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NATURAL HISTORY AND DISTRIBUTION OF *PAPAIPEMA AWEME* (NOCTUIDAE)

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ABSTRACT. *Papaipema aweme* (Lyman) was previously known only from seven specimens and five localities globally, and was thought to be a critically imperiled species of dunes, alvars, and other dry habitats. Life history information was lacking. We documented fifty-nine specimens from 2009–2016 at six new locations spanning 1,555 km from the Upper Peninsula of Michigan to eastern Saskatchewan. Larvae were found boring in the stems and rhizomes of *Menyanthes trifoliata* L. (Menyanthaceae) in open graminoid rich fen habitats at two of these localities. All localities are rich fens with abundant *M. trifoliata*; such habitats are or were present in the vicinity of all five historical records (1905–2005). These discoveries suggest *P. aweme* is a peatland specialist and is likely much more common and widespread than present records indicate.

Additional key words: peatland, fen, host plants, conservation, *Menyanthes*

DEDICATION

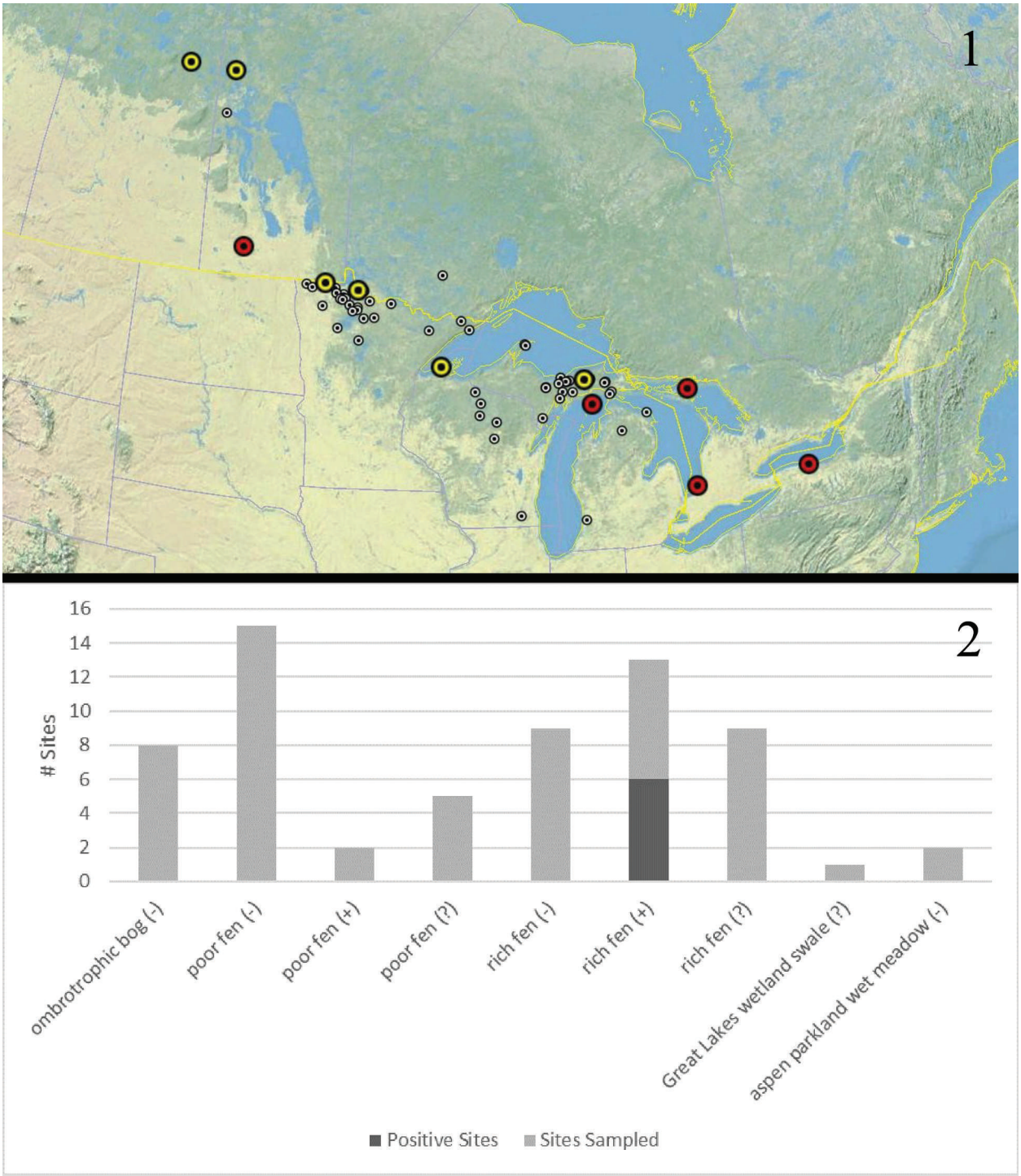
We dedicate this paper to the late Mogens C. "Mo" Nielsen, honorary life member of the Lepidopterists' Society, charter member of the Michigan Entomological Society, and an inspiration for anyone studying Lepidoptera of the Northern Great Lakes. *Papaipema aweme* was a "holy grail" to Mo, and he spent many a night chasing this phantom across the Michigan landscape. Although he never encountered one himself, Mo's encouragement of the authors' studies helped lead to the successes presented in this paper.

Papaipema aweme (Lyman) is an enigmatic species within a relatively popular and well-studied genus of moths. It was known from only seven adult specimens taken at light from 1905–2005 (COSEWIC 2006). From August 24–26, 1905, Norman Criddle collected single specimens on three successive nights in the vicinity of Aweme, Manitoba. The female specimen collected on August 24th would subsequently serve as the holotype (Shepard and Vickery 1975). On August 13, 1925, Sherman Moore took a single specimen on a boat anchored off Beaver Island, Michigan. On August 7, 1932, A. Richards took a single specimen in Rochester, New York. On August 15, 1936, a single specimen was taken (collector unknown) in Grand Bend, Ontario. The moth then went unreported for 69 years until August 19, 2005, when John Morton took a single specimen near Pike Lake on Manitoulin Island, Ontario.

