines that can cause welts which may deter some vertebrate predators but provide little to no defense against parasitic flies and wasps (Tuskes *et al*. 1996, p. 103). Vespid wasps such as *Polistes fuscatus* and *P. dominulus* are documented predators of *Hemileuca lucina* larvae (Stamp and Bowers 1988, entire). The wasps killed the larvae and also indirectly affected larval growth rates by changing larval behaviors (Stamp and Bowers 1988, p. 623). Predation on larvae has been observed by true bugs (Hemiptera) in New York (Pryor 1998, p. 136). Buck moth pupae in New York appear to have been heavily preyed upon by beetles (Coleoptera) (Pryor 1998, p. 131). Selfridge *et al.* (2007, pp. 219-220) reported pupal predation by birds, mammals, and/or large insect predators. Adults have been eaten by wasps, spiders, and birds (Pryor 1998, pp. 136-137). Dragonflies may also eat adults (Scholtens and Wagner 1994, p. 204). We do not fully understand the potential impact of predators on bog buck moth populations.

3.4.2 Disease

The Saturniidae are subject to many bacterial, fungal, viral, and protozoan infections (Tuskes *et al.* 1996, p. 28). Selfridge *et al.* (2007, pp. 216-217) observed death of *Hemileuca maia* larvae from *Beauvaria sp.* fungus and a virus. Pryor (1998, p. 131) suggested that late instar bog buck moth larvae could have been killed by hot summer temperatures or nuclear polyhedrosis virus (NPV). Mitchell *et al.* (1985, p. 496) discovered a NPV that is highly virulent in *H. maia* larvae, but larval susceptibility appeared to decline in older larvae. Tuskes *et al.* (1996, p. 29) suggested that pathogens likely have little impact on Saturniidae populations in most years but that cyclic occurrences of epidemic levels may have tremendous impacts on individual populations.

3.4.3 Pesticides

Use of pesticides may result in mortality of nontarget species like the bog buck moth, depending upon the type of chemical, the application method, length of exposure, and the nontarget species' tolerance. Little has been published on the effects of pesticides on nontarget Lepidopterans, especially sublethal effects (Mule *et al.* 2017, p. 4). However, adult and larval butterflies are susceptible to lethal and sublethal effects from pesticide application from direct aerial spraying and from residues on plant foods (Hoang *et al.* 2011, p. 998).

Mosquito Spraying

NatureServe (2020, p. 4) noted that Oswego County sometimes conducts large-scale mosquito spraying. Oswego County recently has used Kontrol 30-30[12], which contains permethrin, a pesticide known to kill a variety of insects including moths. This spraying is conducted to combat eastern equine encephalitis or West Nile virus, and has included the towns of Constantia, West Monroe, Palermo, Mexico and Hastings. The closest town border to any bog buck moth locations is Mexico which is approximately 5 mi (8 km) away. While the consequences of this kind of effort in the vicinity of buck moth populations would be very high, the New York State Department of Environmental Conservation's (NYSDEC) draft bog buck moth recovery plan found the likelihood of the exposure occurring at this time is low (Bonanno and White 2011, pp. 16-17).

Gypsy Moth Spraying

As discussed above, gypsy moth control efforts have been underway since the early 1900s. Control of gypsy moths currently includes aerial spraying. The four approved insecticides used in aerial spraying to eradicate gypsy moth are two biological insecticides *Bacillus thuringiensis* var. *kurstaki* (Btk) and nucleopolyhedrosis virus (Gypchek) and two chemical insecticides diflubenzuron (Dimilin®) and tebufenozide (Mimic®) (U.S. Department of Agriculture [USDA] 2010, pp. G-2). Of these, only Gypchek is known to be nontoxic to nontarget invertebrates, including lepidopterans, because it is a virus that affects only gypsy moths (USDA 2010, p. G-6). Consequently, Gypchek has been recommended for areas where nontarget Lepidopteran species are of special concern (USDA 2010, p. G-6; 2012, p. 2-3). Its use is not limited to "environmentally sensitive areas" but is the preferred use due to limited production (Reardon *et al.* 2016, p. 16). To date, 33,691 acres in New York were treated with carbaryl (Sevin®) in the 1970s and 1980s, 59,748 acres were treated with trichlorfon (Dylox®) in the 1980s, 2,396 were treated with Dimilin in the 1980s, 30,847 acres were treated with Btk, and 2,052 acres were treated with Gypchek.[13,14]

COSEWIC (2009, p. 18) included gypsy moth control in the list of possible threats to bog buck moth and stated that "Lafontaine speculated that spray programs by cottagers to control gypsy moths (*Lymantria dispar*) may have negatively impacted Bogbean Buckmoth populations at location B in the past (Woulfe pers comm.). Gypsy moths are uncommon in the Richmond area so spraying is unlikely there (M. Wood, pers. comm.)."

In North Carolina, Hall *et al.* (1999, p. 53) predicted the overall risk to 11 saturniid moths from Btk ranged from no risk for 7 species to moderate-to-high for 4 species due to some potential for larval exposure; however, no *Hemileuca* species were part of this study. Btk does not persist long on foliage and must be reapplied after rain. Wagner *et al.* (1996, p. 1452) suggested that saturniid moths that hatch a month later (June or later) than gypsy moths, would not likely be impacted by Btk and may benefit from gypsy moth control. Schweitzer (2004, p. 19) similarly suggested that Btk should benefit summer-feeding species and insensitive to moderately Btk-

[12] https://health.oswegocounty.com/programs/environmental1/mosquitoes.php. Accessed 7.14.2020.
[13] https://www.fs.usda.gov/naspf/programs/forest-health-protection/gypsy-moth-digest accessed 8/10/2020
[14] https://www.fs.usda.gov/naspf/programs/forest-health-protection/gypsy-moth-digest accessed 8/10/2020

sensitive spring species by preventing heavy defoliation and parasitoid buildup. However, he found that species such as *Hemileuca maia* would be 100 percent at risk as first or second instars, and that *H. maia* were highly sensitive in the lab assays (Schweitzer 2004, p. 31). He further stated that "Except for *Hemileuca maia* (which is highly sensitive to BTK), no other eastern U.S. forest Saturniidae would have high exposure within a week (or often even a month) of typical single gypsy moth suppression applications" (Schweitzer 2004, p. 38).

Diflubenzuron is a chitin inhibitor and is lethal to larvae of most arthropods that ingest it (Schweitzer 2004, p. 12). It is considered a contact insecticide, but most research suggests that this is not a major source of nontarget mortality in applications aimed at gypsy moth and that ingestion is clearly the major source of mortality to most terrestrial organisms and aquatic leaf shredders (Schweitzer 2004, p. 35). Diflubenzuron is known to remain on leaves until after leaf fall and will sometimes remain in leaf litter for a second year (Schweitzer 2004, p. 35).

Other Pesticides

Neonicotinoids are a class of insecticides that are poorly studied in terms of impacts to butterflies and moths. Neonicotinoids were developed in the 1980s and have rapidly become one of the most widely used insecticides in the world (Goulson 2013, p. 978). Neonicotinoids are applied via seed coating, foliar spraying, or in irrigation water. As seeds germinate, the insecticide is incorporated into the plant and distributed systemically during growth (Miles *et al.* 2017, p. 2). This process is facilitated by the high water solubility of neonicotinoids (Bonmatin *et al.* 2015, p. 47). Nontarget areas at a distance from agricultural fields may be exposed to neonicotinoids by transportation through water courses (Gilburn *et al.* 2015, p. 3). Gilburn *et al.* (2015, pp. 5–7) modeled potential impacts on population indices for 17 common butterflies in English agricultural landscapes; there was a strong negative correlation with neonicotinoid use, meaning that butterfly abundance decreased as number of hectares treated with neonicotinoids in the previous year increased. In California, there is a significant association between declining butterfly populations and increasing neonicotinoid application, while controlling for the variables of land use and other factors (Forister *et al.* 2016, pp. 3–4). Additional studies are needed to understand the full extent of the toxicity of neonicotinoids to butterflies (Gilburn *et al.* 2015, p. 9).

Summary

In summary, insecticide application has the potential to result in population level effects where bog buck moth populations are exposed to drift from intended application locations or through water courses. Additional information is needed to determine where this may be occurring throughout the range. The Ontario Recovery Strategy includes a recovery action to address the potential threat of pesticides (Gradish and Tonge 2011, p. 12). The recovery action is listed as:

Determine what/if any insecticide applications are affecting Ontario Bogbean Buckmoth populations.

- Ensure the industry and landowners are aware of the species, legal implications and the potential threats caused by aerial spraying.
- Establish spray buffer areas around extant sites.

3.4.4 Habitat Loss due to Development

All subpopulations in New York occur on protected lands owned by the State of New York or conservation organizations and are secure from direct habitat loss from development. While development has not directly significantly impacted the four known sites in Canada, a railway that cuts through Richmond Fen North (Richmond Fen) has caused minor loss (less than 2 ha [5 ac]) of fen habitat and altered the water regime at that site (COSEWIC 2009, p. 12). In addition, a snowmobile trail, in Richmond Fen South (Richmond Fen) caused localized changes in fen vegetation (COSEWIC 2009, p. 12). Because the Canadian populations of buck moths are now protected through critical habitat designation (see 3.5 below), habitat loss due to development is no longer a threat to those populations.

3.4.5 Vegetation Management

Because bog buck moths depend on early successional open fen habitats, maintenance of these habitats are key to the species' conservation and other rare species that may co-occur with the bog buck moth. However, mortality to individual bog buck moths from trampling their habitat may be unavoidable in known occupied sites when conducting land management activities because bog buck moths are present year round within host plant patches. The degree of mortality on the life stages involved (egg, larvae, pupae, and adult) will depend on the type, timing, and scope of the activities being conducted. The Service and NYSDEC have funded vegetation management projects to remove glossy buckthorn at Lakeside 5 and Oswego Inland Site and control cattail at Oswego Inland Site. At Oswego Inland Site, researchers have employed measures to minimize impacts to bog buck moths by conducting hand cutting of cattails, avoiding herbicide use and conducting cutting before larvae emerged in key areas (E. Helquist, pers. comm.).

Vegetation management via herbicide application may also reduce the viability and survivability of Lepidopterans by reducing food plant quality (Stark *et al*. 2012, p. 27). Targeted herbicide application can be important for vegetation control, which preserves habitat conditions required by various species of Lepidoptera. However, even if applied in a targeted manner, certain herbicides have also been shown to have lethal and sublethal effects on butterflies and moths through contact via dermal and digestive routes (Russell and Schultz 2010, p. 53). We are unaware of any research specifically studying the effects of herbicides or vegetation management on the bog buck moth.

3.4.6 Herbivory

Eggs may be incidentally ingested by animals that consume host plant stems. In addition, a number of invertebrate herbivores are known to specialize on bog buckbean including the Aweme borer (*Papaipema aweme*) (Johnson *et al.* 2017, pp. 205-209) found in Richmond Fen in 2020 (C. Schmidt, pers. comm.). However, at this time we have no information to suggest herbivory of host plants resulting in reduced habitat availability is an important factor.

3.4.7 Host Plant Disease

Plant diseases affecting buckbean may reduce individual plant's food quality to bog buck moths or render areas unsuitable for bog buck moths to complete their life cycle, both of which could result in larvae mortality or reduced adult fecundity. We are unaware of any studies linking host plant disease to impacts to the bog buck moth; however, healthy host plants are an important need for this species. We have no information to suggest host plant disease is an issue.

3.4.8 Changes in Temperature and Snowpack

While there are many possible effects to bog buck moths from climate change, here we explore the potential for impacts from ongoing changes in temperature and snowpack. We discuss additional predicted changes in chapter 5, primarily as they are related to changes in water level.

The Ontario Ministry of the Environment (2011, p. 1) reported the average temperature in Ontario has gone up by as much as 2.5 °F (1.4 °C) since 1948. Similarly, between 1951 and 2017, the average annual temperature in the Great Lakes Region has increased by 2.3 °F (1.3 °C) (GLISA 2019, entire). We have no detailed studies to assess whether observed declines in bog buck moth counts at the U.S. populations are related to these increased annual temperatures. However, seasonal changes in temperature can influence the form of precipitation in winter and snowpack (see below), and shifts in phenology. For example, the timing of fall flights may be shifting to later in September. Bog buck moth monitoring windows have been September 12 to 26 at The Oswego Inland Site and September 18 to October 1 at the lakeshore sites since surveys began and in recent years there has been little or no activity near the beginning of the survey window Bonanno (2019, pp. 1-2).

Throughout the Great Lakes Basin, average winter minimum and maximum temperatures increased from 1960 to 2009 by 3.24 and 1.98 °F (1.8 and 1.1 °C), respectively (Suriano *et al.* 2019, pp. 6-8). Increased winter temperatures are associated with decreases in Great Lakes ice cover and increases in winter precipitation occurring as rain. The extent and duration of lake ice on the Great Lakes are two of the principal factors controlling the amount of lake-effect snow (provided the air temperatures are sufficiently cool). When large areas of the lakes are covered with ice, the moisture cycle that generates lake-effect snow systems is greatly diminished (Brown and Duguay 2010, p. 692). During the first half of the 20th century there was an increase in snowfall in the Great Lakes Basin; however, recent studies have shown a decline through the latter half of the 20th and early 21st century (Baijnath-Rodino *et al.* 2018, p. 3947). Similarly, Suriano *et al.* (2019, p. 4) found a reduction in snow depth in the Great Lakes Basin of approximately 25 percent from 1960 to 2009. Trends during this timeframe are variable by subbasin and there were no significant trends for the Lake Ontario sub-basin (Suriano *et al.* 2019, p. 5). At a finer scale (1 degree latitude by 1 degree longitude grids), there were also no significant changes observed for snow depth or snowfall for the grid along Lake Ontario that includes the bog buck moth sites, but there was a significant increase of the number of ablation events (i.e., snow mass loss from melt, sublimation, or evaporation) (Suriano *et al.* 2019, pp. 6-7). These events are associated with rapid snow melt and often lead to localized flooding. There were also significant increases in average annual minimum and maximum temperatures for this grid cell (Suriano *et al.* 2019, p. 7).

There is limited research available on the impacts of bog buck moth associated with the presence, depth, and duration of winter snow. One student paper reported a strong correlation between winter precipitation and buck moth counts the following fall (Serra 2003, pp. 5-8), but she did not have site-specific information and relied on weather stations from nearby cities. The presence of a consistent seasonal snowpack can prevent freeze-thaw cycles. While bog buck moths overwinter in the egg stage which is less vulnerable to freezing than other life stages, they may also periodically overwinter in the pupal stage which would be vulnerable to these cycles. Their egg-clustering habit may decrease the amount of egg surface exposed to ambient conditions and reduce the possibility of desiccation (Stamp 1980, p. 369). However, eggs that are not covered by snowpack are exposed to increased risk of predation (see above).

Increased temperatures in winter and early spring may lead to earlier egg hatch. As temperatures have increased, many insects have been emerging earlier (temperature-induced emergence) (Patterson *et al.* 2020, p. 2), resulting in phenological mismatch with host plants. For example, Karner blue butterfly (*Lycaeides melissa samuelis*) larvae hatched earlier than its host plant, wild blue lupine (*Lupinus perennis*), after unseasonably warm late winter temperatures (Patterson *et al.* 2020, p. 6). Similar to the Karner blue butterfly, bog buck moth early instar larvae rely on specific host plants and are at greater risk of impacts from phenological mismatch than species with wide host plant usage. Earlier spring hatch followed by subsequent spring freezes also increases the risk of mortality of early instar larvae.

Overall, interacting changes in temperature and precipitation are highly influential in terms of flooding or drying out bog buck moth sites. There may be additional compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack but we lack sufficient information on those potential relationships.

3.4.9 Landscape Context

The landscape surrounding bog buck moth sites can impact bog buck moth viability. For example, the ability of the bog buck moth to disperse to other sites whether to repopulate extirpated sites or explore newly found habitat is limited by the lack of additional suitable fens (stepping stones) in the surrounding landscape. As discussed in section 3.1, due to its limited dispersal capacity and behavior and lack of finding bog buck moths at any other sites to date, it is unlikely that the bog buck moth will move from its current fen locations to any additional known suitable areas naturally. In addition, there are few currently suitable fens known to begin with. This has likely been exacerbated over time with loss of suitable habitat between sites.

Activities conducted near bog buck moth sites (e.g., development, agriculture, roads) may indirectly impact bog buck moth habitat suitability through changes in surface or subsurface hydrology or nutrient or contaminant inputs. Examples are provided in the change in water levels, change in vegetation, and pesticide sections above. While landscape context is alluded to several times, it is important to keep this overall component in mind as a potential driver of bog buck moth site suitability, as it may be important to focus conservation efforts in areas outside of the immediate fen habitat.

3.5 Ongoing Conservation Efforts

3.5.1 Canadian Efforts

Listing

The bog buck moth[15] was listed as endangered by COSEWIC in 2009 (COSEWIC 2009, entire). It was listed as endangered under the Ontario Endangered Species Act[16] in 2010. Section 9(1) states that: (1) No person shall, (a) kill, harm, harass, capture or take a living member of a species that is listed on the Species at Risk in Ontario List as an extirpated, endangered or threatened species; (b) possess, transport, collect, buy, sell, lease, trade or offer to buy, sell, lease or trade, (i) a living or dead member of a species that is listed on the Species at Risk in Ontario List as an extirpated, endangered or threatened species, (ii) any part of a living or dead member of a species referred to in subclause (i), (iii) anything derived from a living or dead member of a species referred to in subclause (i); or (c) sell, lease, trade or offer to sell, lease or trade anything that the person represents to be a thing described in subclause (b) (i), (ii) or (iii). 2007, c. 6, s. 9 (1). The bog buck moth was listed as endangered on Schedule 1 of the Species at Risk Act in 2012. This provided the bog buck moth protection from being killed, harmed, harassed, captured, or taken in Canada.

Recovery Planning and Implementation

The Ontario Ministry of Natural Resources and Forestrty (OMNRF) published a recovery strategy for the bog buck moth on December 7, 2011 (Gradish and Tonge 2011, entire). In 2012, the OMNRF issued a response[17] to the scientific advice provided in the recovery strategy (OMNRF 2012, entire). As stated in the response, the government will focus its support on these high-priority actions over the next 5 years:

1. (High Priority) Develop and implement a standardized inventory and monitoring program for Bogbean Buckmoth at occupied and unoccupied sites with suitable habitat to determine current population numbers and trends.
2. (High Priority) Assess the risk posed to Bogbean Buckmoth by invasive species (e.g., Narrow-leaved Cattail, European Common Reed) and, where appropriate, implement invasive species control within and adjacent to occupied fen ecosystems.
3. Evaluate the hydrology of Bogbean Buckmoth wetland habitat, determine the species' tolerance to ranges of fluctuation in water levels, and identify watershed management options that may mitigate harmful impacts.
4. Determine the extent to which suspected threats, such as insecticide applications are impacting Bogbean Buckmoth.
5. As opportunities arise, support the securement of habitat of Bogbean Buckmoth through existing land securement and stewardship programs.

[15] Called Bogbean Buckmoth in Canadian reports
[16] https://www.ontario.ca/laws/statute/07e06. Accessed 7/13/2020.
[17] https://www.ontario.ca/page/bogbean-buckmoth-government-response-statement. Accessed 7.13.2020.

In 2017 the OMNRF published a 5-year review of progress towards the protection and recovery of the bog buck moth[18] (OMNRF 2017, pp. 11-17). Initial progress has been made towards the action:

- Develop and implement a standardized inventory and monitoring program for Bogbean Buckmoth at occupied and unoccupied sites with suitable habitat to determine current population numbers and trends (Action No. 1; High Priority).

  This action has been implemented, in part, through a multi-species survey and monitoring project supported by the Species at Risk Stewardship Fund that included the bog buck moth. Surveys for the species were conducted in suitable habitat, and while no moths were found, the results contribute to our knowledge of where the species is known to occur.

Initial progress has been made towards the action:

- Assess the risk posed to Bogbean Buckmoth by invasive species and, where appropriate, implement invasive species control within and adjacent to occupied fen ecosystems (Action 2; High Priority).

  Initial progress towards this action has been implemented through the government-led Ontario Invasive Species Strategic Plan and *Ontario's Invasive Species Act* that provide the policy and legislative framework for the prevention, detection, response and management goals for Ontario.

Environment Canada (2015, entire) produced the federal recovery strategy for the bog buck moth consisting of three parts based on the cooperation between the federal government and Province of Ontario:

- Part 1 - Federal Addition to the *Recovery Strategy for the Bogbean Buckmoth (*Hemileuca *sp.) in Ontario*, prepared by Environment Canada (Environment Canada 2015, entire).
    - Environment Canada's population and distribution objective for the Bogbean Buckmoth in Canada is to maintain current population abundance and distribution of the species in Ontario and encourage the natural expansion of the species into suitable but currently unoccupied habitat within its current range in Ontario.
- Part 2 - *Recovery Strategy for the Bogbean Buckmoth (*Hemileuca *sp.) in Ontario*, prepared by A. Gradish and M. Tonge for the OMNRF (Gradish and Tonge 2011, entire).
    - The recovery goal is to sustain current populations and distributions of Bogbean Buckmoth at extant locations, and to expand populations into suitable, but currently unoccupied habitat within its current range in Ontario.
- Part 3 - *Bogbean Buckmoth Ontario Government Response Statement*, prepared by the Ontario Ministry of Natural Resources[19] (OMNRF 2012, entire).