The geography of these records suggested a relationship with shorelines of the Great Lakes, or relict shorelines of Glacial Lake Agassiz in the case of Aweme, Manitoba. These records also led to the belief that *P. aweme* was a denizen of dry habitats such as dunes, sand prairie, oak savannah, or alvar (COSEWIC 2006, Michigan Natural Features Inventory 2007, NatureServe 2017). Extensive surveys to re-document the moth at Aweme and Grand Bend (blacklighting), and Manitoulin Island (larval searches) all focused on dry habitats but without success. The small number of localities, presumed restriction to imperiled habitats, and failed re-documentation at historical localities led to listing *P. aweme* as an endangered species in Canada in 2006 (COSEWIC 2006).

On September 10, 2009 DRB chanced upon a single fresh female *P. aweme* at the Wanamaker Lake Peatlands in Michigan. The moth was taken in a UV light trap placed on a sandy conifer woodland low ridge within a large peatland complex. The dry ridge best fit previous habitat hypotheses, but the common and widespread flora growing there could not explain the moth's rarity. The adjacent peatlands, however, contained an assortment of fen types with diverse and interesting flora.

Peatland specialists of comparatively well-known groups such as butterflies have often eluded



FIGS. 1–2. **1**. *Papaipema aweme* historical records (large red circles), new localities (large yellow circles), and negative sampling results (small white circles). **2**. *Papaipema aweme* sampling effort vs. positive results (adults and larvae) across different habitat types. For sites with multiple types, only the predominant type in the sampling vicinity is counted. *Menyanthes trifoliata* presence is ranked as absent/sporadic (–), common (+), or unknown (?).

entomologists until surprisingly recent times. *Boloria freija* (Thunberg) went undocumented from the northern Great Lakes states until May 22, 1965 when Ron Huber collected examples from a raised bog in northern Minnesota; better understanding of its habitats and phenology has since led to widespread documentation across the northern counties of Minnesota, Wisconsin, and Michigan (Johnson 2011). *Boloria frigga* (Thunberg) went undocumented from the region until June 25, 1956 when Steve Hubbell collected a specimen in a peatland near Manistique, Michigan (Hubbell 1957); likewise, there has since been widespread documentation across the northern counties of Michigan, Wisconsin, and Minnesota (Johnson 2011) as well as the first discovery in New England (Maine) in 2002 (Maynadier and Webster 2009).

Similarly, since a cryptic, nocturnal, late-season moth with similar or greater peatland habitat specificity could also be poorly known, we hypothesized *P. aweme* was originating from peatlands or other wetland habitats.

Materials and Methods

Peatland (bog and fen) terminology herein largely follows Wright et al. 1992 and differs from that used in older literature. Plant nomenclature follows USDA, NRCS 2017.

Peatlands are wetlands with an accumulation of poorly decomposed organic matter (peat). They are divided into three major classes based on dissolved mineral content and acidity: rich fen (high mineral content and alkaline to weakly acidic), poor fen (low mineral content and moderately to strongly acidic), and bog sensu stricto (living plant layer isolated from groundwater minerals and strongly acidic). They can be separated with floral indicators. Bogs sensu stricto are always dominated by hummocky *Sphagnum* moss (Sphagnaceae) carpets, low ericaceous shrubs (Ericaceae), a limited suite of sedges (e.g. *Carex oligosperma* Michx., *Eriophorum vaginatum* L. (Cyperaceae)), and variable cover of stunted conifers (usually *Picea mariana* (Mill.) Britton, Sterns & Poggenb. (Pinaceae)). They lack minerotrophic indicators. Poor fens may support any of the flora present in bogs, but also contain weak minerotrophic indicators (e.g. *Betula pumila* L. (Betulaceae), *Carex chordorrhiza* Ehrh. ex L. f. (Cyperaceae)). Many habitats referred to as "bogs" in older literature are actually poor fens in this classification. Rich fens may support both bog and poor fen flora (but lack acidophiles such as *Eriophorum vaginatum*) and also include strong minerotrophic indicators (e.g. *Dasiphora fruticosa* (L.) Rydb. (Rosaceae), *Thuja occidentalis* L. (Cupressaceae), *Trichophorum alpinum* (L.) Pers. (Cyperaceae)). Open sedge dominated rich fens usually support brown mosses (Amblystegiaceae) instead of *Sphagnum*. Forested rich fens and poor fens are often called rich swamps and poor swamps, respectively.

We sampled 62 sites with peatlands or peatland elements across Michigan (24), Wisconsin (6), Minnesota (25), Ontario (3), Manitoba (3; 1 of these also a Minnesota site), and Saskatchewan (1) from 2005–2016 (Fig. 1). We searched for larvae at six of these sites across Michigan (2), Wisconsin (1), Minnesota (3), and Manitoba (1; also a Minnesota site) from 2011–2016.

We sampled ombrotrophic bogs, poor fens (including poor swamps), rich fens (including rich swamps), Great Lakes shoreline interdunal wetlands, and aspen parkland sedge meadows with peatland floral elements (Fig. 2). Some of these habitats were within patterned peatland complexes (peatlands in which the vegetation forms distinctive patterns in aerial view; see Wright et al. 1992. for discussion of the various types) and included raised bogs, internal water tracks of raised bogs, featureless water tracks, ribbed fens, ribbed fens with tear-drop tree islands, and spring fen channels.

We sampled numerous other sites and habitats during this period, but these are not included since many (e.g. dunes, alvar) had already received considerable sampling effort during the appropriate *Papaipema aweme* flight period (COSEWIC 2006, pers. obs.).