[18] https://www.ontario.ca/document/five-year-review-progress-towards-protection-and-recovery-ontarios-species-risk-2017. Accessed 7.13.2020
[19] The Ontario Ministry of Natural Resources is now called the Ontario Ministry of Natural Resources and Forestry

- The government’s goal for the recovery of Bogbean Buckmoth is to sustain current population levels and distributions at existing locations, and to encourage the natural expansion of the species into suitable but currently unoccupied habitat within its current range in Ontario.

Environment Canada (2015, p. 9) adopted the broad strategies from Part 3 to meet the federal population and distribution objective.

Habitat Protection

Bog buck moth habitat was generally protected from being damaged or destroyed since the species was listed in 2010. Bog buck moth “habitat” is further protected through Ontario habitat regulation and federal critical habitat protection. Section 10(1) of the Ontario Endangered Species Act, 2007, S.O. 2007, c. 6 states that: No person shall damage or destroy the habitat of, (a) a species that is listed on the Species at Risk in Ontario List as an endangered or threatened species; or (b) a species that is listed on the Species at Risk in Ontario List as an extirpated species, if the species is prescribed by the regulations for the purpose of this clause. 2007, c. 6, s. 10 (1). Section 17(1) authorizes activities specified in a permit that would otherwise be prohibited by section 9 or 10. 2007, c. 6, s. 17 (1).

Section 41(1)(c) of SARA requires that recovery strategies include an identification of the species’ “critical habitat,” to the extent possible, as well as examples of activities that are likely to result in its destruction (Environment Canada 2015, p. 9). Under SARA, “critical habitat” is “the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species” (Environment Canada 2015, p. 9). As stated above, Environment Canada (2015, p. 10) adopted the description of the buck moth “habitat” under section 24.1.1.1 of Ontario Regulation 242/08 as “critical habitat” in the federal recovery strategy. The area defined under Ontario’s habitat regulation contains the biophysical attributes required by the buck moth to carry out its life processes. To meet specific requirements of SARA, the biophysical attributes of critical habitat were further detailed in the federal strategy (Environment Canada 2015, p. 11). Critical habitat is currently found at four sites for the two known local populations of the buck moth in Canada totaling approximately 551 ha (1,362 ac) (Environment Canada 2015, p. 11). Destruction of critical habitat would result if part of the critical habitat were degraded, either permanently or temporarily, such that it would not serve its function when needed by the species. Appendix B includes those activities likely to cause destruction of critical habitat for the species; however, activities are not limited to those listed (Environment Canada 2015, table 2, pp. 15-18). Under SARA, there are specific requirements and processes set out regarding the protection of critical habitat. Protection of critical habitat under SARA will be assessed following publication of the final bog buck moth federal recovery strategy (Environment Canada 2015, p. 10).

3.5.2 New York Status and Efforts

Listing

The bog buck moth was listed as Endangered[20] by the State of New York in 1999 and is protected by Environmental Conservation Law (ECL) section 11-0535 and the New York Code of Rules and Regulations (6 NYCRR Part 182). An incidental take permit is required for any proposed project that may result in a take of bog buck moths, including, but not limited to, actions that may kill or harm individual animals or result in the adverse modification, degradation or destruction of habitat occupied by the bog buck moth.

Recovery Planning and Implementation

The bog buck moth was included as a Species of Greatest Conservation Need (SGCN) in the NYSDEC's Comprehensive Wildlife Conservation Strategy (NYSDEC 2005, Appendix 5, pp. 14-17) and as a high priority SGCN in the 2015 update (NYSDEC 2015, not numbered). The Comprehensive Wildlife Conservation Strategy (NYSDEC 2005, Appendix 5, pp. 15-16) includes recommendations for the following actions for the bog buck moth:

- Develop a fact sheet for the bog buck moth for paper distribution and for the website.
- Take appropriate action to remove invasive species or control, deter, or repair damage from human activities
- Identify development and other human impacts on the population sites and whether they are negatively affecting the populations.
- Identify invasive species contamination of all population sites and whether it is negatively impacting populations.
- With understanding of habitat requirements and threats, identify methods to maintain and improve habitat and if possible expand the species to other wetlands.
- Conduct research on effects of egg/larvae parasitism on population dynamics at all sites.
- Determine viability parameters for bog buck moth populations.
- Conduct research to better understand pupation habitat, immigration and emigration from population sites, and long term population dynamics.
- Contact experts in Ontario Canada regarding the status of the sites previously known from that province.
- Pursue final naming of the species (subspecies).
- Develop a management/recovery plan for the bog buck moth that includes all current knowledge of the species and its habitat and recommendations for actions to recover the species to the extent that it can be down-listed or de-listed.
- Continue monitoring of all populations. Increase effectiveness of monitoring techniques.
- Incorporate bog buck moth management into management and work plans for NYSDEC lands where it occurs.

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[20] https://govt.westlaw.com/nycrr/Document/I21eb7aa2c22211ddb7c8fb397c5bd26b?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)&bhcp=1. Accessed 7.13.2020

There is a draft recovery plan for the bog buck moth for New York State (Bonanno and White 2011, entire) that has not been finalized. There are two draft recovery objectives (Bonanno and White 2011, p. 18):

- To secure and buffer the currently known breeding sites of *Hemileuca* sp. 1 in NY together with their hydrological and ecological processes.
- To restore viable breeding populations in each of the six NY sites currently known.

There are multiple recovery actions outlined to meet these draft objectives including research, habitat management, and monitoring. The primary recovery action implemented in New York to date has been assessing the status of the species through funding fall moth surveys.

Habitat management has also been conducted at a few sites. For example, annual manual removal of cattail since 2016 at The Oswego Inland Site has pushed cattail encroachment back. Manual removal lowered cattail density, but resprouting remains an issue. The cattail leaf litter has virtually been removed from the mat, promoting the perpetuation of fen plant communities and microhabitat needed by bog buckbean.

Habitat Protection

All known populations are in conservation ownership and are protected from being directly impacted (e.g., wetland fill associated with roads or development). The Nature Conservancy owns the Lakeside 1 and 2. The NYSDEC owns Lakeside 3, 4, and 5. Central NY Land Trust owns the Oswego Inland Site and has periodically conducted invasive species management to restore native habitat and is working with adjacent landowners to reduce nutrient inputs, and pesticide and herbicide use.

The NYSDEC Freshwater Wetlands Act[21] (ECL Article 24) provides protection for wetlands greater than 12.4 acres in size or of unusual local importance. Regulated activities within the wetland or adjacent buffer require permits from the NYSDEC. In addition, in accordance with section 404 of the Clean Water Act, the U.S. Army Corps of Engineers has the authority to regulate discharge of dredged or fill material into waters of the United States, including wetlands. In New York, placing fill into bogs and fens is not authorized under the Nationwide Permit Program[22].

3.5 Key Uncertainties/Assumptions

- We do not have a complete understanding of the role of parasitoids, predation, disease, and pesticides on the status of bog buck moth populations. Egg parasitoids are known in New York bog buck moth populations and it is likely that larval and pupal parasitoids are present. Parasitoids are highly likely to be influencing bog buck moths based on information from other buck moth species. Pesticides have been documented or are considered likely causes of other lepidopteran species; however we have no information

[21] http://www.dec.ny.gov/docs/wildlife_pdf/wetart24b.pdf. Accessed 7.13.2020.
[22] https://www.nan.usace.army.mil/Portals/45/docs/regulatory/NWP/LRB-NAN_Final_2017_RCs_NY.pdf?ver=2017-03-22-110955-210. Accessed 7.21.2020

about pesticides impacting bog buck moth populations. This is an area for future research.

- Interacting changes in temperature and precipitation are highly influential in terms of flooding or drying out bog buck moth sites. There may be additional compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack but we lack sufficient information on those potential relationships.
- We are uncertain about the ability to successfully manage succession and invasive plant species given their persistent nature, continued effects from adjacent lands, and the need for long-term funding and staff resources.

3.6 Summary

The primary factor influencing bog buck moth population health is availability of quality habitat for all life stages. Water level management, weather, invasive species, and succession influence the availability of bog buck moth habitat. In addition to habitat availability, factors such as parasitoids likely influence the boom and bust cycles of the bog buck moth. The declining population size at many sites reduces the likelihood that bog buck moths will recover from bust cycles.

CHAPTER 4. HISTORICAL AND CURRENT CONDITION

4.1 Methods

Our first step was to define a bog buck moth population. For the purpose of this SSA, the Service's working definition of a bog buck moth population includes the following core concepts:

1. A bog buck moth population consists of a group of male and female moths.

2. Bog buck moths rely on one primary larval host plant (*Menyanthes trifoliata*) and do not occur in areas where the host plant is not present. However, bog buck moths also feed on other species as well, especially the later instars.

3. Bog buck moths are sedentary (nonmigratory); therefore, they are present within suitable habitat (see suitable habitat definition below) year-round and while capable of flying a few kilometers, rarely leave habitat.

4. A bog buck moth population is a group of individuals that can self-replenish without a "migration" event, which is relatively rare and results in novel gene exchange.

5. Bog buck moths may occur as single populations or as metapopulations made up of two or more subpopulations that interact with each other (i.e., occasional movement between subpopulations associated with the metapopulation). Interactions between populations or metapopulations are not anticipated.

After defining a bog buck moth population, we evaluated its current condition by assessing whether populations are resilient. We defined resilient as: (1) having healthy demography and (2) occupying areas with suitable habitat conditions for all life stages and seasons. We lacked specific demographic rates for most locations for most years; therefore, we used surrogate information to assess population health. We evaluated resiliency of bog buck moth populations using metrics for assessing population health (number of bog buck moth adult males observed, presence of bog buck moth at multiple subpopulations) and the condition of the supporting habitat (habitat quality) (table 4.1).

We defined a bog buck moth population as "Extirpated" when the habitat is completely unsuitable due to alteration or loss (e.g., fill, alteration to different wetland community). We defined a bog buck moth population as "Presumed Extirpated" when previous records indicate bog buck moths are present and habitat is suitable for bog buck moths, but no moths were observed during multiple subsequent surveys (i.e., no moths observed during multiple subsequent years of standardized transects and/or use of pheromone lures to attract males). We defined a bog buck moth population as having a "Poor" condition as one that has a high demographic vulnerability and a population as having a "Good" condition as one that has a low demographic vulnerability.

Table 4.1. Metrics for scoring bog buck moth condition.

Sufficient Number	**Connectivity**	**Suitable Habitat**	**Condition**
Unknown	Unknown	Unknown	Unknown
Not applicable	Not applicable	Habitat is completely unsuitable due to alteration or loss	Extirpated
No moths or any other life stage were observed during multiple subsequent surveys	Not applicable	Habitat present and can be suitable or unsuitable given “sufficient N” results	Presumed Extirpated
Negative trend over last 10 years	No subpopulations or if subpopulations are present each subpopulation did not have at least one >0 count in within the last 5 years	Insufficient suitable habitat for any of the life stages: • Insufficient buckbean (<4% areal coverage). • Relatively limited oviposition sites. • Lack of suitable pupation sites.	Poor
Neutral or positive trend over last 10 years	Multiple subpopulations and >0 counts for each subpopulation within the last 5 years	Sufficient suitable habitat for all life stages: • Sufficient buckbean (>4% areal coverage). • Relatively abundant oviposition sites. • Suitable pupation sites.	Good

4.2 Results

4.2.1 Historical Distribution

As discussed in section 2.1, the bog buck moth was first identified in 1977 by John Cryan and Robert Dirig from four sites along the southeast shore of Lake Ontario in Oswego County, NY (Legge *et al.* 1996, p. 86; Pryor 1998, p. 126; Cryan and Dirig 2020, p. 3). Four additional sites were discovered in 1977 in eastern Ontario (COSEWIC 2009, p. 7). Given the recent discovery of the existence of bog buck moth, we do not have a full picture of the historical distribution. However, there are records from three populations in New York and two in Ontario (figure 4.1).

- The three New York populations are more than 13 km (8 mi) from each other and one was extirpated in the 1970s (Jefferson County, NY). There are at least six sites associated with the remaining two New York populations. The New York populations include: Jefferson County Population
    - Specimens were collected from the 1950s and labeled as *Hemileuca maia* (Bonanno and White 2011, p. 9). They were later identified as bog buck moth after it was already converted to unsuitable marsh habitat (S. Bonanno, pers comm.).
- Lakeside Population, Oswego County
    - This metapopulation comprises 5 sites that lie in fen openings separated by inhospitable habitat, but these span a total linear distance of 3.2 km (2 mi), set 100 to 500 m (328 to 1640 ft) east of Lake Ontario (Bonanno and White 2011, p. 9)
    - The sites are[23]:
        - Lakeside 1 - 2 ha (5 ac)
        - Lakeside 2 - 25 ha (61 ac)
        - Lakeside 3 - 81 ha (201 ac) including Lakeside 4
        - Lakeside 4
        - Lakeside 5 - 40 ha (100 ac)
- Oswego Inland Site Population, Oswego County
    - Single site with two fen openings (metapopulation dynamics at a smaller scale) - 35 ha (86 ac)

In Canada, the bog buck moth is known from four sites in eastern Ontario where it was first discovered in 1977: two near Richmond south of Ottawa and two other sites approximately 50 km (31 mi) farther west near White Lake (COSEWIC 2009, p. 7) (Figure 4.1). The four Canadian sites could be considered four separate populations based on criteria discussed above. The Richmond fens and White Lake fens are separated by 2.2 and 3.2 km (1.4 and 2 mi) of unsuitable habitat, respectively (COSEWIC 2009, p. 9). The 5-year review (OMNFR 2017, p. 15) describes them as four separate populations. The OMNFR defined a population as "an area of land and/or water on/in which an element (e.g., Bogbean Buckmoth) is or was present. They are comprised of one or more observations and the area has a practical conservation value as it is important to the conservation of the species. An element occurrence is the technical term used to describe this." Alternatively, these four Canadian sites may function as two separate

[23] Size of calcareous fen from Olivero 2001, p. 10.

metapopulations with infrequent periodic dispersal events connecting them. According to COSEWIC definitions they represent two locations (COSEWIC 2009, p. 9) and Environment Canada (2015, entire) describes them as two populations or complexes. There are approximately 236 ha (583 ac) of fen habitat at the bog buck moth sites in Canada, with the majority at location Richmond Fen (215 ha [531 ac]) and relatively little at While Lake Fen (31 ha [77]) (COSEWIC 2009, p. 17).

For the purposes of this SSA we consider there to be two metapopulations of bog buck moths in Ontario:

- White Lake Population
    - This population is made up of two sites (White Lake North and South) of approximately 31 ha (77 ac) of habitat.
- Richmond Fen Population
    - This population is made up of two sites (Richmond Fen North and South) of approximately 215 ha (531 ac) of habitat.

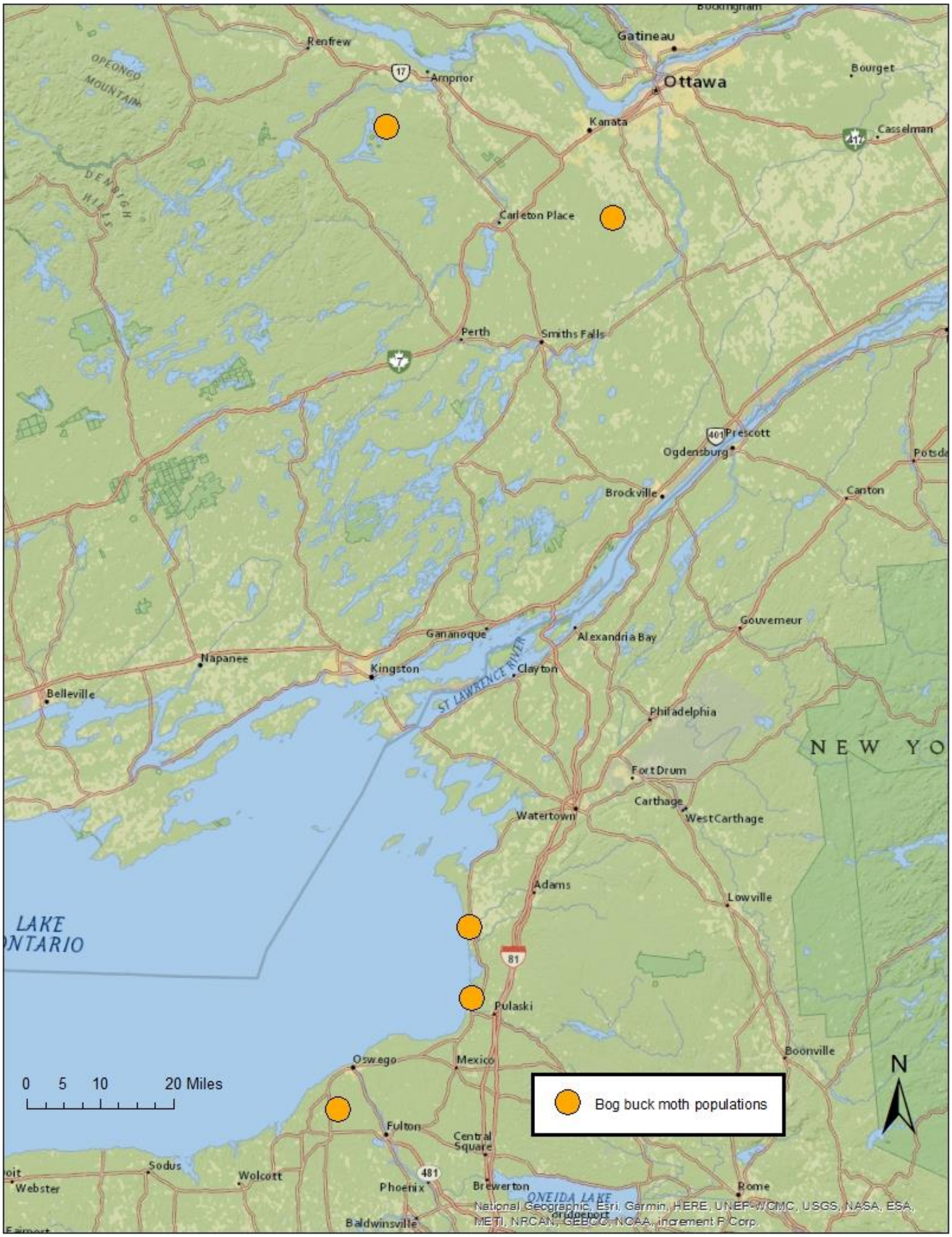

Figure 4.1. Known range of the bog buck moth in United States and Canada.

4.2.2 Current Distribution

All populations are located within the bed of former glacial Lake Iroquois (Cryan and Dirig 2020, p. 27) and Champlain Sea (COSEWIC 2009, p. 9). Pryor (1998, p. 138) suggested that the present distribution suggests this may be relict populations of a postglacial expansion by *Hemileuca* from western North America, and subsequent isolation in isolated fens and bogs as forests subsequently gradually reclaimed postglacial wetland habitats. Tuttle *et al.* 2020 (pp. 23-26) discusses the more southerly distribution of oak feeding buck moths in generally unglaciated area compared to the northerly distribution of willow and buckbean feeders. Gradish and Tonge (2011, p. 6) found that glacial retreat left suitable habitat in disjointed patches. Based on genetic findings, Dupuis *et al.* (2020, p. 4) also suggest that, historically, bog buck moth populations may have been more widespread along the wetlands around Lake Ontario.

There is no change to the distribution of populations in Canada. In New York, the Jefferson County population is extirpated. The site is now a marsh, having been impounded decades ago by beavers, then maintained by management for park flooding control, septic management, and black tern habitat (S. Bonanno, pers. obs.). In addition, the Oswego Inland Site was recently presumed extirpated (see details below).

4.2.3 Current Status

As background we provide the following information about how NatureServe has ranked the bog buck moth. The bog buck moth's global status is G1Q (critically imperiled, taxonomy questions), which is defined as "At very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors" (NatureServe 2020, p. 3). In the United States and Canada, the National status is N1 (critically imperiled) (NatureServe 2020, p. 3). At the sub-national level, it is also ranked as critically imperiled in Ontario and in the State of New York (NatureServe 2020, p. 3). In addition, NYSDEC found the bog buck moth distribution and abundance to be in severe decline (NYSDEC 2015, unnumbered).

As discussed in chapter 2, to capture genetic and ecological diversity we present the results for the two representative units. Using our ranking methods, we find that for the U.S. Representative Unit one population has been extirpated since the 1970s, one is now presumed extirpated, and one is in poor condition (table 4.2, figure 4.2). In the Canadian Representative Unit, both populations are in unknown/likely good condition (table 4.2, figure 4.2). Threats are ongoing at all populations and all subpopulations.

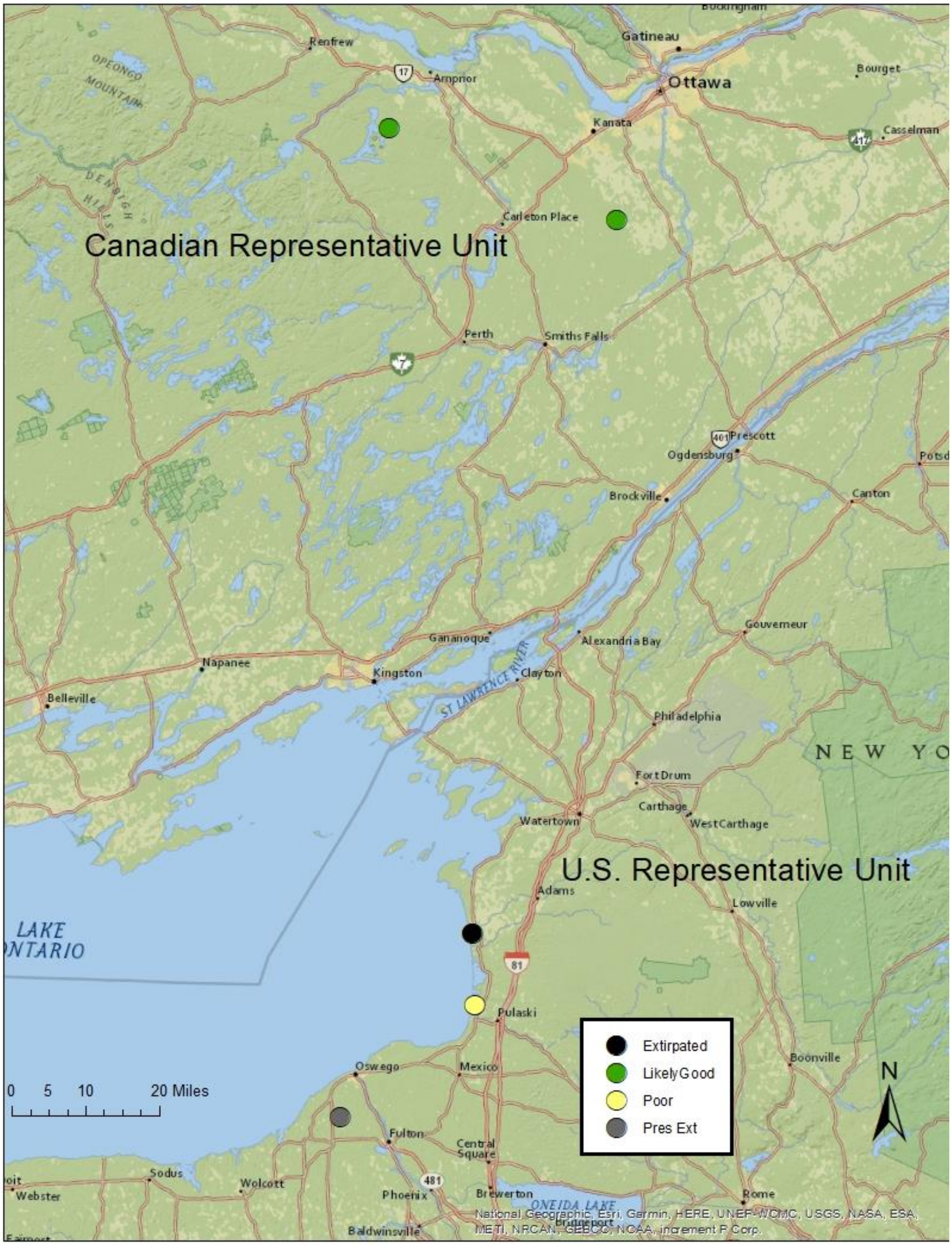

Figure 4.2. Current condition of the bog buck moth in U.S. and Canadian Representative Unit.

Table 4.2. Current condition of bog buck moth populations.

Representative Unit	Population Name	Sufficient N	Suitable Habitat	Connectivity	Overall Current Condition
US	**Jefferson County**	Extirpated	Poor	Poor	Extirpated
US	**Oswego Inland Site**	No - Presumed Extirpated	Good	Poor	Presumed Extirpated
US	**Lakeside**	Poor	Poor	Poor	Poor
Canadian	**White Lake**	Unknown/ Likely Good	Good	Unknown	Unknown/ Likely Good
Canadian	**Richmond Fen**	Unknown/ Likely Good	Good	Unknown	Unknown/ Likely Good

We provide some details on each subpopulation in table 4.3. More detailed habitat information can be found in appendix C.

Table 4.3. Details supporting current condition of bog buck moth populations. Additional details regarding habitat condition are found in appendix C.

Representative Unit	Population	Sufficient N	Suitable Habitat	Connectivity	Current Condition
US	**Jefferson County**	Extirpated	Poor	Poor	Extirpated
US	**Oswego Inland Site**	No - Presumed Extirpated Last observed in 2017 with mean of 0.7 moths/count on peak date. 0 were observed in 2018,2019, 2020 with the pheromone lure deployed (Bonanno 2018, p. 2; 2019, p. 3; Bonanno and Rosenbaum 2020, p. 2). In addition to adult counts, there are larval observations that support this site's condition. In 2017, a single patch of larvae was observed in June, but in 2018 not a single larvae, nor even feeding damage on *Menyanthes*, was seen (Bonanno 2018, p. 2)	Good	Poor – 2 areas of fen within the same site (possible metapopulation dynamics at smaller scale) - each area of the fen did not have at least one >0 count in within the last 5 years	Presumed Extirpated
US	**Lakeside**	Poor	Poor	Poor – multiple subpopulations but each subpopulation did not have at least one >0 count in within the last 5 years	Poor Presumed extirpated in 2 of 4 subpopulations. While recolonization is <u>possible</u> in more closely connected subpopulations (vs. connectivity with the other 2 populations in Canada and the Oswego Inland Site in New York), low population numbers

					and poor habitat conditions render this unlikely without human reintroduction of gravid females.
	Lakeside 1	Poor Last observed in 2003. No moths observed in 2004, 2007, 2008, 2012-2014, 2018 (all years since 2003 – pheromone lure used), not visited in 2019.	Poor	*NA*	Presumed Extirpated
	Lakeside 2	Poor Last observed in 2012. No moths observed in 2013 (with lure), 2014 (with lure), 2015, 2016, 2018 (with lure), not visited in 2019.	Poor	*NA*	Presumed Extirpated
	Lakeside 3	Poor 2 moths observed in 2018 with pheromone, prior to that last seen in 2013, no moths with lure in 2014 and 2016, one survey day in 2019 (highest water levels recorded) and no moths observed.	Poor	*NA*	Poor
	Lakeside 4	Poor Last observed in 2007. No moths in 2012 or 2013 (with lure), not visited in 2018 or 2019.	Poor	*NA*	Poor Never considered a true subpopulation but a “spill-over” site
	Lakeside 5	Poor Most recent counts in 2018 and 2019, mean of 30.7 and 44.4 moths/count on	Good	*NA*	Poor

		peak date, respectively (Bonanno 2018, pp. 2-3; 2019, pp. 2-3).			
Canadian	**White Lake**	Unknown/Likely Good	Good	Unknown - 2 subpopulations but insufficient information for White Lake South	Unknown/Likely Good
	White Lake North	More than 100 adult moths were observed in mid-September 2020. Previously larvae were last observed in 2016, with no surveys in 2017, and larvae absent in 2018, 2019.	Good	*NA*	Unknown/Likely Good based on rebound of adult numbers.
	White Lake South	Unknown	Unknown	*NA*	Unknown
Canadian	**Richmond Fen**	Unknown/Likely Good	Good	Unknown – 2 subpopulations but insufficient information on either subpopulation	Unknown/Likely Good
	Richmond Fen North	Unknown	Good	*NA*	Unknown
	Richmond Fen South	Unknown/Likely Good Site visit in early July 2020 with hundreds of mid-instar larvae. Site visit in 2019, with estimate of minimum 1,500 early instar larvae in small portion of core habitat.	Good	*NA*	Unknown/Likely Good

As discussed in chapter 2, bog buck moth populations (and subpopulations) experience boom and bust cycles. These cycles have been documented during annual fall counts at four of the U.S. sites and may or may not be synchronous (table 4.4, figure 4.3). The Oswego Inland Site peaked in 1998, 2004, and 2014, experienced a crash in 2016 that deepened in 2017, and no moths were observed with pheromone lures in 2018, 2019, or 2020 (Bonanno 2016, pp. 2-3; 2017, p. 5; 2018, p. 2; 2019, p. 2; Bonanno and Rosenbaum 2020, pp. 2-3). Of the three Lakeside subpopulations that have routinely been counted, Lakeside 2 peaked in 1998, had a modest peak in 2007 (half the size of 1998), and declined until moths last seen in 2012 (Bonanno 2019, p. 5). Lakeside 3 peaked in 2007 with just a few moths observed in subsequent years (Bonanno 2019, p. 5). Lakeside 5 peaked in 2011 with a crash in 2012 that deepened in 2013 down to single digits, staying there until 2016 (Bonanno 2019, pp. 2-4). Lakeside 5 has two sections of fen within it with decidedly different counts over time, but counts are averaged across the site for annual reporting, as they are the same subpopulation. The west fen experienced crash conditions following deep long-lasting flooding in 2019, as it did in 2017 (Bonanno 2017, p. 6; 2019, p. 2-4) (table 4.5).

Table 4.4. Bog buck moth fall flight information for the Oswego Inland Site and 3 Lakeside subpopulations, 22 year record. Data are site mean of five minute counts on the peak date. Zero means a search was made, no moths seen. Empty cells indicate no data were collected at that site that year. Cells with counts higher than 100 are highlighted. Data from Bonanno (2018, p. 4; 2019, p. 4) and Bonanno and Rosenbaum 2020, p. 2).

Date	Oswego Inland Site	Lakeside		
		Lakeside 5	Lakeside 3	Lakeside 2
1998	171.3			242.4
1999	49.6		10.6	109.4
2000	7.1		14.8	26.8
2001	16.4		18.6	4.8
2002	37.1		3.3	2.2
2003	46		22.5	6.3
2004	153.2	64.6	21.2	20.2
2005	87.3	51.1		14.4
2006	81.9	126.8		26.3
2007	93.7	65.9	212.0	50.0
2008	63	23.0	5.8	14.2
2009	70	48.7	0.7	14.3
2010				10.0
2011	20.2	141.1	0.1	9.4
2012	18.9	46.0	3.0	1.0
2013	21.4	1.0	0.3	0
2014	126.5	3.8	0	0
2015	98.7	6.7		0
2016	5.0	27.7	0	0
2017	0.7	53.3		
2018	0	30.7	>0 (2 total moths)	0
2019	0	44.4	0	
2020	0			

Table 4.5. Means of 5-minute counts of bog buck moths on peak date at Lakeside 5, by fen opening and averaged over the site (Bonanno 2019, p. 4).

Year	Peak Date Mean Counts		
	East Fen Opening	West Fen Opening	Site Average
2016	19.4	33.6	27.7
2017	103.2	0.9	53.3
2018	52.8	14.3	30.7
2019	80.2	0.8	44.4

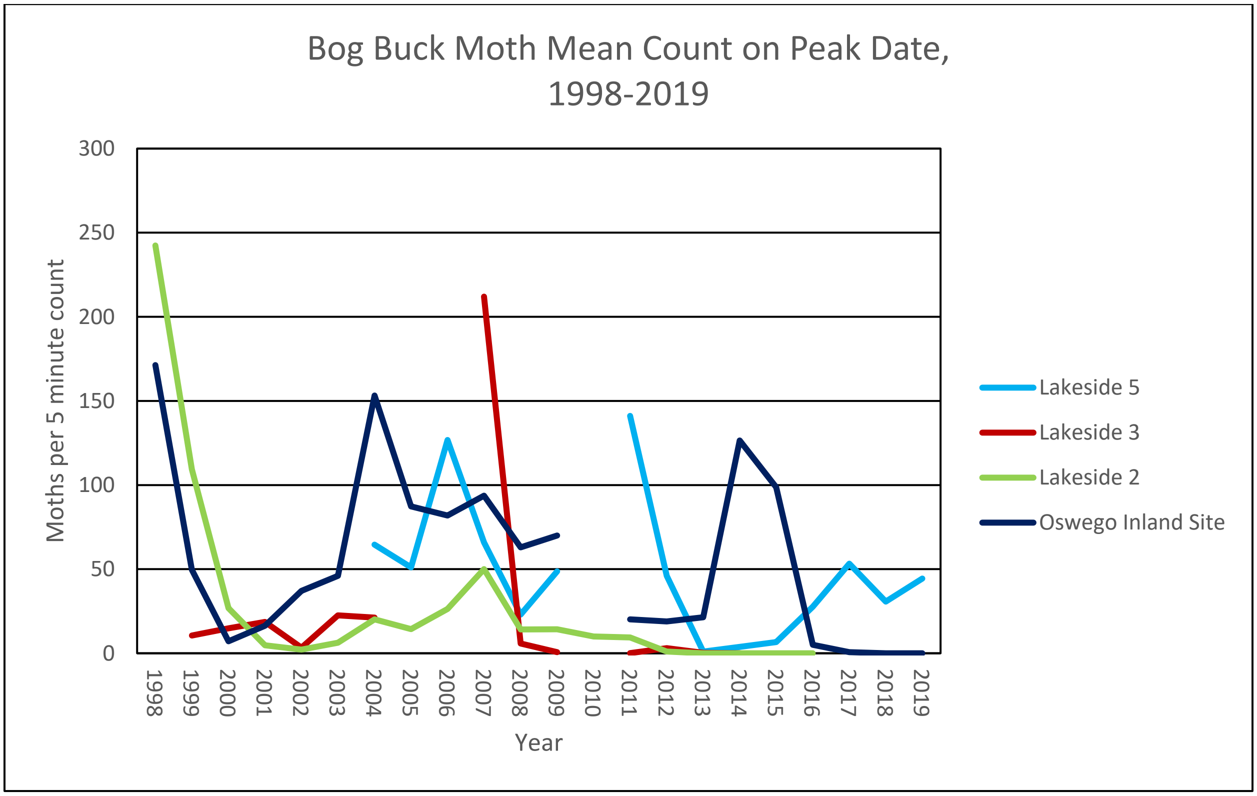

Figure 4.3. Adult male bog buck moth subpopulation trends, Oswego County, 21 year record (1998 to 2019). Data are the site mean of 5-minute counts on the peak date for the year at the Oswego Inland Site and at 3 Lakeside subpopulation (Lakeside 5, Lakeside 3, and Lakeside 2). (Bonanno 2019, p. 3, figure 1).

4.2.4 Possibility of additional unknown bog buck moth populations

Fairly extensive but unsuccessful searches for bog buck moth have been conducted at other potentially suitable wetland habitat in Ontario (COSEWIC 2009, pp. 9-10). No new buck moth sites were found in Ontario since the discovery of the four sites in the late 1970s. COSEWIC (2009, p. 10) found that given the degree of interest by naturalists in these natural areas and the diurnal habits of this large distinctive species, the probability of undiscovered Ontario buck moth populations is low.

The story is similar in New York. Cryan and Dirig (2020, pp. 4-5) described several years of exploring the bed of former glacial Lake Iroquois and its tributaries and outlets, and while they found some fens with buckbean, they found no additional sites with bog buck moth. In addition, researchers had visited New York fens for many years and would have likely observed the highly conspicuous bog buckbean larvae or adult males. Bonanno and White, 2011 (p. 10) describe multiple visitations to possible habitat by NYNHP and researchers familiar with the bog buck moth. For example, to focus conservation efforts on rare species in New York, the NYNHP and The Nature Conservancy initiated a project in 1998 to classify and consistently map calcareous fens in New York (Olivero 2001, p. 1). A second project was initiated to assess prior fen classifications and update information about the fens in which 71 calcareous fens were visited (Olivero 2001, pp. 1,8). Fifteen medium fens were documented (Olivero 2001, p. 10) (figure 4.4); however, no additional bog buck moth sites were found beyond the documented sites. Further, researchers brought lures to the Perch River Wildlife Management Area in Jefferson County in the 1990s and no buck moths were found (Bonanno and White 2011, p. 10).

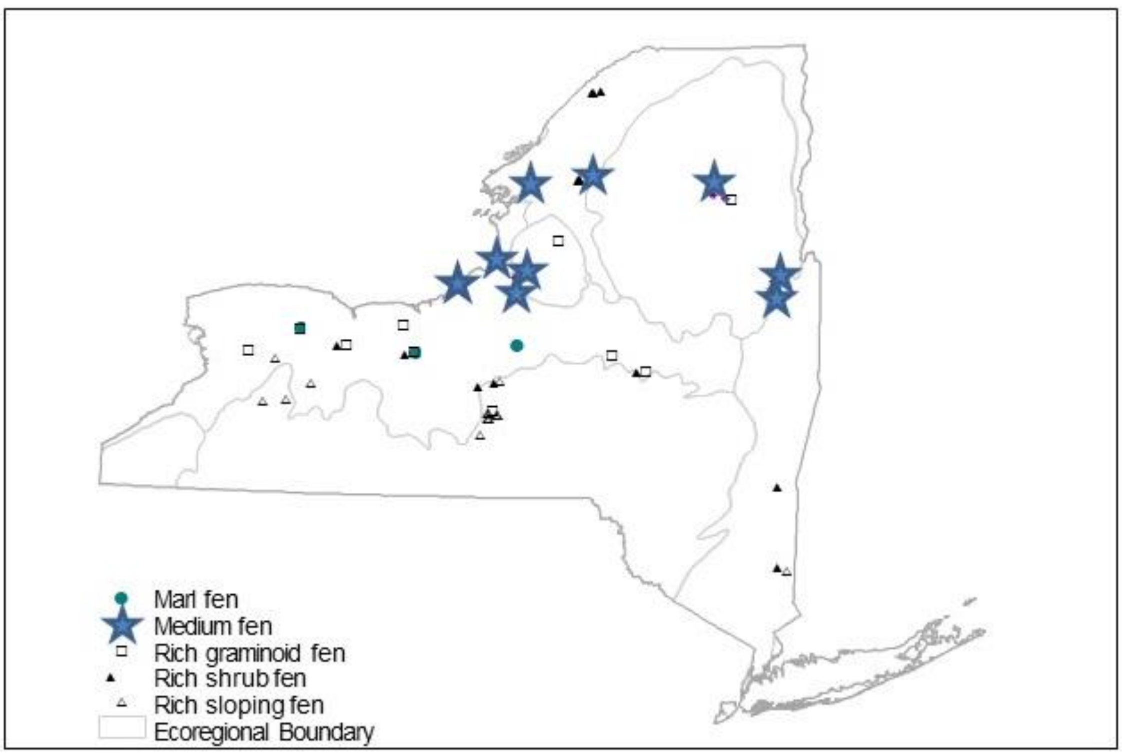

Figure 4.4. Distribution of calcareous fens studies in New York (modified from Olivero 2001, p. 4, figure 2). Bog buck moths use medium fens (blue stars).

4.3 Key Uncertainties/Assumptions

For the Canadian Representative Unit, we have no long-term trend information similar to the U.S. Representative Unit. In addition, only two of the four subpopulations have been visited to provide current condition information. We assume that because those two subpopulations still have reasonably good buck moth numbers, their overall population status is good.

4.4 Summary

In summary, there are two bog buck moth populations across the entire range (Richmond Fen and White Lake Fen) that are considered in "unknown, but likely good" condition and these are both located in the Canadian Representative Unit (table 4.6). This assessment has a high degree of uncertainty given that it is based on current knowledge from half of the associated Canadian Representative Unit subpopulations (one out of the two subpopulations for each population). Most recently, Richmond Fen South had hundreds of mid-instar larvae in early July 2020 with ample suitable habitat. Richmond Fen North has not had any recent moth or larval surveys, but observations during a site visit in 2015 suggested that the habitat remains in good condition. At White Lake North, more than 100 bog buck moth adults were observed in September 2020. Prior to that surveys were based on larvae, with larvae last observed in 2016 and none seen in 2018 or 2019. There is no information on White Lake South.

For the United States, zero populations are in good condition, one is extirpated, one is presumed extirpated, and one is in poor condition. The Lakeside population has experienced multiple sources of habitat loss and degradation and remaining buck moths have faced high flood years. While these may or may not be the true cause of declines and site-level extirpations, they likely contributed to them. The cause of decline and the bog buck moth’s inability to rebound at the Oswego Inland Site is unclear as flooding has not been a concern at this site and seemingly suitable habitat remains. Similar declines at sites with apparently suitable habitat have been documented for another rare fen species, the Poweshiek skipperling (*Oarisma poweshiek*), suggesting that other factors (e.g., contaminants, climate change, disease, and low levels of genetic diversity) may be driving the current distribution and losses (Pogue *et al.* 2019, pp. 383-386).

Overall, three subpopulations (White Lake North, Richmond Fen South and Lakeside 5) associated with two populations are known to have remaining bog buck moths. While some genetic diversity remains through the current existence of at least one subpopulation within each of the representative units, there is no redundancy of healthy populations in the U.S. Representative Unit, and there is uncertainty about the status of the Canadian Representative Unit.