We sampled each site at least once during the documented *P. aweme* flight period extremes (August 7–September 10), though we had no way of knowing whether our efforts (particularly those near the date extremes) coincided with the peak flight period for a particular site in a given year. Some sites were visited multiple times; the Wanamaker Lake Peatlands in Michigan (the 2009 *P. aweme* capture site) received exceptional coverage with 145+ trap nights spread over 18 nights (each light trap or sheet used on a given night was considered a trap night) plus larval searches in 2011 and 2016.

We relied predominately on UV (ultraviolet) light traps (8 and 15 watt) and UV sheets (15 watt) for sampling adults (total of 368 trap nights spread over 132 nights). Other techniques employed sporadically included MV (mercury vapor) sheets, propane lantern sheet, fermenting fruit bait trails and traps, netting adults at flowers, and netting free flying adults.

We searched for larvae between June 14 and August 1, 2010–2016. Timing for larval searches was based on adult flight times and knowledge of larval phenology across the genus. To find larvae we scanned vegetation in various peatland habitats looking for wilted, discolored, or otherwise compromised plants. Any such plants were carefully dissected to reveal larvae or signs of larval presence such as burrows and frass. Our efforts were

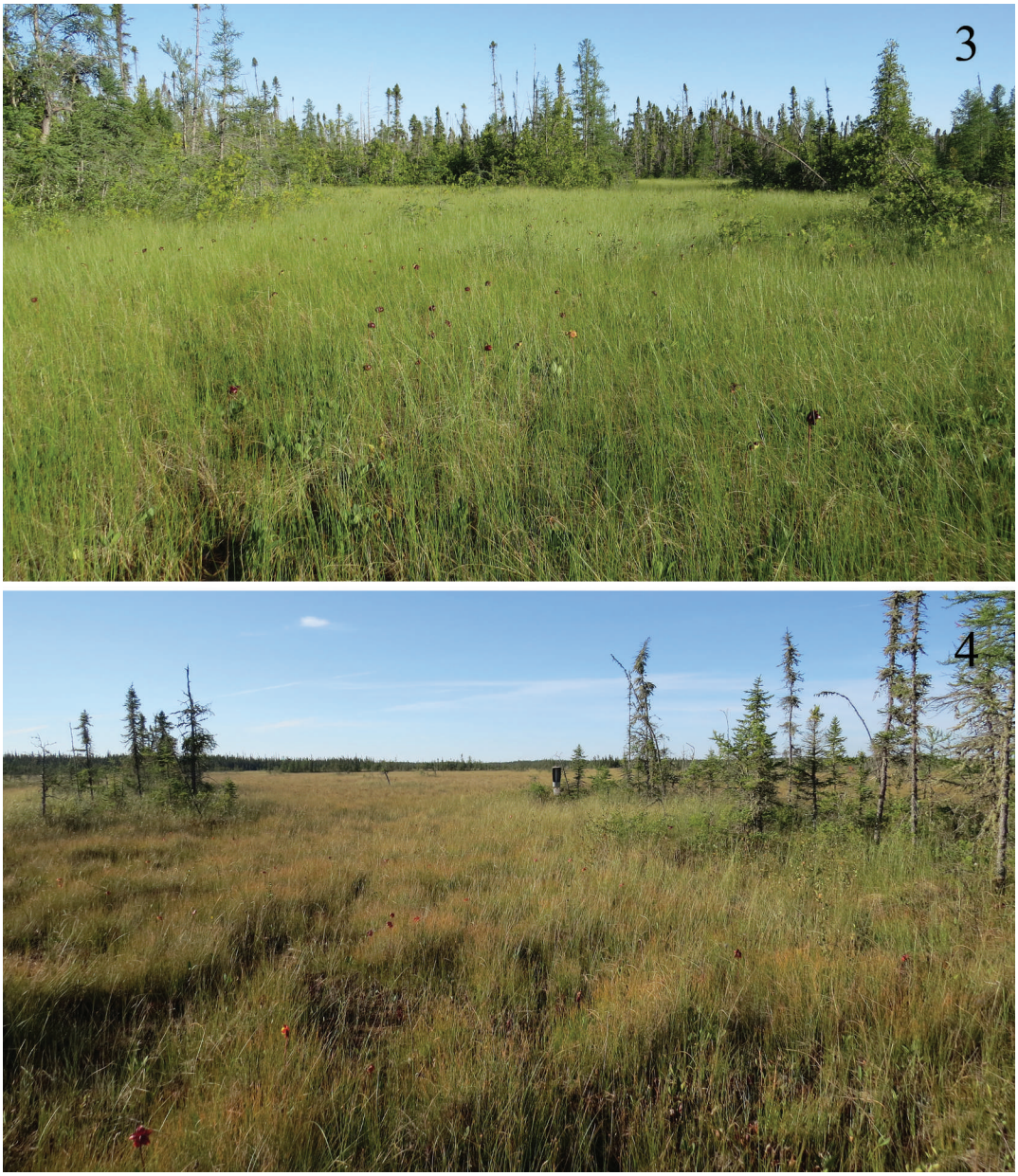
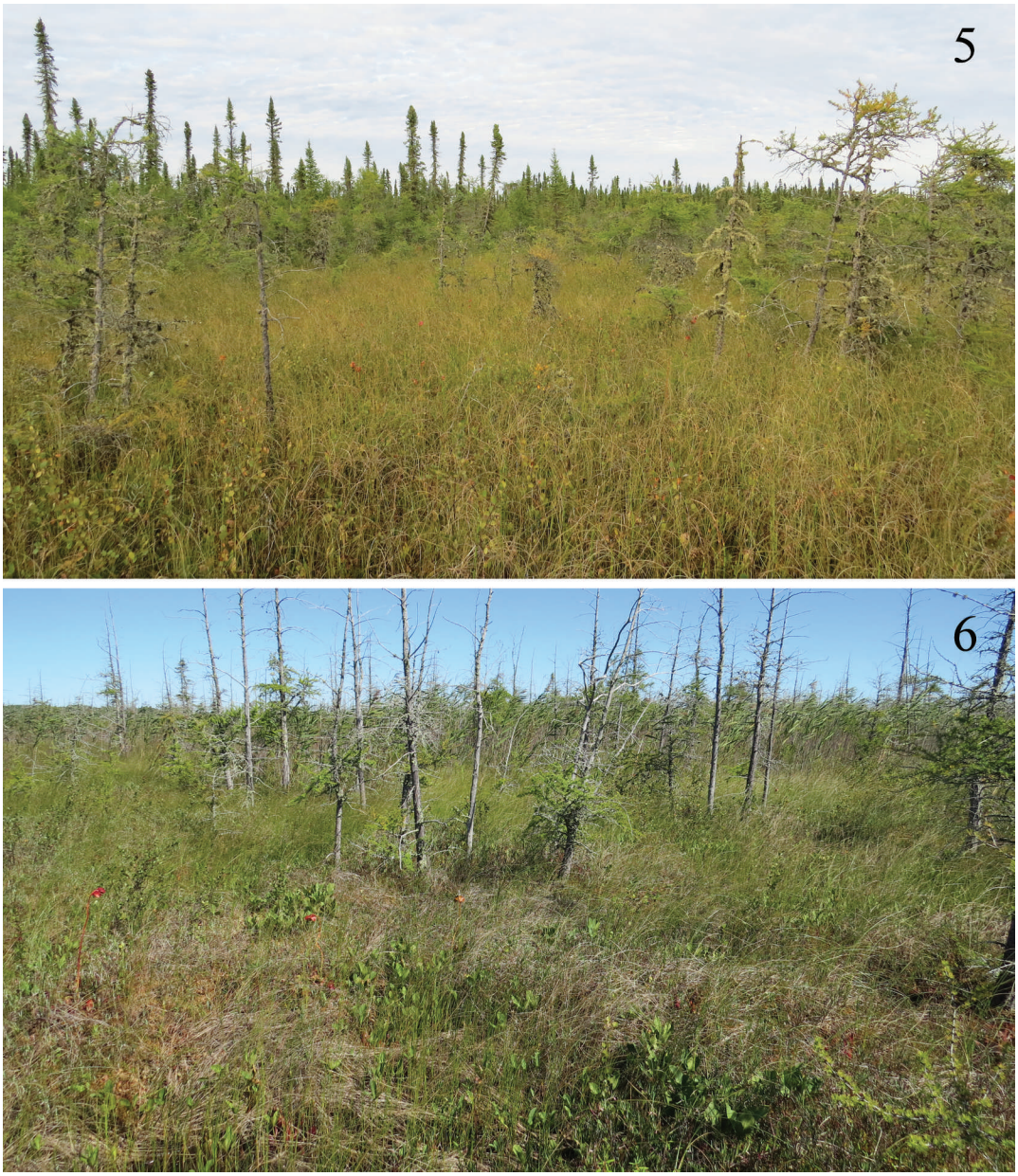


FIG. 3-4. **3**. *Papaipema aweme* habitat, Pine Creek Peatland, Roseau Co., Minnesota (June 23, 2016). Spring fen channel open graminoid rich fen; this is bordered by *Picea mariana* (*Thuja occidentalis-Larix laricina*) rich swamp. *Menyanthes trifoliata* is abundant. **4.** *Papaipema aweme* habitat, First Central Lake, Northern Region, Manitoba (August 21, 2016). Graminoid reticulate ribbed rich fen with *Picea mariana-Larix laricina-Sphagnum*-ericad tree islands; *Menyanthes trifoliata* is abundant.

biased to areas where adults were captured, and toward host plants with distributions that fit the general range of historical captures of the moth. We paid particular attention to the following plants: *Cladium mariscoides* (Muhl.) Torr. (Cyperaceae), *Menyanthes trifoliata* L. (Menyanthaceae), *Pedicularis lanceolata* Michx. (Scrophulariaceae), native genotype of *Phragmites australis* (Cav.) Trin. ex Steud. (Poaceae), *Sarracenia purpurea* L. (Sarraceniaceae), *Triglochin maritima* L. (Juncaginaceae), and various orchids (Orchidaceae).

Specimens collected by the authors were deposited in the University of Wisconsin-Madison Insect Research Collection (WIRC), Canadian National Collection (CNC), University of Minnesota Entomology Collection (UMSP) and the research collections of DRB and AM. Photographs were taken by KEJ with a Canon Powershot SX50 HS digital camera. Maps were created with Google Earth and Earth Point.



FIGS. 5–6. **5**. *Papaipema aweme* habitat, Deschambault Lake, Division No. 18, Saskatchewan (August 22, 2016). Narrow open graminoid rich fen water track through semi-treed *Picea mariana-Larix laricina-Sphagnum*-ericad rich to poor fen. *Menyanthes trifoliata* is abundant. **6.** *Papaipema aweme* habitat, Agassiz Peatland, Rainy River District, Ontario (August 29, 2016). Sparsely treed *Larix laricina*-graminoid-*Sphagnum*-ericad rich fen along featureless margin of patterned water track. *Menyanthes trifoliata* is abundant.

RESULTS

Fifty-nine specimens of *P. aweme* were documented from 2009–2016 at six new locations spanning 1,555 km from the Upper Peninsula of Michigan to eastern Saskatchewan (Fig. 1, Tables 1, 2). We collected 51 specimens from five sites (Michigan, Minnesota, Ontario, Manitoba, and Saskatchewan) which include 18 found as larvae (16 reared to adult, 2 preserved as larvae). Additional larvae were found but not successfully reared or preserved. Les Ferge collected 7 adults from the Lake Superior shoreline in Wisconsin and Jim Vargo took 1 adult at our Minnesota site.