Table 4.6. Summary of bog buck moth current condition.

3Rs	Requisites	Metric	Current Condition
Resiliency (able to withstand stochastic events)	Healthy populations	Populations with: • Both sexes present. • Sufficient survival of all life stages • Sufficient number of bog buck moths to survive bust portion of boom and bust cycles. • Stable to increasing trend over last 10 years (10 generations). • Multiple occupied suitable habitat patches within metapopulation. • Sufficient habitat size. • Sufficient habitat quality. • Intact hydrology and ecological processes.	Poor Of the 5 historically known populations: 1 extirpated 1 presumed extirpated 1 poor 2 unknown/likely good
Representation (to maintain evolutionary capacity)	Maintain adaptive diversity	Healthy populations distributed across areas of unique adaptive diversity (e.g., across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.	Poor There are two potentially healthy populations in the Canadian Representative Unit and none in the U.S. Representative Unit
Redundancy (to withstand catastrophic events)	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events significantly compromising species adaptive diversity.	Poor See above
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.	Poor See above

CHAPTER 5. FUTURE CONDITION

In this SSA, we have defined the demographic and resource needs for bog buck moth viability and presented an analysis of the current condition of the species. Here, we provide an analysis of the future viability of the bog buck moth under two scenarios that serve as examples from the full range of potential futures. Based on the analysis of factors influencing the viability of the bog buck moth, we selected climate change and invasive species as the most important factors to evaluate into the future. These factors were selected as our review has shown that these two factors are most likely to impact all populations across the species' range.

5.1 Scenario Development

5.1.1 Factors Not Considered Explicitly

In this analysis of future condition, we have not directly assessed the effects of all of the factors considered in chapter 3 that may influence the future condition of the species. For example, parasitoids are likely highly influential on bog buck moth boom and bust cycles but we do not have any site-specific information about these relationships. Further, we have no information to suggest changes in parasitoid populations in the future. We assume parasitoids will continue to act on bog buck moth populations similar to what they are doing now. This is also the case for Lake Ontario water level management. Water levels will continue to be managed according to Plan 2014 and while there may be some positive changes to coastal wetland vegetation, intensive habitat restoration is needed to make any kind of meaningful change in bog buck moth habitat suitability. Therefore, the actual water level management is not the driver of habitat suitability moving forward. In addition, there are no plausible changes in water level management to model. We acknowledge these and other factors will continue to influence bog buck moth populations. Further, as discussed in chapter 3, several factors (e.g., pesticides, disease) have the potential to influence bog buck moth populations but we lack an understanding of how significant this influence likely is and what role they play in current and future status. See Section 5.5 Key Uncertainties/Assumptions for an explanation of how not considering these factors in our analysis may affect the results.

5.1.2 Effects from Climate Change

Two families of scenarios are commonly used for future climate projections and considered in this SSA: the 2000 Special Report on Emission Scenarios (SRES) and the 2010 Representative Concentration Pathways (RCP). The SRES scenarios are named by family (A1, A2, B1, and B2), where each family is designed around a set of consistent assumptions. In contrast, the RCP scenarios are simply numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square meter) that results by 2100. Comparing carbon dioxide concentrations and global temperature change between the SRES and RCP scenarios, SRES A1fI and A2 are similar to RCP 8.5; SRES A1B is similar to RCP 6.0 and SRES B1 is similar to RCP 4.5[24]. The RCPs are based on more than 100 scenarios in the scientific literature at the time the RCPs were developed (van Vuuren *et al.* 2011, p. 13). The climate change projections based on RCP 4.5

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[24] https://www.globalchange.gov/browse/multimedia/emissions-concentrations-and-temperature-projections accessed 7/28/2020

and RCP 8.5, represent the “medium-low” and “highest” scenarios, respectively. The RCP 4.5 and RCP 8.5 scenarios are commonly used together for comparative purposes in the scientific community, and these scenarios were selected as the basis of projections for assessing climate change impacts, vulnerability, and adaptation responses in the development of the Fourth National Climate Assessment[25] (U.S. Global Change Research Program 2018, entire). For information about the RCP scenarios, see van Vuuren *et al.* (2011, entire) or Collins *et al.* (2013, pp. 1044–1047). For more information on SRES scenarios, see Nakicenovic *et al.* (2000, entire).

Rather than solely using predicted global changes in temperature and precipitation, we considered results of regional models for the Great Lakes Basin. The authors cited in this section used results of multiple downscaled climate models under a variety of emissions scenarios. Basile *et al.* (2017, entire) used RCP 8.5 to predict changes in the Great Lakes Basin, as present-day emissions are currently following this emissions projection. Using both global and regional climate model data, winter and spring precipitation is projected to increase by mid-century (2041 to 2060) (Basile *et al.* 2017, pp. 4868-4869, 4878). Mean increases among all models examined ranged from 7 to 14.7 percent in spring and 11.1 to 17.4 percent in winter (Basile *et al.* 2017, p. 4868). In contrast, simulations are highly variable for summer with some models showing decreases and other increases in summer precipitation (Basile *et al.* 2017, pp. 4868-4869, 4878).

Similarly, Byun and Hamlet (2018, pp. e539-540) and Byun *et al.* 2019 (pp. 1267-1268) projected increases in winter and spring precipitation over the Midwest and Great Lakes Regions under both RCPs 4.5 and 8.5 starting in the 2020s and continuing throughout the mid- and latecentury when compared to a baseline of 1915 to 2013 (figure 5.1). For the 2020s under both emissions scenarios, winter and spring precipitation is anticipated to increase by approximately 10 percent. The magnitude of change diverges over time and by the 2080s under RCP 8.5, increases of about 30 percent in winter precipitation are anticipated with smaller increases under RCP 4.5 (Byun and Hamlet 2019, p. e540; Byun *et al.* 2019, pp. 1267-1268). Using RCP 8.5, Notaro *et al.* (2015, pp. 1668-1669) predict increases in November to March precipitation along Lake Ontario and the Province of Ontario of 15 to 30 percent, respectively from a baseline of 1980 to 1999 to late century (2080 to 2099). This will primarily be due to increases in rainfall as snowfall declines (Notaro *et al.* 2015, pp. 1860-1861).

Using SRES A1B, Zhang *et al.* (2020, pp. 260-261) predicted increased spring and winter precipitation over the entire Great Lakes Basin by 11.6 and 15.4 percent by mid-century (2040 to 2069) and late century (2070 to 2099), respectively from a baseline of 1980 to 2009. In the eastern Great Lakes Basin, they predicted increases of 10 to 30 percent by mid-century, with greater variability in late-century and variable summer predictions (Zhang *et al.* 2020, pp. 264-265). Also using SRES A1B, Wang *et al.* (2017, p. 2242) predicted increased average annual precipitation of 11.8, 21.2, and 7.3 percent in the Lake Ontario basin in the 2030s, 2050s, and 2080s, respectively compared to a baseline period of 1961 to 1990.

[25] https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf accessed 7/28/2020

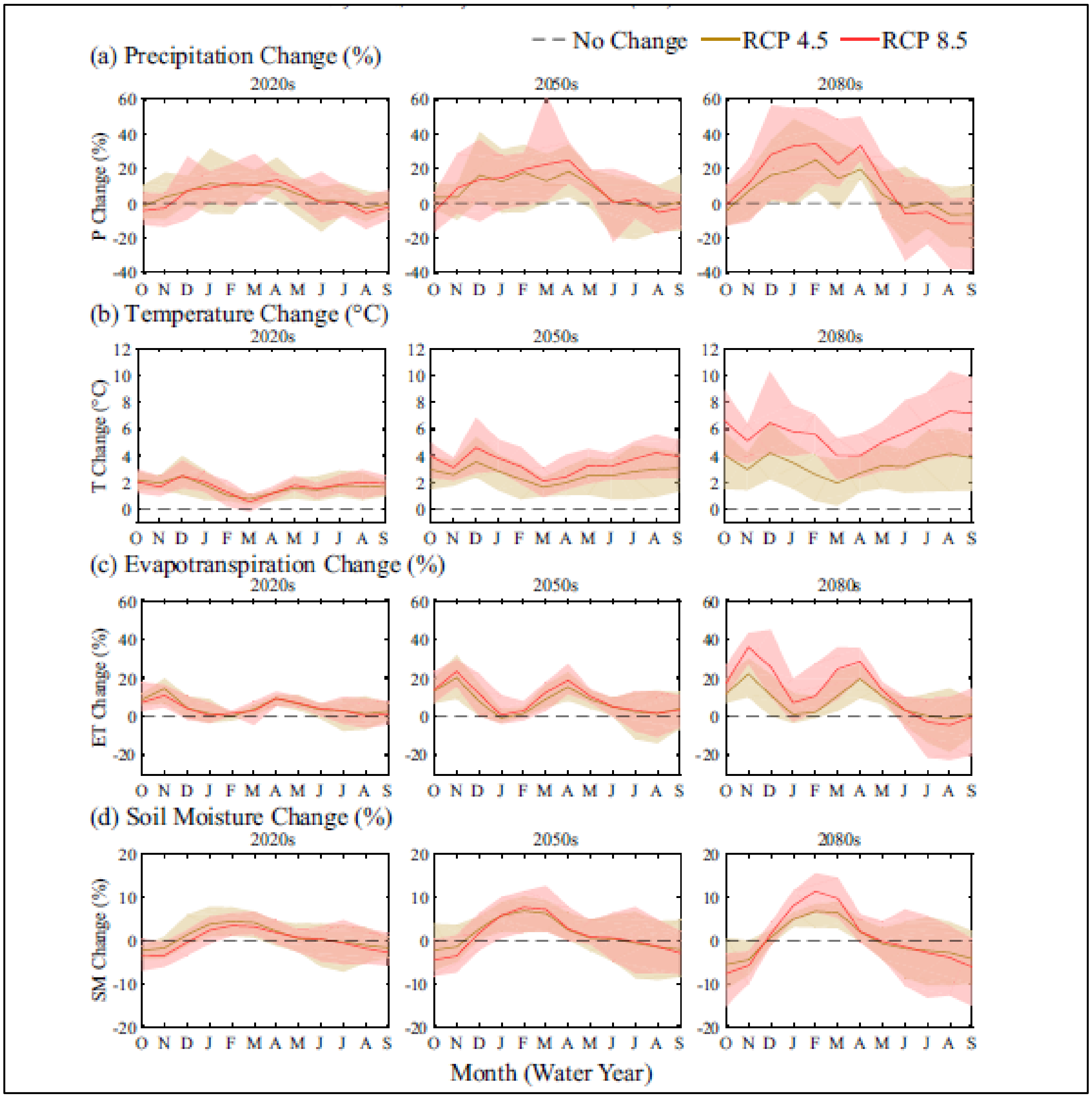

Figure 5.1. Projected monthly changes in (a) precipitation (P), (b) temperature (T), (c) evapotranspiration, and (d) soil moisture change in the Midwest and Great Lakes Region. Each shaded bound represents 95 percent confidence interval (2.5th to 97.5th percentile) and solid lines display the ensemble mean among 6 global climate model results (Byun *et al.* 2019, p. 1268, figure 4).

In addition to changes in the amount of precipitation, increases in temperature have been documented and are anticipated to continue in the Great Lakes Basin. As discussed in chapter 3, since the mid-20th century, the average annual temperature in the Great Lakes Region and Ontario has increased by 2.3 °F (1.3 °C) (GLISA 2019, entire) and 2.5 °F (1.4 °C), respectively (Ontario Ministry of the Environment 2011, p. 1). Temperatures in the Midwest and Great Lakes Region are predicted to continue to climb under both RCP 4.5 and 8.5 (Byun and Hamlet 2017, p. e531; Byun *et al.* 2019, p. 1268) (figures 5.2). Using RCP 8.5, Notaro *et al.* (2015, pp. 1668-1669) predict increases in November to March air temperatures along Lake Ontario and into Ontario of 9 to 11.7 °F (5 to 6.5 °C) from a baseline of 1980 to 1999 to late century (2080 to 2099). Using SRES A1B, Zhang *et al.* (2020, p. 259) predicted increased temperatures across the northeastern region of the Great Lakes of 5 and 7.6 °F (2.8 and 4.2 °C) by mid-century (2040 to 2069) and late-century (2070 to 2099), respectively, from a baseline of 1980 to 2009. Also using SRES A1B, Wang *et al.* (2017, p. 2242) stated the average changes in air temperature for the Great Lakes Basin are very likely to be 4.7 °F (2.6 °C) in the forthcoming decades, 6.8 °F (3.8 °C) in the middle of this century, and 10.1 °F (5.6 °C) by the end of this century, respectively. For Ontario, using SRES A1B, Wang *et al.* (2014, p. 5277) projected increases in temperature from 3.6 to 7.2 °F (2 to 4 °C) by 2049, 5.4 to 9 °F (3 to 5 °C) by 2069, and 10.8 to 14.4 °F (6 to 8 °C) by 2099 compared to a baseline of 1961 to 1990. For the weather station closest to the bog buck moth sites, the central estimates of predicted increases in mean annual temperature were 5 °F (2.78 °C) by 2049, 7.72 °F (4.29 °C) by 2069, and 10.26 °F (5.7 °C) by 2099 (Wang *et al.* 2014, p. 5270).

Increased temperatures interact with changes in precipitation, runoff, and lake evaporation in large water bodies like Lake Ontario. Mailhott *et al.* (2019, entire) assessed the combined effects of precipitation, runoff, and lake evaporation on net basin supply (NBS) or lake level across the Great Lakes Basin and for individual Great Lakes. Basin wide, results show increases in annual NBS of 0.6 to 2.8 in (14 to 70 mm) from 1953 to 2100 that are not equally distributed throughout the year (Mailhott *et al.* 2019, p. 251). Increases in over-lake precipitation and runoff in winter and spring result in positive NBS changes for those seasons while summer is dominated by increased lake evaporation resulting in negative NBS changes (Mailhott *et al.* 2019, p. 257).

While we have more detailed information linking increased flooding at the Lakeside population, overall changing temperatures and precipitation in the Great Lakes region and Ontario are anticipated to result in increased flooding risk at all sites in winter and spring. Winter season run-off will likely be greater due to the combined effects of warming and increasing precipitation (Byun and Hamlet 2018, p. e550). Also, as discussed above, there is already a significant increase of the number of ablation events (i.e., snow mass loss from melt, sublimation, or evaporation) in the grid that includes NY bog buck moth sites (Suriano *et al.* 2019, pp. 6-7). These events are associated with rapid snow melt and often lead to localized flooding.

Increased temperatures will shift precipitation to more rain and less snow across the Great Lakes basin, Midwest, and northeastern United States by both the mid- and late twenty-first century (Notaro *et al.* 2014, p. 1675; Notaro *et al.* 2015, p. 1675), resulting in impacts to bog buck moth food sources. In central Saskatchewan, Canada, study sites that contained bog buckbean with manipulated reductions of snow pack had longer periods of frost, earlier disappearance of standing water, and deeper frost levels (Benoy *et al.* 2007, pp. 505-507). These sites also had less bog buckbean biomass (Benoy *et al.* 2007, p. 508). Reduced bog buckbean influences bog buck moth larval growth and survival (see chapters 2 and 3).

In addition, increased annual temperatures will lead to higher evapotranspiration and reduced groundwater recharge, resulting in drying of headwater streams such as those arising from fens (Landis *et al.* 2011, p. 133). While increased soil moisture is predicted during the winter as a result of increased precipitation; reduced soil moisture is predicted in summer and fall (Byun *et al.* 2019, p. 1267) (figure 5.2). This is anticipated to further accelerate vegetation succession (transition to shrubs) that has already been documented at several sites.

Increasing temperatures appear to be shifting bog buck moth phenology. As discussed in chapter 3, the timing of fall bog buck moth flights appears to be shifting to later in September. Most butterflies in the United Kingdom have also significantly advanced their dates of first appearance in spring (Diamond *et al.* 2011, p. 1007). Continued increasing temperatures may further shift these flights, or as discussed in section 3.8, lead to earlier egg hatch and mismatch in timing with host plants. Earlier spring hatch followed by subsequent spring freezes also increases the risk of mortality of early instar larvae.

Increasing temperatures may influence the future distribution of bog buck moths, as microclimate may help explain the current distribution of the bog buck moth (Sime 2019, pp. 16-17). In New York, fen habitats farther from Lake Ontario may be too cold in the winter and/or too hot in the summer, as the lake tends to moderate temperatures nearby. Sime (2019, p. 17) also suggests that the distribution may be related to the current high amounts of lake effect snowfall.

Long-term increases in global temperatures are correlated with shifts in butterfly ranges. For example, Parmesan *et al.* (1999, p. 580) found that 34 of 52 European nonmigratory butterfly species have extended their boundaries northward 35 to 240 km (21.7 to 149.1 mi) in the past 30 to 100 years; this seems to be a result of sequential establishment of new populations over time. They suggested that continued northward range extension in highly fragmented landscapes of northern Europe may prove difficult for all but the most efficient colonizers (Parmesan *et al.* 1999, p. 583). Breed *et al.* (2013, p. 142) estimated butterfly population trends in Massachusetts from 1992 and 2010 and observed declines in northern species with less of a decline in cooler, high-altitude regions. Similarly, in Spain, butterfly distributions shifted to higher elevations between 1967 and 1973 to 2004 and 2005 (Wilson *et al.* 2007, p. 1880). Bog buck moths will be unable to generally shift their ranges in response to increasing temperatures given the sedentary nature of females and their specific habitat needs.

Increased temperatures may also directly affect various life stage survival or growth. Bog buck moths overwinter as eggs which should be more resilient to changes in temperature compared to other life stages. However, from 1992 to 2010, many of the fastest declining butterfly species in Massachusetts were butterflies that overwinter as eggs or neonate larvae (Breed *et al.* 2013, p. 144). If eggs survive the winter, increased temperatures could have a beneficial impact for bog buck moth larval growth and feeding behavior (Stamp and Bowers 1990, pp. 1035-1036) as long as it is not too high for too long.

Summary

Overall, there appears to be consensus around increasing average annual, winter, and spring precipitation in the Great Lakes Basin and specifically the eastern portion of the Great Lakes regardless of which climate models are used. A minimum increase of 10 percent in winter and spring precipitation by mid-century is predicted compared to a baseline of late 20th century or early 21st century. However, larger increases of 15 to 30 percent are also predicted.

In addition, there appears to be consensus around increasing annual temperatures in the Great Lakes Basin and Ontario of a minimum of 5 °F (2.8 °C) and 8 °F (4.4 °C) by mid-century and late-century, compared to the late 20th century respectively regardless of climate models used. These increases are likely to shift snow to rain with increased flooding risk and is anticipated to reduce suitable habitat either by directly making it unavailable (under water) or reducing bog buckbean survival and growth. Increased temperatures may also shift bog buck moth flight periods to later in the fall. It is unclear whether increased temperatures may also directly impact survival or growth rates of any life stage. Shifts in distribution of butterflies in response to increased temperatures have already been documented and it is unlikely that bog buck moths will be able to shift their range.

5.1.3 Invasive Species and Succession

We chose to include cattail, Phragmites, and glossy buckthorn in future scenarios for the bog buck moth. These species were chosen because they are already present at or in areas near to current bog buck moth populations and are expected to cause population level impacts to the bog buck moth when they reduce the amount of suitable bog buck moth habitat. Vegetation succession has also been documented at several sites. Both succession and invasive species can reduce the amount of available suitable oviposition plants and/or larval host plants.

5.2 Scenarios

Using the same methodology and criteria described in chapter 4 for assessing current condition, we modeled two scenarios to assess the potential viability of the bog buck moth up to the mid-21st century (2050 to 2060). We chose to model scenarios out to 30 to 40 years because we have data to reasonably predict potential climate and invasive species changes and their effects on the bog buck moth within this timeframe. In addition, we do not have precise enough information about bog buck moths to differentiate anticipated responses from predicted climate changes between mid- and late-century within the Great Lakes Basin. Based on the information discussed above, we developed two scenarios which are summarized in table 5.1 and further described below.

Table 5.1. Bog buck moth future scenarios.

Scenario Name	Winter and Spring Precipitation	Annual Temperature	Invasive Species and Succession	Parasitoids and Predation
Scenario 1	Increase of at least 10%	Increase of at least 5 °F (2.8 °C)	Glossy buckthorn, phragmites at current levels. Vegetation succession continues at sites where this is already documented.	Maintain at current levels
Scenario 2	Increase of at least 20%	Increase of at least 5 °F (2.8 °C)	Glossy buckthorn, phragmites, cattails and shrubs increase.	Maintain at current levels

5.2.1 Scenario 1

This scenario includes increased winter and spring precipitation, increased annual average temperatures, maintenance of glossy buckthorn and phragmites at current levels, increased cattails and shrubs, and continued influence of parasitoids and predators in boom and bust cycles.

Both scenarios include the same minimum increase of at least 5 °F (2.8 °C) by the mid-21st century, compared to the late 20th century. This scenario also includes an increase of winter and spring precipitation of 10 percent compared to the late 20th century.