Habitat. Sites where *Papaipema aweme* were sampled were mosaics of different peatland habitats, but all contained areas of open to sparsely treed graminoid rich fen (Tables 1, 2; Figs 3–6). These areas were sedge (Cyperaceae) dominated and very wet (quaking or at least with shallow standing water). *Carex lasiocarpa*

TABLE 1. *Papaipema aweme* positive adult survey results 2005–2016.

State/Prov.	Site (County/District)	Date	Collector	Method	Weather (Time)	#	Habitat
MI	Wanamaker Lake Peatlands (Luce)	2009 Sept. 10	DRB	8 watt UV trap		1 ♀	sandy conifer woodland raise bordering peatland (semi-treed poor to rich fen)
MN	Pine Creek Peatland (Roseau)	2014 Sept. 8	KEJ	15 watt UV trap	15–9°C; mostly cloudy night/light wind	1 ♂	wide graminoid-herb path (*Menyanthes trifoliata* common) through *Larix laricina* rich swamp (trees 7-10m); *Picea mariana* common in understory, few *Thuja occidentalis*; hummocky *Sphagnum*-feathermoss-ericad-herb-graminoid carpet; *Sarracenia purpurea*, *Betula pumila*, *Salix*, *Cornus* common
MN	Pine Creek Peatland (Roseau)	2015 Aug. 21	KEJ	15 watt UV trap	16–14°C; mostly clear/calm night	1 ♂	wide graminoid-herb path (*Menyanthes trifoliata* common) through *Larix laricina* rich swamp (trees 7-10m); *Picea mariana* common in understory, few *Thuja occidentalis*; hummocky *Sphagnum*-feathermoss-ericad-herb-graminoid carpet; *Sarracenia purpurea*, *Betula pumila*, *Salix*, *Cornus* common
MN	Pine Creek Peatland (Roseau)	2015 Aug. 21	KEJ	15 watt UV sheet	16–14°C; mostly clear/ calm night (0130 h)	1 ♂	spring fen forest; wide path through *Picea mariana* rich swamp (trees 6-10m) with hummocky *Sphagnum*-feathermoss-ericad-herb-graminoid carpet; few *Larix laricina*, *Thuja occidentalis*; near spring fen channels
MN	Pine Creek Peatland (Roseau)	2015 Aug. 21	KEJ	15 watt UV trap	16–14°C; mostly clear/calm night; scattered strong storms the following morning	9 ♂	spring fen channel; quaking graminoid rich fen (*Carex lasiocarpa* dominant, *Menyanthes trifoliata* abundant) bordering *Picea mariana* rich swamp (*Sphagnum*-feathermoss-ericad-herb-graminoid carpet) and border path; *Thuja occidentalis*, *Larix laricina*, *Dasiphora fruticosa*, *Betula pumila* common along margin
MN	Pine Creek Peatland (Roseau)	2015 Aug. 29	KEJ	net	18°C; mostly clear /calm night (2159 h)	1 ♂	weakly patterned ribbed fen; sparsely treed *Larix laricina*-graminoid-mixed moss-ericad-*Betula pumila-Dasiphora fruticosa* rich fen; *Picea mariana*, *Thuja occidentalis Menyanthes trifoliata*, *Sarracenia purpurea*, *Salix* common; near spring fen forest/channels
MN	Pine Creek Peatland (Roseau)	2015 Aug. 29	Jim Vargo	UV trap	19–12°C; mostly clear/calm night	1 ♂	spring fen forest/channel; *Picea mariana-Thuja occidentalis-Sphagnum*-mixed moss-ericad-graminoid rich swamp (trees 2-8m) bordering quaking graminoid rich fen; *Larix laricina*, *Dasiphora fruticosa* common
MB	First Central Lake (Northern Reg.)	2016 Aug. 21	KEJ	15 watt UV trap	13–7°C; partly cloudy/ mostly calm night	1 ♀	reticulate ribbed fen with tree islands; wet quaking graminoid rich fen with *Sphagnum*-ericad-*Picea mariana-Larix laricina* tree islands; *Menyanthes trifoliata*, *Sarracenia purpurea* common; scattered *Betula pumila*, *Salix*
SK	Deschambault Lake (Div. No. 18)	2016 Aug. 22	KEJ	15 watt UV trap	17–16°C; partly cloudy night/light wind; T-storms around 0200 h	14 ♂ 1 ♀	semi-quaking graminoid rich fen narrow water track through semi-treed *Larix laricina*-graminoid-mixed moss-ericad-herb rich fen; abundant *Menyanthes trifoliata*; *Betula pumila*, *Salix*, *Sarracenia purpurea* common
SK	Deschambault Lake (Div. No. 18)	2016 Aug. 22	KEJ	8 watt UV trap	17–16°C; partly cloudy night/light wind; T-storms around 0200 h	2 ♂	semi-quaking graminoid-*Menyanthes trifoliata* rich fen narrow water track through semi-treed *Larix laricina*-graminoid-mixed moss-ericad rich fen; *Betula pumila*, *Salix*, *Sarracenia purpurea* common
WI	Lake Superior shoreline (Bayfield)	2016 Aug. 28	Les Ferge	15 watt UV trap	18–15°C; mostly clear/calm night, T-storms around sunrise	7 ♂	Lake Superior coastal peatland; shrubby margin of wet graminoid rich fen (*Carex lasiocarpa* dominant); sparse *Larix laricina*
ON	Agassiz Peatland (Rainy River)	2016 Aug. 29	KEJ	8 watt UV trap	13–7°C; clear/ mostly calm night	1 ♂	wet sparsely treed *Larix laricina*-graminoid-*Sphagnum*-ericad rich fen; *Betula pumila*, *Menyanthes trifoliata*, *Sarracenia purpurea*, *Phragmites australis* common