Changes in winter and spring precipitation are important to bog buck moths because:

- Increased precipitation leads to increased winter and spring water levels
- Flooding of bog buckbean impacts spring growth of plants
- If flooding happens after buckbean plants have already begun to regrow, later spring flooding impacts overall availability of bog buckbean and alternate larval food sources (only what is above water is available)
- Reduced bog buckbean resulting in reduced bog buck moth larval growth and survival
- Winter and spring flooding impacts egg survival
- Periodic, short-term flooding is important as it helps sets back vegetation succession

Changes in annual temperatures are important to bog buck moths because:

- Increased temperatures shift snow to rain, increasing ablation events, and changes periodic flooding potential
- While there is increased likelihood of flooding of sites in winter and spring, increased annual, summer and fall temperatures are likely to dry out fens in summer or fall, especially in drier years, resulting in increased vegetation succession
- There may be additional compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack but we lack sufficient information on those potential relationships. Such alterations in phenology could impact parasitoid-prey relationships, egg hatch phenology, and pupal eclosion/diapause termination (particularly impactful for a taxon that requires synchronous emergence) (J. Daniels, pers. comm.).

Overall, interacting changes in temperature and precipitation are highly influential in terms of flooding or drying out bog buck moth sites, particularly at the wrong time of the year. These impacts are anticipated to be greatest for the Lakeside subpopulations because flooding risk is already highest at these sites but is also plausible for the other populations. There is a tension between the need for flooding and drying of sites for maintenance of habitat and the impacts of those changes to individual animals. Populations with large areas of habitat and higher numbers of individuals are more likely to be resilient to these impacts.

Under this scenario, we assume that invasive plant species are maintained at their current levels due to periodic management. This may be optimistic because management at bog buck moth sites has been limited to date and is labor intensive and costly (E. Helquist, pers. comm.). However, ongoing vegetation succession continues due to continued nutrient inputs and local water level manipulation as well as increased temperatures and evapotranspiration. In addition, under this scenario, parasitoids and predators continue to influence boom and bust cycles. We lack information to incorporate potential impacts from disease and pesticides.

5.2.2 Scenario 2

This scenario includes greater increased winter and spring precipitation, increased annual average temperatures, increased invasive plants and increased succession, and continued influence of parasitoids and predators in boom and bust cycles.

Both scenarios include the same minimum increase of at least 5 °F (2.8 °C) by the mid-21st century, compared to the late 20th century. This scenario also includes an increase of winter and spring precipitation of 20 percent compared to the late 20th century.

As discussed above, changes in temperature are anticipated to influence bog buck moth populations. This scenario assumes the same effects as described above except the likelihood and severity of flooding increases.

Under this scenario, we assume that invasive plant species are unable to be maintained at their current levels and that ongoing vegetation succession continues. In addition, under this scenario, parasitoids and predators continue to influence boom and bust cycles. We lack information to incorporate potential impacts from disease and pesticides.

5.3 Results

5.3.1 Scenario 1

Under Scenario 1, ongoing threats from flooding, succession, parasitoids, and predation are anticipated to continue to impact the U.S. populations. For the U.S. Representative Unit, the Jefferson County and the Oswego Inland Site populations remain extirpated (figure 5.1, table 5.2). The Lakeside population is anticipated to continue to be in poor condition or extirpated, with increased flooding and succession.

For the Canadian Representative Unit, Richmond Fen is likely to still be in good condition based on the higher resiliency and larger area of suitable habitat of one of the subpopulations to begin with and limited risk of flooding. White Lake is likely to shift to poor condition with periodic flooding and continued parasitoids and predation. Results do not incorporate potential impacts from disease and pesticides. There may be catastrophic events with a pesticide application impacting a year's worth of reproduction, or effects may take time, with pesticides contaminating water supply and entering larval host plants. In addition, we do not fully understand the potential compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack.

While some genetic diversity may remain through the existence of at least one subpopulation within each of the representative units, there is no redundancy of healthy populations in either representative unit.

5.3.2 Scenario 2

Under Scenario 2 (figure 5.2, table 5.3), ongoing threats from flooding, succession, and invasive species are anticipated to continue to impact the U.S. populations. For the U.S. Representative Unit, the Jefferson County and the Oswego Inland Site populations remain extirpated. The Lakeside population is anticipated to also be extirpated resulting in the loss of the U.S. Representative Unit.

For the Canadian Representative Unit, Richmond Fen is likely to change to poor condition based on reduced habitat availability from invasive species/succession. White Lake is likely to shift to poor condition with periodic flooding and continued parasitoids and predation. As with Scenario 1, results do not incorporate potential catastrophic events impacts from disease and pesticides or potential compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack.

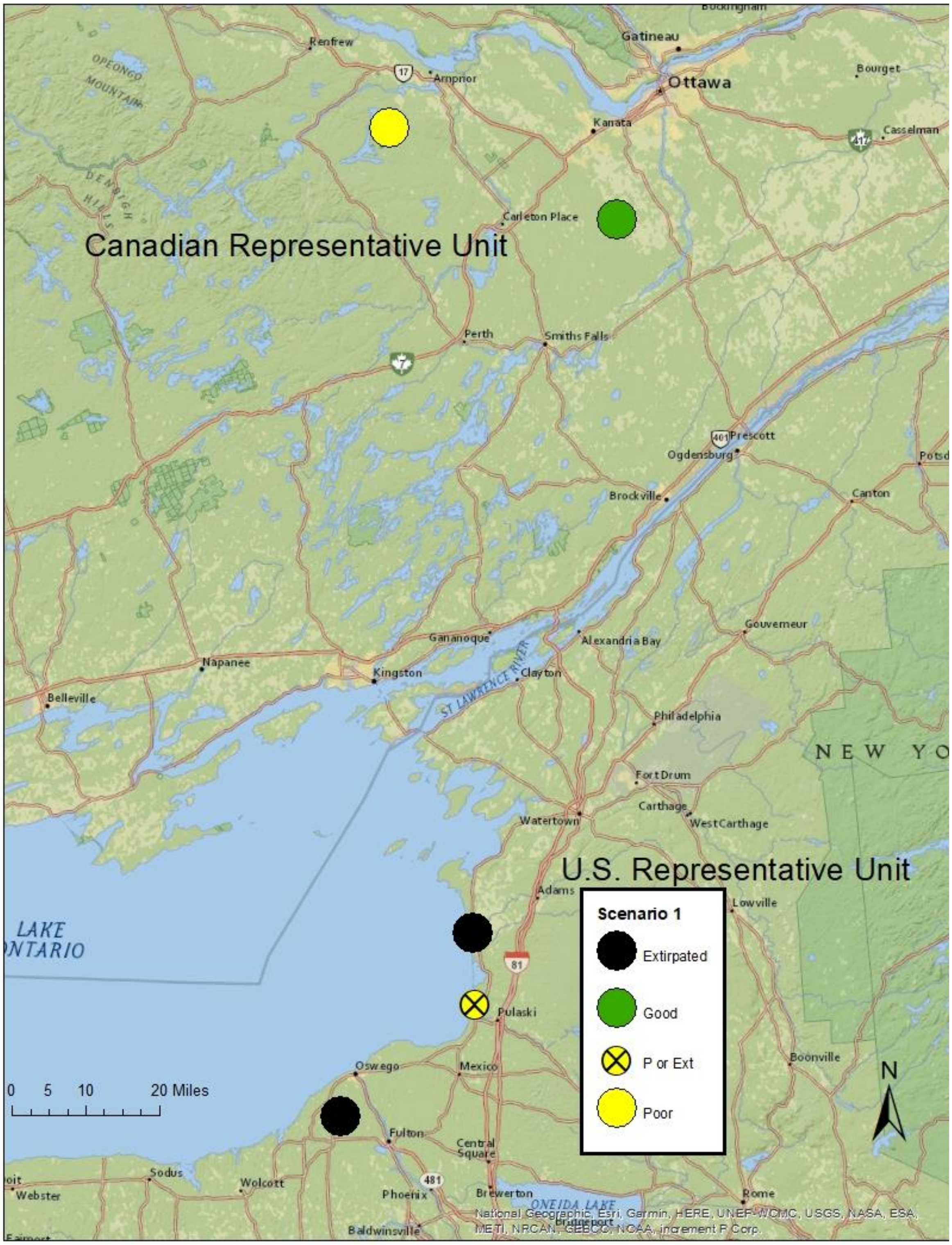

Figure 5.1. Scenario 1 future condition of bog buck moth populations in the U.S. and Canadian Representative Units.

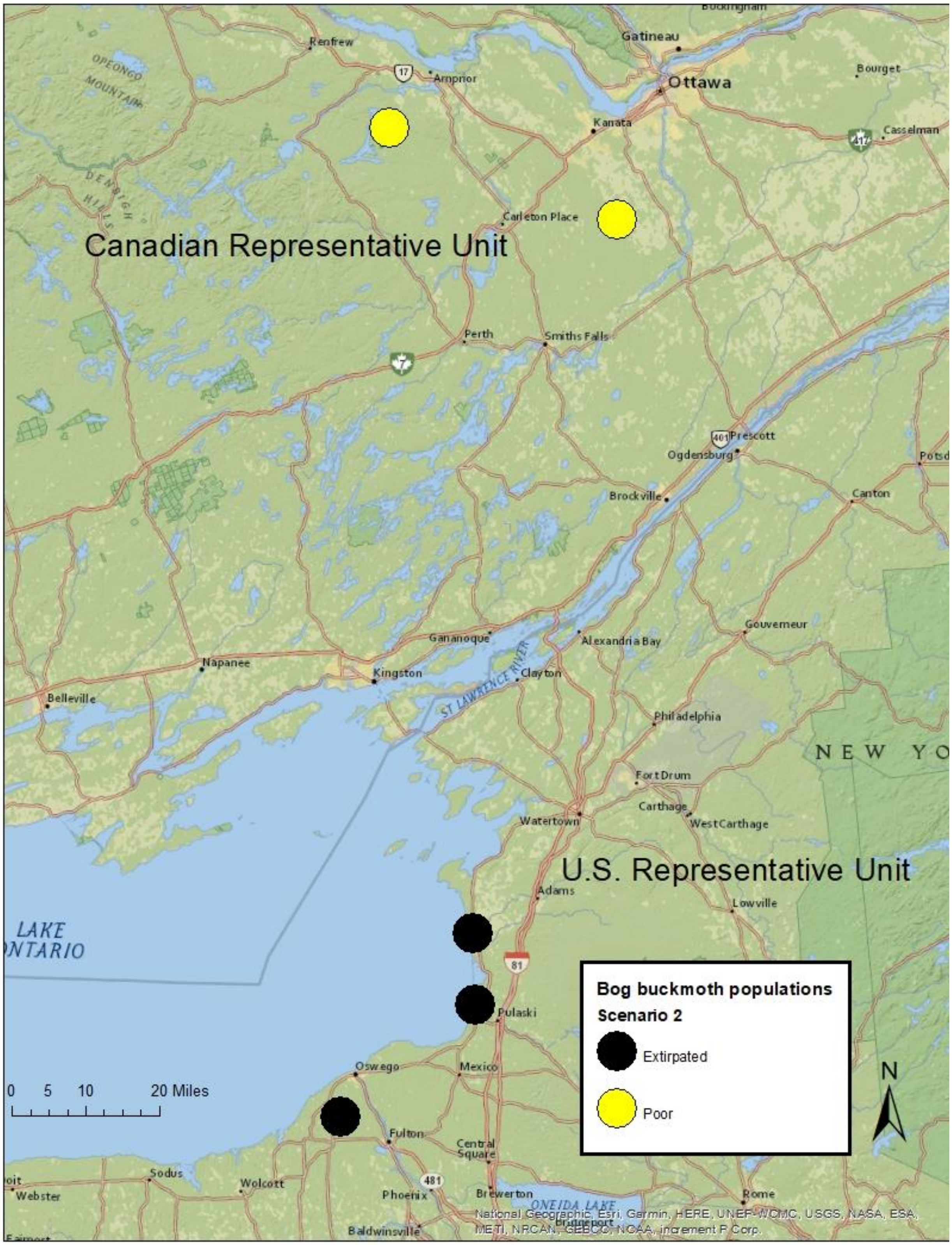

Figure 5.2. Scenario 2 future condition of bog buck moth populations in the U.S. and Canadian Representative Units.

Table 5.2. Scenario 1 future condition of bog buck moth populations. Additional details are found in Appendix E.

Representative Unit	Population Name	Sufficient N	Suitable Habitat	Connectivity	Threats	Current Condition	Future Condition
US	**Jefferson County**	Extirpated	Poor	Poor	Resulted in extirpation	Extirpated	Extirpated
US	**Oswego Inland Site**	Presumed Extirpated	Good	Poor – no change	Resulted in presumed extirpation	Presumed Extirpated	Extirpated
US	**Lakeside**	Poor – no change	Poor – no change	Poor – no change	Increased flooding. Increased succession. Continued parasitoids/predation.	Poor	Poor or Extirpated
Canadian	**White Lake**	Unknown/likely Good – change to Poor	Poor – change	Unknown – no change	Increased flooding. Increased succession. Continued parasitoids/predation.	Unknown/ Likely Good	Poor
Canadian	**Richmond Fen**	Unknown/likely Good – no change	Good – no change	Unknown – no change	Increased flooding. Continuation of minimal succession. Continued parasitoids/predation.	Unknown/ Likely Good	Good

Table 5.3. Scenario 2 future condition of bog buck moth populations. Additional details are found in Appendix E.

Representative Unit	Population Name	Sufficient N	Suitable Habitat	Connectivity	Threats	Current Condition	Future Condition
US	**Jefferson County**	Extirpated	Poor	Poor	Resulted in extirpation	Extirpated	Extirpated
US	**Oswego Inland Site**	Presumed Extirpated	Good	Poor – no change	Resulted in presumed extirpation	Presumed Extirpated	Extirpated
US	**Lakeside**	Poor – no change	Poor – no change	Poor – no change	Increased flooding. Increased succession and invasives. Continued parasitoids/predation.	Poor	Extirpated
Canadian	**White Lake**	Unknown/ Likely Good– change to Poor	Poor – change	Unknown – no change	Increased flooding. Increased succession and invasives. Continued parasitoids/predation.	Unknown/ Likely Good	Poor
Canadian	**Richmond Fen**	Unknown/ Likely Good – change to Poor	Poor – change	Unknown – no change	Increased flooding. Increased succession and invasives. Continued parasitoids/predation.	Unknown/ Likely Good	Poor

5.4 Ability of the bog buck moth to respond to changes

While we focused our analyses on ongoing and anticipated climatic changes and invasive species, we also recognize that novel threats (e.g., disease, new invasive species) may emerge for the bog buck moth. As discussed in chapter 3, the bog buck moth has several inherent traits that limit its ability to respond to changes in its environment, especially to rapid changes. These include its specialized habitat requirements, dependence on appropriate climatic conditions for various life stages, dependence upon a specific host plant, rarity of populations, limited ability to expand to unoccupied habitat, existing exposure to other threats, and boom and bust cycles. The ability for a species to adjust to changes in its environment is related to the features associated with sensitivity (described above) and is facilitated by high levels of phenotypic plasticity, dispersal ability, or genetic diversity (Foden *et al.* 2018, p. 10). These can enable a species to adjust to new conditions by (1) shifting locations, (2) modifying behaviors, physiology or life history, or (3) evolving new traits (Foden *et al.* 2018, p. 10).

Higher dispersal ability of Lepidopterans has been linked to larger wingspan (Sekar 2012, p. 179); less larval host plant specificity (Niemienen *et al.* 1999, pp. 703-704; Sekar 2012, p. 180), longer flight period length (Sekar 2012, p. 181); and feeding as adults (Slade *et al.* 2013, p. 1528). Despite having a large wingspan, the bog buck moth is host-plant specific, has a short adult flight period, and does not feed as adults, and therefore has low dispersal ability. As discussed in chapter 3 and above, it is unlikely that natural dispersal between any extant populations is possible: the two Ontario populations are 50 km (31 mi) apart, and the populations in New York are even farther away from those in Ontario. Environment Canada (2015, p. 6) found that given the fragmented distribution of the buck moth, the potential for natural recolonization should one location become extirpated is severely limited.

Given the limited dispersal ability of the bog buck moth (particularly for females) and specific habitat needs, it is unlikely that the bog buck moth will shift locations, leading to the need to adapt in place. We assume that bog buck moths have the ability to stay in the pupal stage when conditions are poor for a given year, and that plasticity in behavior may be important if poor condition years increase. However, this may not be sufficient to withstand climatic changes. Similar to other butterflies/moths, bog buck moths are likely adapted to their local temperatures, precipitation, and host plants (Aardema *et al.* 2011, pp. 295–297), limiting their potential for adapting in place. In addition, Dupuis *et al.* (2020, pp. 3-4) found low genetic diversity within the species, perhaps further limiting the potential for adapting in place.

In Sweden, between 1950 and 2004, butterflies and moths that were wetland or dry grassland species, were active in the day, had short flight periods, and had specific host plant needs were more likely to have become extinct (Franzen and Johannesson 2007, pp. 373-375). Similarly, for 306 and 284 species of Finnish noctuiid and geometrid moths, respectively, larger bodied monophagous species and species with shorter flight period were at greater risk of extinction (Mattila *et al.* 2006, pp. 1165-1168; 2008, pp. 2324-2325). The bog buck moth is active in the day, is specific to wetlands, has specific host needs, is larger bodied, and has a short flight period and therefore has characteristics similar to moths determined to be at greater risk of extinction.

5.5 Key Uncertainties/Assumptions

- Scenario 1 – ability to maintain current levels of succession in Canada and current levels of invasives rangewide may be overly optimistic resulting in an overly optimistic future condition
- Both scenarios – given that we do not fully understand several possible current factors (parasitoids, predation, disease, and pesticides) impacting population status, we are also unable to consider their possible future impacts. We also lack information to reasonably predict any changes in these factors. However, they likely play a role in current and future condition and the scenarios may be overly optimistic resulting in an overly optimistic future condition.
- Both scenarios – Our future condition for the Canadian Representative Unit is based on the underlying assumption that the two Canadian populations are starting in good condition and may be overly optimistic resulting in an overly optimistic future condition.

5.6 Summary

As discussed above, maintaining populations in both Canada and New York is important to conserve the remaining genetic diversity within the bog buck moth. In addition, maintaining populations across historical latitudinal and climatic gradients increases the likelihood that the species will retain the potential for adaptation over time. The current status of the bog buck moth is poor. The Canadian Representative Unit comprises two potentially healthy populations (table 5.4). In the U.S. Representative Unit, one population is extirpated, one is presumed extirpated, and one is in poor condition. Under either scenario considered, we anticipate a continued declining status of the bog buck moth in the remaining U.S. population due to ongoing and increasing threats, primarily reduced habitat availability and flooding combined with natural boom and bust cycles. We also anticipate similar declines in the Canadian populations reducing their resiliency. These anticipated declines do not incorporate potential impacts from disease and pesticides or the potential compounding effects from changes in temperature associated with shifts in phenology or reduced snowpack. It is unlikely that bog buck moths will disperse and shift their range in response to these habitat changes and bog buck moths have traits similar to other moths that have been at greater risk of extinction.

Table 5.4. Summary of bog buck moth current and future condition.

3Rs	Requisites	Metric	Current Condition	Scenario 1	Scenario 2
Resiliency (able to withstand stochastic events)	Healthy populations	Populations with: • Both sexes present. • Sufficient survival of all life stages • Sufficient number of bog buck moths to survive bust portion of boom and bust cycles. • Stable to increasing trend over last 10 years (10 generations). • Multiple occupied suitable habitat patches within metapopulation. • Sufficient habitat size. • Sufficient habitat quality. • Intact hydrology and ecological processes.	Poor Of the 5 historically known populations: 1 extirpated 1 presumed extirpated 1 poor 2 unknown/ likely good	Poor Of the 5 historically known populations: 2 extirpated 1 poor or extirpated 1 poor 1 good	Poor Of the 5 historically known populations: 3 extirpated 2 poor
Representation (to maintain evolutionary capacity)	Maintain adaptive diversity	Healthy populations distributed across areas of unique adaptive diversity (e.g., across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.	Poor There are two potentially healthy populations in the Canadian Representative Unit and none in the U.S. Representative Unit	Poor There is one healthy population in the Canadian Representative Unit and none in the U.S. Representative Unit	Poor There are no healthy populations

3Rs	Requisites	Metric	Current Condition	Scenario 1	Scenario 2
Redundancy (to withstand catastrophic events)	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events significantly compromising species adaptive diversity.	Poor See above	Poor See above	Poor See above
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.	Poor See above	Poor See above	Poor See above

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Appendix A.1. U.S. Fish and Wildlife Service Bog Buck Moth Taxonomy Finding

This appendix summarizes recent papers discussing the taxonomy of the bog buck moth and provides our conclusion and support for considering the bog buck moth as a valid taxonomic entity for consideration for listing under the Endangered Species Act (ESA). We incorporate several explanations that were provided by Dr. Paul Z. Goldstein, USDA Systematic Entomology Laboratory, Smithsonian Institution.

Overview of Literature

Here we provide a general overview of papers that have discussed bog buck moth taxonomy including a general introduction, genetics, behavior and morphology.

The bog buck moth is a silk moth (family = Saturniidae) in the buck moth genus (*Hemileuca*). The bog buck moth was first identified as a variant of the *maia* species group within *Hemileuca* in 1977 by John Cryan and Robert Dirig from four sites along the southeast shore of Lake Ontario in Oswego County, NY but was not formally named at that time (Legge *et al.* 1996, p. 86; Pryor 1998, p. 126; Cryan and Dirig 2020, p. 3). Four additional sites (two populations) were discovered in 1977 in eastern Ontario (COSEWIC 2009, p. 7). Multiple common names have been used since then (e.g., bogbean buckmoth, Cryan's buckmoth, fen buck moth).

The bog buck moth's taxonomic status has been confusing and uncertain until recently. Ferguson's (1971, entire) Moths of America North of Mexico did not address the bog buck moth. Ferguson (1971, pp. 115-116) described *Hemileuca maia* as the well-known and widely distributed oak-feeding buck moth of the eastern half of the United States. He further stated that along the northern boundary of its range there has been confusion with the *Spiraea*-feeding *H. lucina* and found a perplexing area of overlap in the northern Midwest with the western willow-feeding *H. nevadensis*. It was at this time that Cryan, Dirig, and others began to study the bog buck moth, which they found did not fit into the taxonomic or ecological pattern previously assigned to the *maia* group.

Tuskes *et al.* (1996, p. 111) included the bog buck moth as part of the *Hemileuca maia* complex, which is a broadly distributed group of closely related taxa including *H. maia, H. lucina, H. nevadensis* among others. Tuskes *et al.* (1996, pp. 120-121) further refined the description of populations of buck moths in the Great Lakes region, including the bog buck moth, as the *H. maia complex of Great Lakes Region Populations*. Kruse (1998, p. 109) included includes *H. maia* and *H. nevadensis* as part of the Great Lakes complex; however, using genomewide single nucleotide polymorphisms (SNPs) Dupuis *et al.* (2018, pp. 6) and Dupuis *et al.* (2020, pp. 3) show that *H. nevadensis* is restricted to the west buck moth (figure A.1). The Annotated Taxonomic Checklist of the Lepidoptera of North America (Pohl *et al.* 2016, p. 735) included the Great Lakes populations of buck moths as part of *Hemileuca maia* (based on Tuskes *et al.* 1996), pending species-level taxonomic classification.

Recently, Dupuis *et al.* (2018, pp. 5-7) and Dupuis *et al.* (2020, pp. 2-3) used SNPs and found unambiguous results supporting the conclusion that both Ontario and Oswego County, NY populations are part of the bog buck moth lineage that is divergent from *Hemileuca lucina*, *H. peigleri*, *H. slosseri*, and all other *H. maia* (figure A.1). They also found clear differentiation from Wisconsin and Michigan populations (Dupuis *et al.* 2020, p. 3).

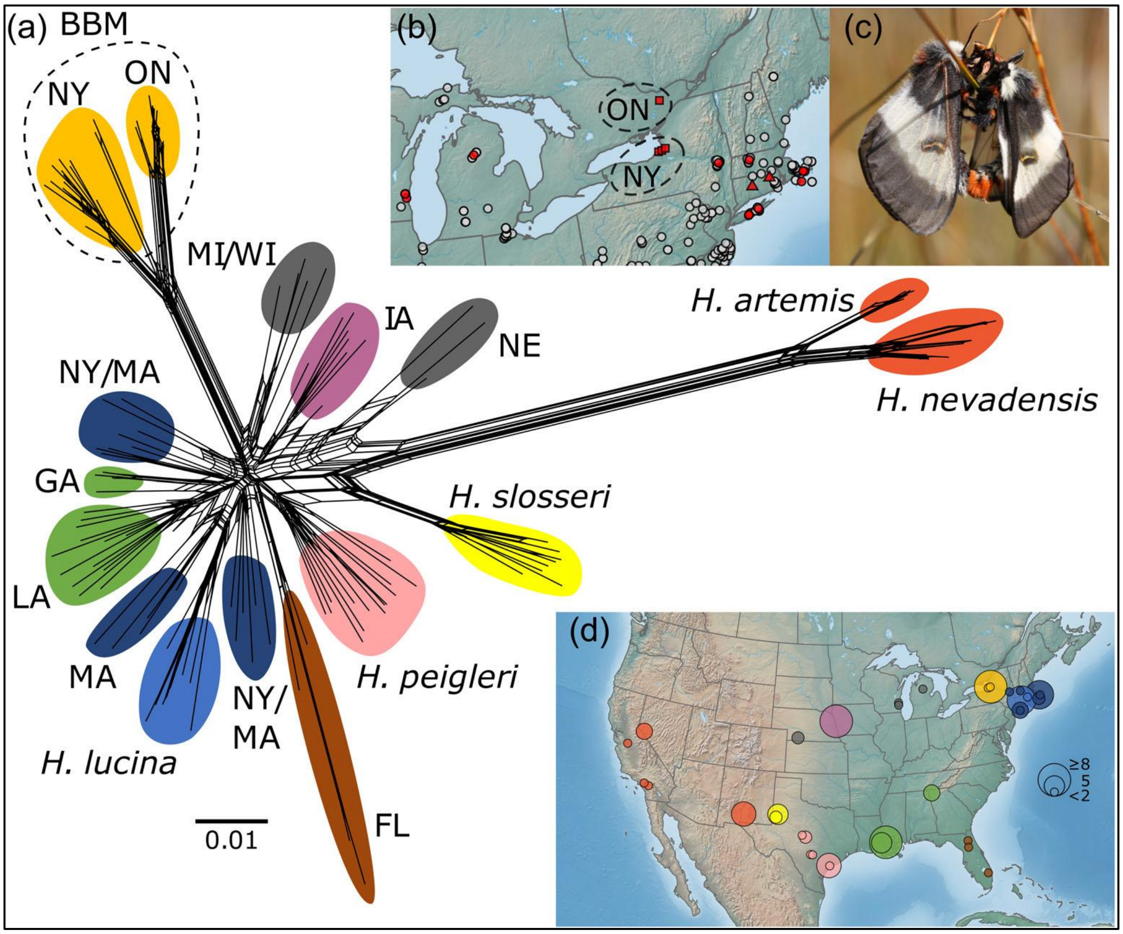

Figure A.1. Neighbornet phylogenetic network generated with SplitsTree (a), specimen samples and *H. maia* occurrence data around the range of the bog buck moth (BBM) (c), photograph of mating BBMs (b), and sampling localities from Dupuis *et al.* (2018) to which Ontario BBM samples were integrated (d). In (a) and (d), colors match those used in the study by Dupuis *et al.* (2018) and state/province abbreviations are used to differentiate *H. maia* groupings. In (b), red shapes indicate sampling localities for ddRAD data (circles: *H. maia*, squares: BBM, triangles: *H. lucina*), and grey dots represent GBIF records matching *H. maia* or *H. maia maia* (accessed 10 December 2019). In (d), circle size indicates sample size per locality (for interpretation of colors in this figure, we refer readers to the web version of this paper). For comparison between Ontario BBM to New York BBM, our New York samples were collected at three localities: Oswego Inland, Lakeside 2 and Lakeside 5. [Color figure can be viewed at wileyonlinelibrary.com](Dupuis *et al.* 2020, p. 3, Figure 1).

The bog buck moth was variously recognized as an undescribed species ("*Hemileuca* sp. 1") by state Heritage programs since the 1980s, as a candidate species by the Service in the 1990s, and as an evolutionary significant unit beginning with the first published mtDNA sequence data (Legge *et al.* 1996, entire). During this time it has been common knowledge that Cryan and

Dirig intended to describe it formally. Their long-awaited recently published description is embedded in the second installment of an unreviewed privately published series as *Pine Bush Historic Preservation Project Occasional Publication No. 2* (Cryan and Dirig 2020, entire). As other researchers, primarily Rubinoff and Peigler, undertook genus-wide molecular phylogenetic research on *Hemileuca* beginning in the early 2000's, they appear to have extended customary professional courtesy to Cryan and Dirig and avoided duplicating their ongoing taxonomic efforts to describe the species. In 2020, Pavulaan (2020, entire) published descriptions of four new *Hemileuca* subspecies, including the name *menyanthevora* (=”sp. 1”), in *The Taxonomic Report*[26].

Pavulaan (2020, pp. 8-14) considered host plant use and morphology for the designation and included the Oswego County, NY, Ontario, and Marquette and Ozaukee County, WI populations as part of the range. However, all specimens used for describing morphology were from one location in Oswego County, NY and he relied on host plant use discussed in Kruse (1998, entire) for inclusion of those two sites (Pavulaan, pers. comm.). Cryan and Dirig (2020, pp. 26-31) subsequently named the bog buck moth as *Hemileuca iroquois*[27] and included the Oswego County, NY, and Ontario populations as part of the range. The diagnoses presented in both Cryan and Dirig (2020, entire) and Pavulaan (2020, entire) are limited, resting primarily on the width of the median band on the forewing relative to similar species/subspecies. For more information on the various studies, see below.

Genetic Analyses

Bartron (2020, entire, Appendix A.2) summarized recent literature that address bog buck moth taxonomy with a focus on relationships based on genetic analyses. Since the 1990s, researchers using multiple marker molecular methods found only minor genetic divergence for the entire Great Lakes complex group (Legge *et al.* 1996, entire; Rubinoff and Sperling 2004, entire; Rubinoff *et al.* 2017, entire). The consensus was that ecological characters evolved much more rapidly in the Great Lakes complex of buck moths than did the genome as a whole, as sampled with 'standard' markers used with Lepidoptera. Most recently, SNP data support significant differentiation of the bog buck moth as representative of a genetically unique group (Dupuis *et al.* 2018, entire; 2020, entire). Specifically, Dupuis *et al.* (2018, pp. 5-7) and Dupuis *et al.* (2020, pp. 2-4) found unambiguous results supporting the conclusion that both Ontario and Oswego County, New York populations are part of the bog buck moth lineage that is divergent from *Hemileuca lucina*, *H. peigleri*, *H. slosseri*, and all other *H. maia*. They also found clear differentiation from Wisconsin and Michigan populations (Dupuis *et al.* 2020, p. 3), counter to the range used by Pavulaan (2020, entire).

[26] Pavulaan is Editor

[27] which was described as a “semi-species,” an explicit hybrid of *H. maia* and *H. nevadensis*. The term “semispecies” is borrowed from Mayr, but is not a rank recognized by the ICZN.

Host Plants

Hemlileuca peigleri feed on various species of oaks (*Quercus* sp.) (Peigler and Stone 1989, pp. 156-157). *Hemileuca nevadensis* primarily feed on willows (*Salix* sp.) and cottonwoods (*Populus* sp.) (Tuskes *et al.* 1996, p. 118). *Hemileuca lucina* feed primarily on meadowsweet (*Spiraea latifolia*) (Scholtens and Wagner 1997, p. 47; Schweitzer 2007, p. 4). Most populations of *Hemileuca maia* feed on oaks (Peigler and Stone 1989, p. 156; Tuskes *et al.* 1996, p. 114) and those of the Great Lakes Population complex feed on willows (Tuttle *et al.* 2020, p. 18). Bog buck moth larvae in New York and Ontario may feed on a variety of host plants but appear to require the bog buckbean (*Menyanthes trifoliata*). Bog buckbean is also used by two buck moth populations in Wisconsin (Kruse 1998, p. 110); however, it is not common at these sites and its use by buck moths is incidental (J. Watson, pers. comm).

Morphology

In the Great Lakes Population complex, Tuskes *et al.* (1996, p. 120) observed a north-south cline in adults with translucent *lucina*-like adults in the north and dark, *maia*-like adults in the south and an east-west transition from *lucina*-like adults in the east with narrow white forewing bands to *nevadensis*-like adults in the west with wide white forewing bands except for the bog buck moths which have wider wing bands. Overall they found that members of the Great Lakes populations were impossible to separate phenotypically from other currently named taxa (Tuskes *et al.* 1996, p 121).

Scholtens and Wagner (1997, pp. 49-51) similarly observed increased forewing length, decreased forewing white band width, and increased darkness from north to south (Canada, Michigan, and Ohio). They found no morphological or host plant information to definitively put the Great Lakes *Hemileuca maia* into one of the recognized species (Scholtens and Wagner 1997, pp. 54-55).

Tuttle *et al.* (2020, p. 21) observed that Oswego County, NY bog buck moths have faint, pale yellow stippling while the bogbean-feeding population in Ozaukee County, WI had both boldly striped and faint, weakly striped larvae.

Cryan and Dirig (2020, p. 26) state that the best diagnostic characteristic of adult bog buck moth are white wing bands that are narrower than *Hemileuca nevadensis, latisfascia*[28], and *artemis*, but wider than *H. maia, lucina, peigleri,* and *slosseri*. They also report that wings are more transparent than all but *H. lucina* and the northern part of the Great Lakes Population in Michigan. They found that larvae have a very limited, broken stripe in later instars.

Pavulaan (2020, p. 9)[29] states that bog buck moths are distinct yet nearly identical to *Hemileuca lucina.* He finds them to be larger than other *H. maia* species and with larger median bands. He also found that female wings are not as broad as other *H. maia* and wings are more rounded and possess dark gray wing margins on both sets of wings.

[28] Few authors accept *Hemileuca latisfascia* as a valid name/taxon (M. Collins, pers. comm.).
[29] The accession number is 2005-15 for the *H. m. menyanthevora* and the collection numbers read MGCL/FLMNH Specimen no. 136026 on the allotype and UF/ FLMNH/ MGCL 1053173 for the holotype.

Reproductive Behavior

At least some populations within the Great Lakes complex of buck moths appear to be reproductively isolated from the eastern, oak-feeding *Hemileuca maia*. *Hemileuca maia* females from southern Ohio and western Massachusetts failed to attract *maia*-like males from northern Ohio (along the Great Lakes) while local *H. maia* females attracted the males (Tuskes et al. 1996, p. 120). Similarly, Tuttle *et al.* (2020, pp. 21-26) found that caged oak-feeding *maia* females did not attract wild willow-feeding Great Lakes population males and that Great Lakes willow-feeding females did not attract wild oak-feeding *maia* males. However, using a similar pheromone test, a captive female bog buck moth (Oswego County, NY) did attract a willow-feeding *maia*-like male from northern Ohio (and vice versa) and Tuttle *et al.* (2020, p. 27) suggests this is strong evidence of a recent lineage between the Great Lakes Population willow and bog buckbean feeders. Bog buck moths were crossed with Wisconsin bog buckbean-feeding buck moths and the average crossing reproductive success was 50 to 60 percent with some crosses failing altogether (Dirig, personal communication). As two taxa diverge genetically from a common ancestor, increasing incompatibility in test crosses would be expected (Tuttle *et al.* 2020, p. 27).

Relevant Law, Regulation, and Policy

The Service must base its ESA listing determinations solely on the best available data. Under section 3(16) of the ESA, only species, subspecies, and distinct population segments of vertebrate species are considered listable entities. The ESA's implementing regulations at 50 CFR 424.11(a) and a 1992 Service Director's Memorandum on "Taxonomy and the Endangered Species Act" (Service 1992) provide guidance on how to consider taxonomic information when assessing a species for listing under the ESA. Under the regulation, in determining whether a particular taxon or population is a species for the purposes of the ESA, the Secretary is to rely on standard taxonomic distinctions and the biological expertise of the Department and the scientific community concerning the relevant taxonomic group. The Memorandum specifies that "we are required to exercise a degree of scientific judgment regarding the acceptance of taxonomic interpretations, particularly when more than one possible interpretation is available." The Memorandum further states that, "When only one credible taxonomic authority is available, we accept it. This would apply in cases of findings by AOU, monographs and revisions, and species descriptions that have not been challenged by knowledgeable scientists," and "When informed taxonomic opinion is not unanimous, we evaluate available published and unpublished information and come to our own adequately documented conclusion regarding the validity of taxa," and "When we have credible scientific evidence of the existence of an undescribed taxon that qualifies for listing under the Act, we treat it as we would any other species, i.e. assign a priority and prepare a proposal as appropriate."

Thus, we address whether existing data support designation of the bog buck moth as a distinct species or subspecies. We compare the available and relevant morphological, ecological, and genetic data to established criteria for designating subspecies.

Conclusion Regarding Listable Entity

There is no universally accepted definition of a subspecies and this term is not defined in the ESA. Patten (2010, p. 36) described four important features about the nature of subspecies: (1) a subspecies is not reproductively isolated from other subspecies of that species, (2) its defining features have a genetic or developmental basis, (3) it has a unique breeding range separate from that of other subspecies, and (4) it is diagnosably distinct from other subspecies. Patten and Unitt (2002, p. 27) summarized those concepts into the definition "diagnosable clusters of populations of biological species occupying distinct geographic ranges."

Dupuis *et al.* (2018, entire; 2020, entire) provide genetic evidence that bog buck moth is diagnosably distinct from all other *Hemileuca* species and subspecies, a conclusion that was endorsed by peer reviewers of the draft SSA (Chambers, pers. comm., Collins, pers. comm., Goldstein, pers. comm.). Morphological characteristics described by Pavulaan (2020, entire) and Cryan and Dirig (2020, entire), albeit limited, support the genetic evidence. We find this information to be markedly more persuasive than host plant information from Kruse (1998, entire) that Pavulaan relied upon when including two Wisconsin sites in the range, noting also information from J. Watson (pers. comm.) that bog buckbean is not common at the Wisconsin sites and its use by buck moths is incidental. The bog buck moth also clearly satisfies the "unique breeding range" criterion with its separation from the other subspecies of over 200 kilometers (124 miles) in New York. Thus, we conclude that the bog buck moth satisfies this definition of subspecies[30].

Conclusion Regarding Name and Distribution of Taxonomic Entity

Although Pavulaan (2020, entire) and Cryan and Dirig (2020, entire) became available less than 48 hours apart, the official scientific name has to follow the rule of publication priority under the International Code of Zoological Nomenclature which dictates that the species name *Hemileuca iroquois*, which was the second name put forth, be rendered a junior synonym of the subspecies *H. maia menyanthevora* pending formal status revision. Based upon the strong evidence provided by Dupuis *et al.* (2018, entire and 2020, entire), we consider the current range of *H. maia menyanthevora* as Oswego County, NY and Ontario[31].

[30] Pavulaan (2020) and Rubinoff (pers. comm.) have suggested that the bog buck moth may merit full species status. Consistent with ICZN rules, the status is a subspecies based on priority of naming. Therefore, we consider the bog buck moth to be a subspecies unless and until a formal review revision is conducted.

[31] This is consistent with the range described when the Service originally considered the bog buck moth (*Hemileuca* sp.) as a Category 2 Candidate in 1991 (56 FR 58804). It is also consistent with the range described by NatureServe (2020, pp. 1-4) and COSEWIC (2009, pp. 5,7).

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Appendix A.2. Review of recent literature to support taxonomic decision for the bog buck moth

by

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Determination of species and subspecies characterization is critical for appropriate management and conservation of a species. Incorporation of multiple lines of evidence, ranging from life history, environmental parameters, genetic data, and other factors all can contribute to identification of the proper relationships between populations and species. In the case of the bog buck moth and other species within the *Hemileuca* complex, taxonomic relationships were initially identified based on various morphological and life history traits. Increasingly, genetic tools have been used to improve resolution within the *Hemileuca maia* species complex, with specific focus on the bog buck moth found in the northwestern region of New York along Lake Ontario, and extending north into Ontario, Canada. This review will focus on discussion of the recent literature related to bog buck moth taxonomy.

The term bog buck moth is used in variations in the papers referenced below: Sime 2019 refers to "bog buck moth" as (*Hemileuca nevadensis*), Dupuis *et al.* (2018 and 2020) refers to "bog buck moth" as "*H. maia* (bog buck moth)", Buckner *et al.* (2014) refers to "bog buck moth (*H. maia*)." Regardless of the specific nomenclature used by the individual paper authors, the specific group of individuals that are the focus of this review is the buck moths that are found in Oswego County, NY, along Lake Ontario and extending north into Ontario, Canada. Recent publications (Cryan and Dirig 2020 and Pavulaan 2020) propose new classification for the bog buck moth and vary in the geographic range they included.

This summary of genetic information highlights the evolution of molecular techniques over time and their application to understand species and population relationships. Each study is challenged with small samples sizes in part due to declining populations, populations that are currently locally extirpated, or difficulties with conducting field collections. Each successive study included an increasing number of markers (genetic sequencing to AFLPs to SNPs), resulting in an improved ability to offset low sample size and to resolve population and phylogenetic differences within the *Hemileuca* complex, specifically within *H. maia*.