Ehrh. was usually dominant, with numerous other sedges present including *Carex chordorrhiza*, *C. limosa* L., *C. livida* (Wahlenb.) Willd., *C. tenuiflora* Wahlenb., *Cladium mariscoides*, *Eleocharis compressa* Sull., *Rhynchospora alba* (L.) Vahl, and *Trichophorum alpinum*. Forbs were prominent and included *Menyanthes trifoliata*, *Sarracenia purpurea*, and *Drosera* spp. (Droseraceae). Brown mosses including *Scorpidium scorpioides* (Hedw.) Limpr. (Amblystegiaceae) were sometimes prominent. Raised areas of *Sphagnum* moss hummocks, adjacent to (or sometimes intermixed with) the graminoid rich fen habitats, were dominated by various ericaceous shrubs, stunted trees of *Larix laricina* (Du Roi) K. Koch (Pinaceae), *Picea mariana*, and/or *Thuja occidentalis*, and additional shrubs including *Betula pumila*, *Salix* spp. (Salicaceae), *Myrica gale* L. (Myricaceae), and *Dasiphora fruticosa*. Raised *Sphagnum* areas included well-developed strings and tear-drop tree islands in ribbed fens and transitions between open fen and rich swamp forests dominated by *Picea mariana* and/or *Larix laricina*. The raised *Sphagnum* areas graded into poor fen or poor swamp at some sites.

Two sites had distinct patterned peatland features, and three others had either subtle patterns or were near patterned features. The Pine Creek Peatland of Minnesota-Manitoba had both a well-developed complex of spring fen channels (Fig. 3; where most specimens were taken) and a ribbed fen (one specimen taken). First Central Lake in Manitoba featured a reticulate ribbed fen with tree islands (Fig. 4). Captures at Deschambault Lake in Saskatchewan were within a featureless water track (Fig. 5) which connected to a well-developed ribbed fen within 1 km. The Agassiz Peatland in Ontario (Fig. 6) was along the non-patterned margin of a large water track dominated by a well-developed ribbed fen with tear-drop tree islands. The larval collections at Wanamaker Lake Peatlands in Michigan were within a predominately featureless water track with subtle elements of strings and flarks.

Adults. Of the 41 specimens taken as adults (August 21–September 10), 34 were taken with 15 watt UV light traps, 5 were taken with 8 watt UV light traps, 1 was taken at UV sheet, and 1 was netted (Table 1). The netted and UV sheet specimens were taken at 2159 h and 0130 h, respectively, indicating *P. aweme* flies both before and after midnight, though our data does not establish ideal nightly temporal parameters for survey work. Temperatures ranged from 19 to 7°C. The three most productive nights (11 specimens on August 21, 2015; 16 specimens August 22, 2016; 7 specimens on August 28, 2016) were unseasonably warm (17–14°C) and featured strong storms during or the morning after the sampling night.

Larvae. We found 30 larvae (plus the burrow and parasitized remains of 1 larva) at two sites (Pine Creek Peatland in Minnesota-Manitoba; Wanamaker Lake Peatlands in Michigan) from June 23–July 24, 2016. Larvae were found boring in the lower stems and rhizomes of *Menyanthes trifoliata* in open graminoid rich fen habitats (Table 2, Figs 7–11). Plants harboring larvae were typically wilted and sometimes discolored (Fig. 8), though plants containing earlier instars were not always so obviously affected. Plants exhibiting these symptoms often did not harbor *P. aweme* but rather a variety of other invertebrates including sawfly larvae (Hymenoptera: Symphyta), snails feeding externally, and an unidentified small lepidopteran boring in the stems (burrows approx. 1–3cm long, much smaller than those of *P. aweme*).

The plants bored by *P. aweme* were relatively large (stem length approximately 20–30 cm, Fig. 8) and always rooted in a wet (quaking or at least with shallow standing water) sedge mat typically dominated by *Carex lasiocarpa*. Brown mosses (e.g., *Scorpidium scorpioides*) were sometimes prominent. We failed to find any sign of larvae in *M. trifoliata* rooted in other microhabitats such as atop *Sphagnum* hummocks. Both peatland complexes where we found larvae were very large (over 15 km2) but larvae were localized in relatively small areas of habitat (Fig. 12).

Larvae of *P. aweme* (Fig. 9) had markings that were consistent with the genus, with pale dorsal and subdorsal longitudinal stripes. These stripes were unbroken on abdominal segments 1 –4 and helped differentiate larvae of this species from those of congeners also present at the sites (McBride and Wiker 2017).

Larvae were reared in the lab on *Menyanthes trifoliata* stems and rhizomes. AM initially tried transferring larvae to potatoes, as is a common practice for rearing other species in the genus, but most fed very little after a few days and some ceased feeding entirely. These were transferred back to *M. trifoliata* where they resumed feeding activity. Pupation (Fig. 10) occurred within the stem (AM recorded pupation dates from July 7–31 with a mean pupal period of 17.5 days; n=9) and adults (Fig. 11) emerged July 24–September 3 (all rearings).

Companion species. We documented over 139 species in 18 families of Lepidoptera on the evenings and at the sites where *P. aweme* was taken 2009–2016. The most frequent associates are shown in Table 3. *Oligia minuscula* (Morrison) was the only species co-collected with every *P. aweme* capture. However, it is

TABLE 2. *Papaipema aweme* positive larval survey results 2010–2016. Numbers include failed rearings lacking vouchers.