Three primary questions about the genetic relationship of bog buck moth were evaluated as the focus of this review: (1) are bog buck moth populations more closely related to *Hemileuca maia* than to other named species, (2) are the Michigan and Wisconsin populations more closely related to eastern populations described as bog buck moth than to other Midwestern populations of *H. maia* not associated with fens or *Menyanthes* and (3) are the eastern bog buck moth populations in Oswego County, NY and Ontario, Canada each other's closest relatives.
Of the recent literature reviewed, the most applicable to resolve all three questions is the most recent Dupuis *et al.* (2020) analysis. Due to the inclusion *H. maia* and other *Hemileuca* sp. from various parts of its range, and a single nucleotide polymorphism (SNP)-based dataset resulting in a large number of genetic data points (2354 SNPs, Dupuis *et al.* 2020) used to compare among all samples, Dupuis *et al.* (2020) expanded on Dupuis *et al.* (2018) to include bog buck moth

from Ontario, Canada. Rubinoff *et al.* (2017), Rubinoff and Sperling (2004), and Buckner *et al.* (2014) address specific questions about the relatedness among populations of bog buck moth and among bog buck moth and other subspecies.

Prior to Dupuis *et al.* (2020), it was observed that bog buck moth was most genetically similar to *Hemileuca maia* (Rubinoff and Sperling 2004; Rubinoff *et al.* 2017; Dupuis *et al.* 2018) and not *H. nevadensis*. However, bog buck moth was identified as a genetically distinct group from both *H. maia* (including *H. lucina*, *H. peigleri* and *H. slosser*i), and *H. nevadensis* (including *H. artemis*) (Dupuis *et al.* 2018; 2020). Earlier studies such as Rubinoff and Sperling (2004) did not find bog buck moth to be monophyletic, and with the exception of an individual classified as *H. nevadensis,* primarily bog buck moth was genetically most similar to other *H. maia*. Rubinoff *et al.* (2017) identified the bog buck moth from New York to be monophyletic for the consensus trees with a high degree of bootstrap support, but genetically differentiated from what was also considered to be bog buck moth from Wisconsin (Michigan samples were not included), and in fact more closely related to other *H. maia* populations from elsewhere in its range. Dupuis *et al.* (2018 and 2020) supported the finding of Rubinoff *et al.* (2017) that the bog buck moth from New York (Dupuis *et al.* 2018) and Ontario (Dupuis *et al.* 2020) were a different genetic group, and hypothesized that Michigan and Wisconsin bog buck moth, which share similar ecology to New York and Ontario bog buck moth and had likely been geographically isolated, resulting in the genetic differentiation.

The cause for the observed significant genetic differences between bog buck moth and other *Hemileuca* species identified by studies conducted prior to Dupuis *et al.* (2020) was not clear. One hypothesis is that the genetic divergence was a unique occurrence due to more recent isolation and lack of gene flow with other bog buck moth such as those in Michigan and Wisconsin, or with other *H. maia*. In this case, the genetic divergence of bog buck moth would be due to genetic drift and loss of genetic diversity due to small population sizes relative to other, more larger or connected populations. In this case, divergence would not represent a more long-term evolutionary divergence resulting from speciation. Buckner *et al.* (2014) demonstrated gene flow between fen areas locally, the diversity within the New York collection may just reflect a single group that had been under similar genetic isolation from the broader species even when multiple sites from within the same localized area were analyzed. However, the inclusion and observed genetic relationships of the bog buck moth from Ontario indicated the single population isolation hypothesis was unllikely, but rather as suggested by Dupuis *et al.* (2020), bog buck moth distribution was more likely widespread in favorable wetland habitat around the Lake Ontario. Slight genetic differences observed between New York and Ontario bog buck moth were likely due to a recent loss of connectivity between the New York and Ontario sites, and these differences were significantly less than those between the New York site and any other *H. maia*. The genetic data presented in Dupuis *et al.* (2018; 2020) support significant differentiation of bog buck moth as representative of a unique genetic group.

Rubinoff and Sperling 2004

In order to better understand the genetic relationships within the *Hemileuca maia*, *H. nevadensis*, and what was considered as undescribed taxa at the time, the bog buck moth, Rubinoff and Sperling (2004) sequenced a region of the COI gene of mitochondrial DNA (624 base pairs). To characterize the bog buck moth, four samples from one location in New York (Oswego County), and three from Wisconsin (2 from Marquette County and 1 from Ozaukee County) were sequenced, including five individuals used to describe *H. maia*, and four individuals to describe *H. nevadensis*, including species from the *H. electra* complex and other *Hemileuca* species considered outgroups from the western and southwestern United States. The maximum parsimony consensus analysis placed the bog buck moth within the *H. maia* complex, but did not support either the bog buck moth or *H. maia* to be monophyletic. Specifically, one individual from Wisconsin was identified to be *H. nevadensis*. With that exception, bog buck moth grouped primarily with *H. maia*, with the other *H. nevadensis* individuals grouping separately. The lack of monophyly indicated to Rubinoff and Sperling (2004) that the bog buck moth is not isolated from surrounding *H. maia* populations elsewhere. However, this analysis was limited to a single mtDNA gene region, although built upon previous work which evaluated nuclear gene sequencing (Rubinoff and Sperling 2002). Given the low sample sizes, and the limitation to a single mitochondrial gene, if as the authors hypothesized that more recent genetic contact among bog buck moth and *H. maia* has occurred, use of additional genetic markers could potentially reveal finer-scale levels of genetic differentiation not detected in this study.

Buckner *et al.* 2014

This study used analysis of amplified fragment-length polymorphisms (AFLPs) to generate estimates of genetic diversity among sampled bog buck moth. Samples were limited to two sites within Oswego County, NY. The Oswego Inland Site was represented by 22 individuals, and Lakeside 5 was represented by 14 individuals. In total, ALFP analysis was able to use 203 fragments to compare individuals from the two sites. Analyses indicated two genetically distinct genetic clusters based on STRUCTURE (Pritchard *et al.* 2000). However, both sites had individuals from each genetic cluster present, and neither site had sufficient genetic differences that would allow discrimination between sites. Because individuals of both genetic groups were identified at each of the two sample sites, Buckner *et al.* (2014) inferred that these results indicated historic gene flow between the two sites, providing insight into the migratory distance potential for bog buck moth. This finding is important, demonstrating genetic connectedness (gene flow) between the two sites, and the potential for dispersal at least up to 30 km given the distance between sites. Alternately, historic sites interspersed between the two sites sampled in Buckner *et al.* 2014) may have also helped to facilitate gene flow between sites as well. No other *Hemileuca maia* from other locations were included in Buckner *et al.* (2014), so no genetic comparisons of these two sites to other bog buck moth or other *Hemileuca* spp. were made.

Rubinoff *et al.* 2017

Building upon previous studies (Rubinoff and Sperling 2002, Rubinoff and Sperling 2004), Rubinoff *et al.* (2017) expanded regions of mitochondrial DNA and included nuclear DNA to evaluate the evolutionary relationships among *Hemileuca maia*, *H. lucina*, and bog buck moth. Four gene regions were sequenced for analysis, including one mitochondrial DNA gene, and three nuclear genes. Using both mitochondrial and nuclear regions provides insight about genomes with different mutations rates and can inform whether there is sex-linked dispersal mediated gene flow or patterns of variation.

Individual gene maximum likelihood trees revealed different genetic relationships among individual groups. For example, based on cytochrome c oxidase I (mitochondrial genome), bog buck moth in New York are monophyletic, but not if considering the Wisconsin bog buck moth.

Nuclear based gene trees showed more random similarities among individuals, and branch lengths were shallow (Rubinoff *et al.* 2017). Consensus trees (combined results for all four gene regions analyzed) identified New York bog buck moth as monophyletic; however, neither the maximum likelihood nor Bayesian consensus trees identified the Wisconsin bog buck moth with the New York bog buck moth: in both cases the most similar were other *Hemileuca maia* samples. Individuals from Michigan and Ontario were not included in these analyses.

Dupuis *et al.* 2018

Understanding the distribution of characters among populations and the inference of relationships among those populations may inform the composition of named species.

Dupuis *et al.* (2018) used genomewide single nucleotide polymorphisms (SNPs) to quantify genetic relationships among individuals range-wide across the *Hemileuca* species complex. Although sample size for the bog buck moth was lower in comparison to Buckner *et al.* (2014), the advantage of the approach used by Dupuis *et al.* (2018) was the number of data points available to compare individuals for population (2,111 SNPs) and phylogenetic (43,424 sites) analysis, and covered a larger portion of the genome (903,168 base pair alignment). Sample sizes ranged from 3 to 20 individuals per species or location (multiple locations were sampled for *H. maia*) for a total of 119 samples (Dupuis *et al.* 2018). The low sample sizes would normally be considered too small to provide informative results about population genetic structure using other marker types, but the large number of genetic comparisons possible through the number of SNPs evaluated in this study should not limit inferences about population or phylogenetic structure. For example, Nazareno *et al.* (2017) evaluated the impact of sample size on inferences of genetic structure for a plant species, and found that estimates of genetic diversity did not significantly change when sample sizes greater than eight individuals with more than 1000 SNPs were evaluated. Specific to bog buck moth (*H. maia*), samples were only available from New York along the shore of Lake Ontario, and did not include potential locations from Canada.

Dupuis *et al.* (2018) evaluated hierarchical population and phylogenetic structure using a variety of analysis methods. STRUCTURE was used to evaluate genetic relationships among all species and populations sampled. This method considers the potential number of genetic groups present in the sample based on differences in genetic data without (a priori) knowledge of the number of sample groups within the dataset. Evaluation of the potential number of groups indicated two likely numbers of groups within the data: K=3 and K=11 (Dupuis *et al.* 2018). The analysis of ΔK evaluates the rate of change in the log probability of data between successive K values. The analysis is sensitive to the marker type used, based on the variability of the markers considered, however given the large number of SNP loci considered in this analysis simulations considered in Evanno *et al.* (2005) indicate that little if any bias would be observed. Dupuis *et al.* (2018) indicated the optimal number of groups based on ΔK was 3: *Hemileuca nevadensis* with *H. artemis*; *H. maia* (bog buck moth); and the remaining *Hemileuca* species that were evaluated (*H. slosseri, H. peigleri, H. maia, H. lucina*). Under a K=11 scenario, again *H. nevadensis* and *H. artemis* were grouped, and most of the species hypotheses were identified as unique with the exception of the *H. maia* complex, which indicated genetic structuring within the group. It is important to note that under both K scenarios (K=3 and K=11), the bog buck moth (*H. maia*) from samples obtained in western New York represented a distinct genetic group.

Other analyses conducted by Dupuis *et al.* (2018) included a maximum-likelihood consensus tree and distance-based phylogenetic network. Both resulted in differential groupings of individuals consistent with the STRUCTURE analyses based on K=11. In each case, the bog buck moth from New York represented a separate cluster of individuals. F_{ST} was used to compare pairwise differences between populations. All pairwise comparisons between the bog buck moth (*Hemileuca maia* in New York) and all other sample groups (including other *H. maia* and other *Hemileuca* sp.) were statistically significant.

Dupuis *et al.* (2018) addresses two of three of our primary questions (1) are bog buck moth populations more closely related to *Hemileuca maia* than to other named species – yes; (2) are the Michigan and Wisconsin populations more closely related to eastern populations described as bog buck moth than to other Midwestern populations of *H. maia* not associated with fens or *Menyanthes* – no; and could not address the third question (3) are the eastern bog buck moth populations in Oswego County, NY and Ontario, Canada each other's closest relatives.

One question that is unresolved from Dupuis *et al.* (2018) is the mechanism for why the bog buck moth (*Hemileuca maia* New York) is so genetically differentiated from other *H. maia* and *Hemileuca* sp. Given the demographic history of the population (Sime 2019, Cryan and Dirig 2020), the population may have had gene flow occurring within its range (at least the two fens sampled in Buckner *et al.* 2014), but may have undergone a genetic bottleneck due to the reduced number of individuals in the population. Neither Buckner *et al.* (2014) or Dupuis *et al.* (2018) tested specifically for evidence of genetic bottleneck. The observed heterozygosity for the bog buck moth from New York was less than other *H. maia* locations (H_o=0.044, Dupuis *et al.* 2018), and the inbreeding coefficient (G_{IS}= 0.215, Dupuis *et al.* 2018) was higher in comparison to most other *H. maia* sites, which both support a likely decrease in genetic diversity as a result of either isolation or decreased population locally.

Alternately, another hypothesis is that isolation from other *Hemileuca maia* populations has resulted in genetic drift resulting in the differentiation, and that the genetic differences are a result from that genetic drift occurring independently specifically for the bog buck moth group in New York (Dupuis *et al.* 2020). Without inclusion of additional bog buck moth from the Ontario, Canada portion of the suspected range, it was difficult to conclude which hypothesis was appropriate for the New York bog buck moth.

The results from Dupuis *et al.* (2018) call into question the current taxonomic delineations among *Hemileuca* sp. throughout their range. Although genetic data is not the sole information used in identification of a species, the current species descriptions are not fully supported by the genetic data presented in Dupuis *et al.* (2018).

Dupuis *et al.* 2020

The primary change from Dupuis *et al.* (2018) was the addition of bog buck moth samples from Ontario. Dupuis *et al.* (2018) found that the bog buck moth in New York was genetically divergent from *Hemileuca maia* (including *H. maia* found elsewhere in New York) as well as bog buck moth found in Wisconsin and Michigan. Given the observed divergence, the mechanism and subsequent conservation implication was not clear. If divergence was due to population isolation, then differentiation could be due to effects of genetic drift in small populations, rather than reflect a more specific evolutionary adaptation or divergence due to selection. However, if inclusion of additional samples of what was thought to be a connected population from Ontario was similarly divergent, then likely the genetic differences observed for the New York bog buck moth reflected some different lineage.

Dupuis *et al.* (2020) addresses all three of our primary questions (1) are bog buck moth populations more closely related to *Hemileuca maia* than to other named species - yes, (2) are the Michigan and Wisconsin populations more closely related to eastern populations described as bog buck moth than to other Midwestern populations of *H. maia* not associated with fens or *Menyanthes* - no and (3) are the eastern bog buck moth populations in Oswego County, NY and Ontario, Canada each other's closest relatives - yes.

Slight differences between the New York and Ontario bog buck moth populations (nonsignificant pairwise Jost's D distances, Dupuis *et al.* 2020), and genetic clustering (neighbornet phylogenetic network, Dupuis *et al.* 2020) indicated gene flow may have decreased more recently between the two groups, likely due to loss of favorable connecting habitat (Dupuis *et al.* 2020). As with previous studies, sample sizes were small (New York n=14, Ontario n =11), but a total of 2354 SNPs were available to be compared among all samples (Dupuis *et al.* 2020) which can help to offset limitations of small sample sizes to reveal patterns of genetic variation. Both the New York and Ontario bog buck moth had low estimates of heterozygosity, indicating that sites are potentially losing some diversity due to declining population sizes and decreased connectivity.

Pavulaan 2020

This paper describes the new subspecies *Hemileuca maia menyanthevora* Pavulaan 2020, Bogbean Buckmoth. The description of the new subspecies by Pavulaan (2020) is based on evaluation of morphology, habitat, hosts, distribution, and includes reference to genetic results from Rubinoff *et al*. (2017) and Dupuis *et al.* (2018). This new subspecies includes what Dupuis *et al.* (2018) referred to as the bog buck moth (*H. maia*). Specifically, Pavulaan (2020) included wetland-associated populations in northern New York State (which would include those included in Buckner *et al.* (2014) and Dupuis *et al.* (2018), around Ottawa, Ontario, and also southwestern Wisconsin. The inclusion of the Wisconsin group as part of the newly described subspecies is not supported by the findings of Rubinoff *et al.* (2017), Dupuis *et al.* (2018) or Dupuis *et al.* (2020), where the genetic results indicated that the New York and Ontario groups were genetically similar, but more distantly related to the Michigan and Wisconsin groups. In the introduction to the subspecies description, Pavulaan (2020) states "It is not clear whether the New York, Wisconsin, and Ontario populations all represent the same exact taxon." The genetic results of Dupuis *et al.* (2018) did not include the Ontario, Canada populations but clearly showed that the New York group was genetically distinct from Wisconsin populations. Dupuis *et al.* (2020) included the Ontario, Canada group and supported the genetic grouping of New York and Ontario, as separate from Wisconsin. Both Dupuis *et al.* (2018) and (2020) included samples from Michigan, which grouped genetically with the Wisconsin population, but Pavulaan (2020) did not address the status or inclusion of the Michigan group in the new subspecies description.

Cryan and Dirig 2020

This paper focused on describing *Hemileuca iroquois* (*H. maia x H. nevadensis*), S. n. p., incorporating information on the species distribution, habitat and ecology, life history, morphology, and genetic relationships. No new genetic information was used to base the determination on Cryan and Dirig (2020) to describe this new species, which would include the bog buck moth from New York and Ontario.

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Appendix B. Activities likely to destroy the critical habitat of the buck moth (Environment Canada 2015, Table 2, pp. 15-18)

Description of Activity	Description of effect in relation to function loss	Details of effect (including related threat, scope, and thresholds)
Activities (e.g., digging, clearing, or gathering) that cause vegetation removal	If it occurs within the fen, can result in the direct physical removal of individuals of the species' primary larval host, Bogbean and other plant species used by the Bogbean Buckmoth during its lifecycle (e.g., for feeding or egg laying). Done at a large scale within the fen, it could alter the plant community (abundance of plant material and species composition) such that the habitat is no longer suitable for Bogbean and/or other plant species used by the Bogbean Buckmoth during its lifecycle (e.g., for feeding or egg laying). If it occurs on a large scale either within or outside critical habitat, it could also alter the fen's water regime- see below.	Bogbean Buckmoths are dependent on the vegetation communities found in fens; removal or alteration of the vegetation community could therefore result in destruction of critical habitat. The activity could cause destruction of critical habitat at any time throughout the year, because the species' entire lifecycle, from egg to moth, occurs in the fen. The activity could cause destruction of critical habitat if it occurs within or outside the bounds of critical habitat. Vegetation removal within the fen would directly result in the destruction of critical habitat. Effects of vegetation removal within the 120m zone surrounding the fen boundary or outside of critical habitat would be predominantly cumulative; the activity could gradually lead to the destruction of critical habitat and would be more likely to cause destruction if it occurs within the 120m zone than if it occurs outside of critical habitat. The information available at this time is insufficient to develop a threshold for the amount of vegetation that could be removed without causing the destruction of critical habitat.
Peat removal	If it occurs within the fen, can result in the direct physical removal of the species' pupation sites as well as primary larval host, Bogbean, and other plant species used by the Bogbean Buckmoth during its lifecycle (e.g., for feeding or egg laying). If it occurs within or outside of critical habitat, it can also alter the fen's water regime- see below. This activity may also require vegetation removal- see above.	Because the Bogbean Buckmoth uses specific fen vegetation communities for the entirety of its lifecycle, peat removal that causes changes in the hydrological cycle, that in turn alters the vegetation community, can result in the destruction of critical habitat at any time throughout the year. The activity does not have to occur within the bounds of critical habitat to cause its destruction; for example, in the event that peat is removed in a location that is hydrologically linked to the water table supporting the critical habitat.

		Peat removal within the fen would directly result in the destruction of critical habitat. Effects of peat removal within or beyond the 120m zone surrounding the fen boundary would be predominantly cumulative; the activity would gradually lead to the destruction of critical habitat. The information available at this time is insufficient to develop a threshold for the amount of peat that could be removed without causing the destruction of critical
New construction of houses, other structures, roads and recreational trails	If it occurs within the fen, this activity can result in the direct physical removal of the species' primary larval host plant, Bogbean, as well as other plants which may be used during the lifecycle of the Bogbean Buckmoth (e.g., for feeding or egg laying). If significant construction occurs either within or outside of critical habitat, it can also alter the fen's water regime - see below.	The activity could cause destruction of critical habitat at any time throughout the year, because the species spends its entire lifecycle in the fen. The activity could cause destruction of critical habitat if it occurs within or outside the bounds of critical habitat. Constructing structures and roads within the fen will directly result in the destruction of critical habitat. Effects of new construction projects within the 120m zone surrounding the fen boundary or outside of critical habitat are predominantly cumulative; the activity could gradually lead to the destruction of critical habitat and would be more likely to cause destruction if it occurs within the 120m zone than if it occurs outside of critical habitat. The information available at this time is insufficient to develop a threshold for the amount of new structures or roads that could occur without causing the destruction of critical habitat.
Activities (e.g., draining or dam construction) which alter the fen's water regime	Because critical habitat for the Bogbean Buckmoth consists of a type of wetland community, changes to the fen's water regime can lead to habitat conditions that will no longer be suitable for survival of the species' primary larval host, Bogbean, as well as other plants which may be used during the lifecycle of the Bogbean Buckmoth (e.g., for feeding or egg laying).	The activity does not have to occur within the bounds of critical habitat to cause its destruction; for example, a fen's water level can be affected if water is being drained from a point located outside of the critical habitat but that is hydrologically linked to the fen. It could cause destruction of critical habitat at any time throughout the year. Draining or flooding of wetlands could have direct and cumulative effects; depending on the extent of area

		affected by altered water levels, a single occurrence of the activity could cause destruction of critical habitat. However, its effects are most likely to be cumulative, with changes over time to the water regime leading to unsuitable habitat conditions. The information available at this time is insufficient to develop a threshold for this activity.
Use of motorized vehicles (e.g., ATVs and snowmobiles)	If it occurs within the fen, this activity can kill the species' primary larval host, Bogbean, as well as other plants which may be used during the life cycle of the Bogbean Buckmoth (e.g., for feeding or egg laying) through direct trampling.	Driving motorized vehicles would directly result in the destruction of critical habitat if the activity occurs within the fen. It could cause destruction of critical habitat at any time throughout the year; for example, trampling could destroy plants on which eggs have been deposited and on which they overwinter. Thresholds are not applicable to this activity.