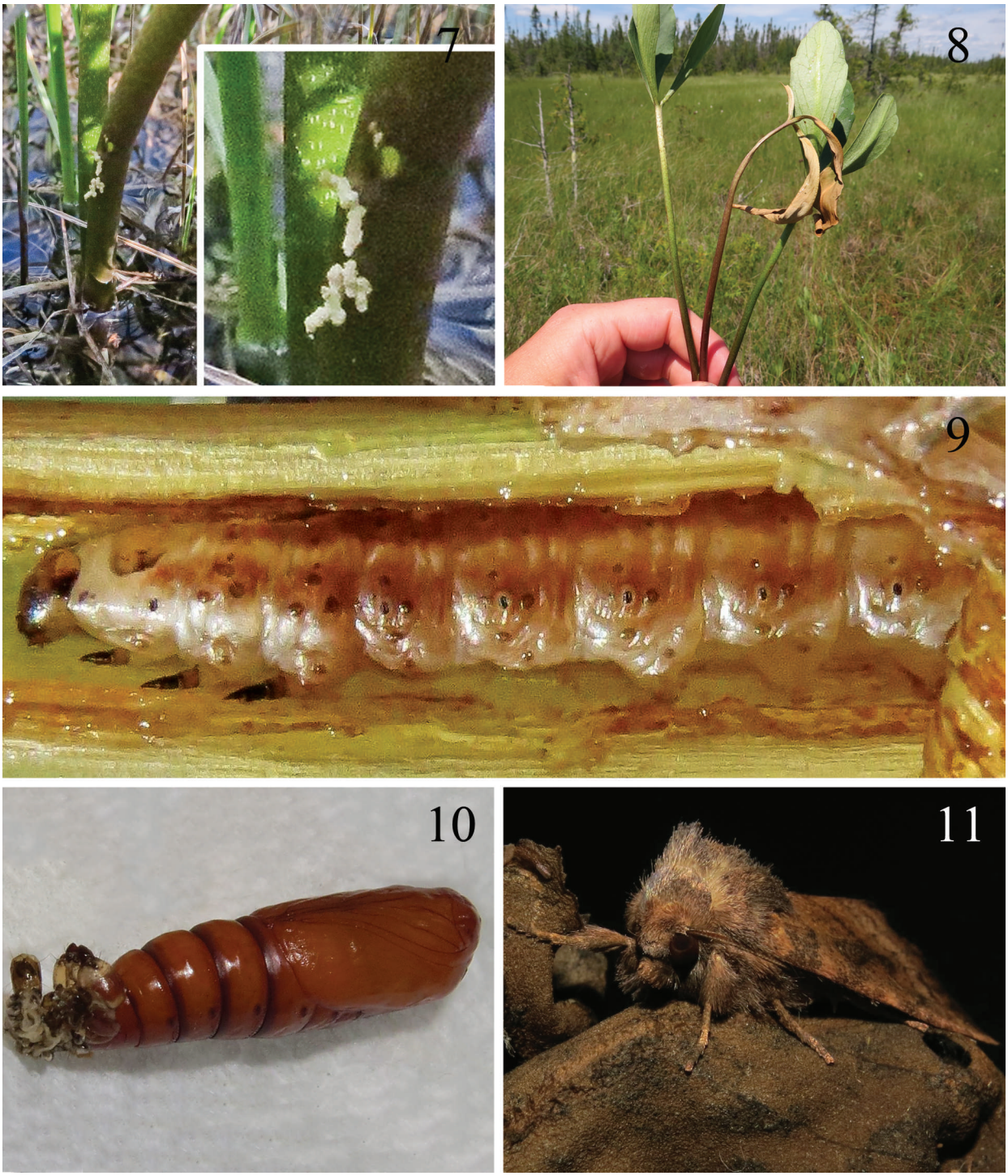
State/ Prov.	Site (County/District)	Date	#	Habitat	Microhabitat of host *Menyanthes trifoliata*
MB	Pine Creek Peatland (Eastman Reg.)	2016 June 23	2	spring fen channel; quaking graminoid rich fen (*Carex lasiocarpa* dominant) bordering *Picea mariana* rich swamp; *Thuja occidentalis*, *Larix laricina*, *Dasiphora fruticosa*, *Betula pumila* common along margin	plant growing in shallow water of quaking *Carex lasiocarpa-Menyanthes trifoliata-Sarracenia purpurea*-mixed sedge mat; brown mosses present
MN	Pine Creek Peatland (Roseau)	2016 June 23	8	as above	as above
MN	Pine Creek Peatland (Roseau)	2016 June 24	18	as above	as above
MI	Wanamaker Lake Peatlands (Luce)	2016 July 24	3	wet sparsely treed *Larix laricina*-graminoid rich fen; scattered *Sphagnum*-ericad hummocks; *Menyanthes trifoliata*, *Betula pumila*, *Dasiphora fruticosa*, *Viburnum cassinoides*, *Sarracenia purpurea* common; few *Picea mariana* plant growing in shallow water of flark-like *Carex lasiocarpa-Rhynchospora alba*-mixed sedge-*Menyanthes trifoliata* mat; brown mosses present	

nearly ubiquitous in northern Great Lakes peatlands and has a relatively long flight period (KEJ data July 6–October 5; n=124) and thus is not a useful indicator of either habitat or flight period of *P. aweme*. Better flight period indicators included *Papaipema appassionata* (Harvey) (KEJ data August 12–September 18; n=113) and *Hypocoena basistriga* (McDunnough) (KEJ data August 21–September 7; n=63). We did not find any conspicuously helpful habitat indicator moths, but combinations of the above species as well as others with specialized peatland niches (e.g., *Crambus awemellus* McDunnough) might prove useful, although this would certainly vary by region.