Appendix C. Metrics and results for bog buck moth habitat condition.

Table C1. Metrics for scoring bog buck moth habitat condition.

Suitable Habitat	**Condition**
Unknown	Unknown
Habitat is completely unsuitable due to alteration or loss	Extirpated
Habitat present and can be suitable or unsuitable given "sufficient N" results	Presumed Extirpated
Insufficient suitable habitat for any of the life stages: • Insufficient buckbean (<4% areal coverage). • Relatively limited oviposition sites. • Lack of suitable pupation sites.	Poor
Sufficient suitable habitat for all life stages at multiple subpopulations: • Sufficient buckbean (>4% areal coverage). • Relatively abundant oviposition sites. • Suitable pupation sites.	Good

Table C.2. Current status of habitat by population and subpopulation.

NY information is primarily from S. Bonanno, pers comm. unless otherwise cited. Ontario information is from C. Schmidt, per comm. unless otherwise cited.

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
Jefferson County (no subpopulations)	Poor	Poor	Poor	**Extirpated**	No remaining habitat
Oswego Inland Site (no subpopulations)	Good	Good	Good	**Good**	2 fen openings – separated by a drainage in wooded area – either side has floating mat. Plenty of good habitat but continued encroachment by cattail and glossy buckthorn. Subdivision built immediately to north of site and since that time cattail has spread. *Typha angustifolia* is a significant threat at the Oswego Inland Site. Typha litter as a whole smothers plant communities and alters community attributes. Annual management for cattails has been underway since 2016 (E. Helquist, pers. comm.). Glossy buckthorn has been treated at the site twice but comes back and is long term threat. In addition, SUNY Oswego has conducted cattail suppression on east opening for the past 5 years. Flooding has not been an issue at the Oswego Inland Site. Water levels on Lake Ontario have no direct effect on the Oswego Inland Site population; however, temperature,

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
					precipitation and evaporation potential will impact hydrology (Stanton 2004, p. 11). 2016 crash – June researchers observed larvae everywhere but adult flight crash on both sides. Egg parasitoid is known. Potential for larval parasitoid but no research. 2018, 2019, 2020 – no adults with pheromone.
Lakeside (Overall)	Poor 2/4 Good 2/4	Poor 2/4 Good 2/4	Poor 3/4 Good 3/4	**Poor**	Only 1 subpopulation with suitable habitat for all life stages.
Lakeside – Lakeside 1	Poor	Poor	Poor	**Poor**	Lakeside 1 has no direct connection to Lake Ontario but is indirectly connected via adjacent wetlands and is influenced by water levels of Lakeside 2. Once single fen with Lakeside 2 but cottage road was installed and separated the two. Receives drainage from campground on north side from culvert under a road. In addition, the Lakeside 1 fen may have become isolated from its groundwater source to some extent, by an impoundment south of a road (Bonanno 2006, p. 8). 1988 owner of campground received permit to dredge pond. 1994 great year with a crash in 1995.

Population and Subpopulation	**Sufficient buckbean**	**Relatively abundant oviposition sites**	**Suitable pupation sites**	**Overall habitat quality**	**Notes**
					1997 Stanton noted reduction in buckbean. Very thick moss now and taller shrubs and trees. Olivero (2001, p. 10) reported that fen habitat contracted from 6 to 2 ha (15 to 5 ac) at Lakeside 1 from 1998 to 2001. Bonanno (2014, p. 5) noted beaver are maintaining the impoundment south of Lakeside 1 resulting in the drying of the fen. Bonanno (2014, p. 6) further found that vegetation in Lakeside 1 was succeeding to a black spruce-tamarack bog forest with deep sphagnum, taller shrubs, and scarce buckbean. Dramatic habitat management would be needed.
Lakeside – Lakeside 2	Poor	Poor	Poor	**Poor**	Lakeside 2 fen has no direct connection to Lake Ontario but is indirectly connected via surface level of adjacent Pond which is connected to Lake Ontario. Once single fen with Lakeside 1 but cottage road was installed separated the two. There has been recent improvement of culvert that regulates hydrology between Lakeside 1 and Lakeside 2 sites 1997-98 boom years with crash in 1999-2000 almost everywhere. Rebounded to about ½ of prior peak numbers. Similar as Lakeside 1 – shrubs growing, thicker moss, cattail has reduced open fen.

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
					Olivero (2001, p. 10) reported that fen habitat contracted from 32.4 to 24.7 ha (80 to 61 ac) at Lakeside 2 Fen from 1998 to 2001. Habitat appears to be primary driver with dramatic habitat management needed.
Lakeside – Lakeside 3	Good	Good	Poor	**Poor**	Lots of habitat present for eggs and larvae but not for pupae. Cattail is also reducing open fen. Around Lakeside 3 and vicinity, there are areas colonized extensively by Typha but when you rummage below the Typha litter you find vegetation remains characteristic of fen communities (E. Helquist, pers. comm.). Flooding appears to be primary driver and there are few hummocks for pupae safety. Bonanno (2015, p. 7) noted that Lakeside 3 and 4 are subject to the greatest amount of hydrologic variability of all NY sites given their proximity to a creek. Eggs can stand flooding as long as dewatering by time of hatch. 2007 boom year – very dry year followed by 2008 crash with high water. Proximity to adjacent populations is important for repopulating habitat after flood events.

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
Lakeside – Lakeside 4 (spillover site)	Poor	Unknown	Unknown	**Poor**	Never known to be a good site since bog buck moth were discovered there. Cattail has reduced open fen. Much shrubbier than Lakeside 3. Moat effect – deep and very difficult to access fen especially during high water events.
Lakeside – Lakeside 5	Good	Good	Good	**Good**	Lots of habitat change and contraction but still good habitat. Moat now has dense shrub area (glossy buckthorn is dominant, with winterberry, purple loosestrife). On the upland side there is a red maple, tamarack swamp and then red maple hardwood swamp – both of which may buffer the fen. 2 fen openings are separated by dense shrubby band. Both openings are approximately 16 ha (40 ac). Having variety of habitat seems important – openings that behave differently hydrologically. The west fen is impacted more than east fen by water levels (closer to the lake). West fen - *Carex lasiocarpa* and sweet gale. Shrubs are not out of control.

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
					East fen - lots of standing water with shorter shrubs, different sedges and lots of buckbean and hummocks. Glossy buckthorn could actually provide higher place for larvae and hummocks could help pupae. Primary stressors include hydrology, nutrient input (campground), woody vegetation encroachment from north and west. Habitat management has included glossy buckthorn cut-stump treatment of all of the west fen and barely into edge of east fen. Glossy buckthorn will likely keep returning.
Canada (Overall)					General information in addition to site-specific information below: Survey conducted in 2008 at the four sites in Ontario estimated the presence of approximately 6,200 larvae. Taking into account natural mortality during pupation and losses due to predation or parasitism [based on data collected from *H. Maia* populations in Massachusetts (Selfridge *et al.* 2007)], approximately 3,000 of these would be expected to survive to adulthood (COSEWIC 2009, p. 17). There are only about 236 ha (583 ac) of fen habitat at the bog buck moth sites in Canada, with the majority at location Richmond Fen (215 ha [531 ac])

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
					and relatively little at While Lake Fen (31 ha [77]) (COSEWIC 2009, p. 17). Since 1979, the number of larvae documented at Richmond Fen has ranged from as low as one larva to thousands. Due to significant annual variation in population numbers and the intermittency of monitoring, determining long-term population trends in Ontario has been difficult (COSEWIC 2009).
White Lake- North	Good	Appears adequate	Appears adequate	**Good**	Core habitat is of good quality but very limited areal extent (<30 ac [12 ha]); may be declining in extent due to encroachment of Phragmites and narrow-leaved cattail from north (lakeshore side). Amount of suitable buckbean (in nontreed areas) is relatively limited. More than 100 adult moths were observed in mid-September 2020. Previously larvae were last observed in 2016, with no surveys in 2017, and larvae absent in 2018, 2019.
White Lake – South	?	?	?	**Unknown**	This site has not been visited or assessed in recent years.
Richmond Fen – North	?	?	?	**Good**	Bog buck moth has not been assessed here in recent years, but a site visit in 2015 indicated that encroachment of nonnative plants has not significantly advanced into core bog buck moth habitat, and it is therefore assumed to still be of good quality.

Population and Subpopulation	Sufficient buckbean	Relatively abundant oviposition sites	Suitable pupation sites	Overall habitat quality	Notes
Richmond Fen – South	Good	Good	Good	**Good**	Abundant buckbean, oviposition sites and pupation sites. Site visit in early July 2020 with hundreds of mid-instar larvae. Site visit in 2019, with estimate of minimum 1,500 early instar larvae in small portion of core habitat. Phragmites encroachment into fen in general, but currently no direct impact on bog buck moth habitat within fen.

Appendix D. Factors currently influencing the status of bog buck moth populations.

We estimated the magnitude of impact of each of the primary risk factors (table D.1). We did not consider the factors of predation or disease and their direct effects on the bog buck moth; while individual moths are likely impacted, we do not have any information regarding whether or not there are population-level effects from predation or disease on the bog buck moth for any of the populations.

The categories we used to assess level of magnitude of risk factors at each site are listed below:

- Unlikely (data suggests it is not occurring, or it is not suspected to occur);
- Past (data confirms past impact);
- Likely (data suggests it is occurring but we have no direct evidence);
- Low (data confirms minimal current impact);
- Moderate (data confirms ongoing regular current impact); and,
- High (data confirms ongoing high impact).

Table D.1. Factors currently influencing the status of bog buck moth populations.

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids**
Jefferson County	Past - Habitat was lost due to water level management and change in wetland type to marsh	High – site has not been suitable since the 1970s when dam was installed	NA	NA
Oswego Inland Site	Unlikely	Unlikely	High – glossy buckthorn and cattail	Moderate – egg parasitoid Likely – larval parasitoid
Lakeside (overall)	Past	High	High	Moderate – egg parasitoid Likely – larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids**
Lakeside 1	Past - pond dug south of Lakeside 1 in 1988	High – receives drainage from campground to north	High – thick moss, tall shrubs	Moderate– egg parasitoid Likely – larval parasitoid
Lakeside 2	Unlikely	High – directly connected to pond, Lake Ontario levels influence previously connected to Lakeside 1 and now cut off by road	High – thick moss, shrubs, cattail	Moderate– egg parasitoid Likely – larval parasitoid
Lakeside 3	Unlikely	High (greatest) – directly connected to tributary of Lake Ontario – see more details below. Documented flooding impacts at this site.	Low – cattail has reduced open fen but still lots of good egg and larval habitat because of large size	Likely – egg and/or larval parasitoid
Lakeside 4	Unlikely	High (greatest) – directly connected to tributary of Lake Ontario Outlet to creek and lake level management -When the outlet is open – lake level is primary driver -When the outlet is closed the site fills up until enough pressure to open outlet and then very quick drainage	Moderate – cattail has reduced open fen, glossy buckthorn is present, much shrubbier than Lakeside 3	Likely – egg and/or larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids**
		Culvert drains Lakeside 5 through campground into stream Creek effects		
Lakeside 5	Unlikely	High - Lakeside 5 drains to the mouth of a creek just upstream of its outlet to Lake Ontario. Documented flooding impacts at this site	Moderate - glossy buckthorn encircles and invades openings	Moderate – egg parasitoid Likely – larval parasitoid
White Lake	Low (past)	Low - Historical flooding due to damming	Moderate to high- Phragmites, narrow leaved cattail	Likely – egg and or larval parasitoid
WL North	Low	Low	Moderate to high- Phragmites, narrow leaved cattail	Likely – egg and or larval parasitoid
WL South	Low	Low	Unknown	Likely – egg and or larval parasitoid
Richmond Fen	Low	Low	Low to moderate - Phragmites encroachment on outskirts of fen, but not currently into core bog buck moth habitat	Likely – egg and or larval parasitoid
North	Low (railway)	Low - Railway embankment likely changed the hydrology historically, but assumed unchanged in recent decades	Low to moderate	Likely – egg and or larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids**
South	Low (snowmobile trail)	Low	Low to moderate	Likely – egg and or larval parasitoid

Egg parasitoids were confirmed at Lakeside 1, Lakeside 2 and Lakeside 5 by Greg Pryor (1994-1995) and/or Ed Stanton (1997-1998)(S. Bonanno, pers comm). Not sure about Lakeside 3 – population there was low in the late 1990s

Appendix E. Factors influencing the future status of bog buck moth populations.

We estimated the future magnitude of impact of each of the primary risk factors (table D.1). In addition, while we do not fully understand predation, we considered that any ongoing impacts will continue, along with impacts of parasitoids.

Table E.1. Bog buck moth future scenarios.

Scenario Name	Winter and Spring Precipitation	Annual Temperature	Invasive Species and Succession	Parasitoids and Predation
Scenario 1	Increase of at least 10%	Increase of at least 5 °F (2.8 °C)	Glossy buckthorn, phragmites at current levels. Vegetation succession continues at sites where this is already documented.	Maintain at current levels
Scenario 2	Increase of at least 20%	Increase of at least 5 °F (2.8 °C)	Glossy buckthorn, phragmites, cattails and shrubs increase.	Maintain at current levels

We started with the current condition categories to assess level of magnitude of risk factors and indicated which stressors are anticipated to change.

The categories we initially used to assess level of magnitude of risk factors at each site are listed below:

- Unlikely (data suggests it is not occurring, or it is not suspected to occur);
- Past (data confirms past impact);
- Likely (data suggests it is occurring but we have no direct evidence);
- Low (data confirms minimal current impact);
- Moderate (data confirms ongoing regular current impact); and,
- High (data confirms ongoing high impact).

Table E.2. Factors influencing the future status of bog buck moth populations under Scenario 1.

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
Jefferson County	Past - Habitat was lost due to water level management and change in wetland type to marsh	High – site has not been suitable since the 1970s when dam was installed	NA	NA
Oswego Inland Site	Unlikely **Remains same**	Unlikely **Changes to Low – Increase flooding**	High – glossy buckthorn and cattail **Remains High – Increase succession**	Moderate – egg parasitoid Likely – larval parasitoid
Lakeside (overall)	Past **Remains same**	High **Remains High - Increase flooding**	High **Remains High - Increase succession**	Moderate – egg parasitoid Likely – larval parasitoid
Lakeside 1	Past - pond dug south of Lakeside 1 in 1988 **Remains same**	High – receives drainage from campground to north **Remains High - Increase flooding**	High – thick moss, tall shrubs **Remains High - Increase succession**	Moderate– egg parasitoid Likely – larval parasitoid
Lakeside 2	Unlikely **Remains same**	High – directly connected to pond, Lake Ontario levels influence previously connected to Lakeside 1 and now cut off by road **Remains High - Increase flooding**	High – thick moss, shrubs, cattail **Remains High - Increase succession**	Moderate– egg parasitoid Likely – larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
Lakeside 3	Unlikely **Remains same**	High (greatest) – directly connected to tributary of Lake Ontario – see more details below **Remains High - Increase flooding**	Low – cattail has reduced open fen but still lots of good egg and larval habitat because of large size **Changes to Moderate – Increase succession**	Likely – egg and/or larval parasitoid
Lakeside 4	Unlikely **Remains same**	High (greatest) – directly connected to tributary of Lake Ontario Outlet to creek and lake level management -When the outlet is open – lake level is primary driver -When the outlet is closed the site fills up until enough pressure to open outlet and then very quick drainage Culvert drains Lakeside 5 through campground into stream Creek effects **Remains High - Increase flooding**	Moderate – cattail has reduced open fen, glossy buckthorn is present, much shrubbier than Lakeside 3 **Changes to High - Increase succession**	Likely – egg and/or larval parasitoid
Lakeside 5	Unlikely **Remains same**	High Lakeside 5 drains to the mouth of a creek just	Moderate – glossy buckthorn encircles and invades openings **Remains Moderate**	Moderate – egg parasitoid Likely – larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
		upstream of its outlet to Lake Ontario. Documented flooding impacts at this site **Remains High - Increase flooding**		
White Lake	Low (past) **Remains same**	Low Historical flooding due to damming **Changes to Moderate – Increase flooding**	Moderate to high - Phragmites, narrow leaved cattail **Changes to High – Increase succession**	Likely – egg and or larval parasitoid
WL North	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Moderate to high - Phragmites, narrow leaved cattail **Changes to High – Increase succession**	Likely – egg and or larval parasitoid
WL South	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Unknown **Remains same**	Likely – egg and or larval parasitoid
Richmond Fen	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Low to moderate Phragmites encroachment on outskirts of fen, but not currently into core bog buck moth habitat **Remains same**	Likely – egg and or larval parasitoid
North	Low (railway) **Remains same**	Low Railway embankment likely changed the hydrology historically, but assumed unchanged in recent decades	Low to moderate **Remains same**	Likely – egg and or larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
		Changes to Moderate – Increase flooding		
South	Low (snowmobile trail) **Remains same**	Low **Changes to Moderate – Increase flooding**	Low to moderate **Remains same**	Likely – egg and or larval parasitoid

Table E.3. Factors influencing the future status of bog buck moth populations under Scenario 2.

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
Jefferson County	Past - Habitat was lost due to water level management and change in wetland type to marsh	High – site has not been suitable since the 1970s when dam was installed	NA	NA
Oswego Inland Site	Unlikely **Remains same**	Unlikely **Changes to Low – Increase flooding**	High – glossy buckthorn and cattail **Remains High – Increase succession and invasives**	Moderate – egg parasitoid Likely – larval parasitoid
Lakeside (overall)	Past **Remains same**	High **Remains High - Increase flooding**	High **Remains High - Increase succession and invasives**	Moderate – egg parasitoid Likely – larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
Lakeside 1	Past - pond dug south of Lakeside 1 in 1988 **Remains same**	High – receives drainage from campground to north **Remains High - Increase flooding**	High – thick moss, tall shrubs **Remains High - Increase succession and invasives**	Moderate– egg parasitoid Likely – larval parasitoid
Lakeside 2	Unlikely **Remains same**	High – directly connected to pond, Lake Ontario levels influence previously connected to Lakeside 1 and now cut off by road **Remains High - Increase flooding**	High – thick moss, shrubs, cattail **Remains High - Increase succession and invasives**	Moderate– egg parasitoid Likely – larval parasitoid
Lakeside 3	Unlikely **Remains same**	High (greatest) – directly connected to tributary of Lake Ontario – see more details below **Remains High - Increase flooding**	Low – cattail has reduced open fen but still lots of good egg and larval habitat because of large size **Changes to Moderate – Increase succession and invasives**	Likely – egg and/or larval parasitoid
Lakeside 4	Unlikely **Remains same**	High (greatest) – directly connected to tributary of Lake Ontario Outlet to creek and lake level management -When the outlet is open – lake level is primary driver -When the outlet is closed the site fills up until enough	Moderate – cattail has reduced open fen, glossy buckthorn is present, much shrubbier than Lakeside 3 **Changes to High - Increase succession and invasives**	Likely – egg and/or larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
		pressure to open outlet and then very quick drainage Culvert drains Lakeside 5 through campground into stream Creek effects **Remains High - Increase flooding**		
Lakeside 5	Unlikely **Remains same**	High Lakeside 5 drains to the mouth of a creek just upstream of its outlet to Lake Ontario. Documented flooding impacts at this site **Remains High - Increase flooding**	Moderate – glossy buckthorn encircles and invades openings **Changes to High – Increase succession and invasives**	Moderate – egg parasitoid Likely – larval parasitoid
White Lake	Low (past) **Remains same**	Low Historical flooding due to damming **Changes to Moderate – Increase flooding**	Moderate to high - Phragmites, narrow leaved cattail **Changes to High – Increase succession and invasives**	Likely – egg and or larval parasitoid
WL North	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Moderate to high - Phragmites, narrow leaved cattail **Changes to High – Increase succession and invasives**	Likely – egg and or larval parasitoid

	Stressor			
Population and Subpopulation	**Habitat loss/fill**	**Water levels**	**Invasive plants and plant succession**	**Parasitoids – no change**
WL South	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Unknown **Likely - Increase succession and invasives**	Likely – egg and or larval parasitoid
Richmond Fen	Low **Remains same**	Low **Changes to Moderate – Increase flooding**	Low to moderate Phragmites encroachment on outskirts of fen, but not currently into core bog buck moth habitat **Changes to Moderate – Increase succession and invasives**	Likely – egg and or larval parasitoid
North	Low (railway) **Remains same**	Low Railway embankment likely changed the hydrology historically, but assumed unchanged in recent decades **Changes to Moderate – Increase flooding**	Low to moderate **Changes to Moderate – Increase succession and invasives**	Likely – egg and or larval parasitoid
South	Low (snowmobile trail) **Remains same**	Low **Changes to Moderate – Increase flooding**	Low to moderate **Changes to Moderate – Increase succession and invasives**	Likely – egg and or larval parasitoid