DISCUSSION

Historical localities. All five historical localities have (or had) *Menyanthes trifoliata* and rich fen habitats in the general vicinity. KEJ examined an extensive graminoid rich fen (part of a spring fen channel complex) with abundant *M. trifoliata* near Aweme, Manitoba (Fig. 13). The habitat there appeared ideal for *P. aweme*, but weather conditions were not optimal during sampling attempts in 2016. Judith Jones (pers. comm.) examined a fen with abundant *M. trifoliata* 7 km east of John Morton's capture site on Manitoulin Island. The fact that Morton only took one specimen in 20 years of sampling the area, and that strong winds gusted out of the east on the night of capture (Jones 2015) suggest this fen was the source population. Ms. Jones and Chris Schmidt sampled this fen and two others in 2016 without success, but sampling conditions were not ideal. Satellite imagery (Google Earth) reveals numerous fens on Beaver Island, Michigan that could have been the source of the dispersing individual captured offshore by Sherman Moore, and *M. trifoliata* has been recorded from the island (Reznicek et al. 2011). Most fens in the vicinity of Rochester, New York are largely degraded but some still include localized, high quality areas with *Menyanthes trifoliata* (Steven Daniel pers. comm.). Grand Bend, Ontario had a potentially suitable fen in the vicinity but this was drained sometime after the moth's capture there (Dale Schweitzer pers. comm.). Extensive surveying at this locality over several decades has failed to turn up any specimens (COSEWIC 2006). Thus, Grand Bend is the only historical locality where a persisting *P. aweme* population is doubtful.

Larval food plants. Although more effort is needed to search alternative food plants, a hypothesis that *P. aweme* larvae are monophagous on *Menyanthes trifoliata* is supported by our preliminary data. All recorded sites were in the vicinity of rich fen habitats that support or could have supported *M. trifoliata*. A



FIGS. 7–11. **7**. White frass visible on lower stem of *Menyanthes trifoliata* inhabited by *Papaipema aweme* larva; Pine Creek Peatland, Eastman Region, Manitoba (June 23, 2016); inset, a detailed view of frass and larval boring hole. **8**. Wilted and browned central petiole of *Menyanthes trifoliata* induced by *Papaipema aweme* larval boring; Pine Creek Peatland, Roseau Co., Minnesota (June 24, 2016). **9.** *Papaipema aweme* larva inside lower stem of *Menyanthes trifoliata*; Pine Creek Peatland, Eastman Region, Manitoba (June 23, 2016). **10**. *Papaipema aweme* pupa in lab, removed from burrow in stem of *Menyanthes trifoliata* (July 13, 2016), reared from larva collected at the Pine Creek Peatland, Roseau Co., Minnesota. **11**. *Papaipema aweme* adult resting on dead leaf of *Menyanthes trifoliata* in lab (August 5, 2016), reared from larva collected at the Pine Creek Peatland, Roseau Co., Minnesota.

FIGS. 12–13. **12**. Distribution of *Papaipema aweme* larvae (yellow circles) and adults (red squares n = 1-2; red star n = 9) at the Pine Creek Peatland on the Minnesota-Manitoba border. Habitats range from open rich fen to rich swamp; patterned types include spring fen channels (left) and ribbed fen (lower center). The points span 1.9 km. **13.** Potential *Papaipema aweme* habitat near Aweme, Manitoba (August 24, 2016). Spring fen channel open graminoid rich fen bordering *Larix laricina* (*Picea mariana*) rich swamp groves. *Menyanthes trifoliata* is abundant. A UV light trap is visible in the photo center.

restriction to this host plant, growing in this particular rich fen microhabitat, would explain the moth's rarity in collections.

At Michigan's Wanamaker Lake Peatlands, DRB and others attempted to re-document *P. aweme* 2010–2015 with over 143 trap nights targeting adults, and seven days searching for larvae. None was found despite targeting a wide variety of peatland habitats with diverse flora, including most of the targeted potential larval food plants mentioned above. Attempts prior to 2016, however, were isolated from habitats with plentiful *Menyanthes trifoliata* by 0.8 km or more. By contrast, once *M. trifoliata* was known as a host in 2016 (based on the Pine Creek Peatland discoveries) DRB and KEJ found larvae on the first attempt at the Wanamaker Lake Peatlands, and KEJ collected 19 adult specimens with only 22 trap nights/9 calendar nights of effort across Manitoba, Ontario, and Saskatchewan (of these, 12 trap nights/5 calendar nights were probably not suitable for proper survey given phenology and weather). The extensive negatives of 2010–2015 versus successes of 2016 could be readily explained if *P. aweme* was restricted to *Menyanthes trifoliata*.

Additional effort is also needed to search for larvae in *Menyanthes trifoliata* growing in other microhabitats such as among *Sphagnum* mosses (both in rich and poor fen habitats), in open water on the edge of peatland pools, or in partial shade of *Picea mariana* and *Larix laricina* rich swamps. Larval presence of *P. aweme* in these situations would expand the possibilities for new localities.

Negative sites. The 57 sites where we failed to document *P. aweme* give a misleading impression of rarity since prior to 2016, most of our sampling sites appear to lack suitable habitat (Fig. 2), at least in the vicinity of searches. In addition, many sites were sampled only once, and some of these under marginal survey conditions. We expect that additional effort at our "negative" sites with abundant *Menyanthes trifoliata* will disclose additional *P. aweme* localities.

Phenology. Our adult capture dates (August 21–September 10) averaged later than historical records (August 7–26) but this could be an artifact of insufficient sampling during advanced seasons. *Papaipema appassionata* specimens co-collected with *P. aweme* exhibited similar wear. We found relatively fresh *P. appassionata* as early as August 12 and as late as September 8, but appropriate *P. aweme* habitats were not sampled on early dates during advanced seasons. Thus surveys should adjust for advanced or delayed seasons and not rely solely on calendar dates.

Our larval captures were split between earlier instars (June 23–24) and mature larvae (July 24). Although *P. aweme* larval damage was not always obvious during the early dates, finding larvae was relatively easy since damage from other invertebrates was not yet widespread among the *M. trifoliata*. By contrast, the few larvae found on the latter date had all dramatically disfigured their hosts (brown and wilted), but the majority of plants in their vicinity had been sufficiently damaged by other invertebrates to make finding *P. aweme* larvae considerably more difficult. Pupae could conceivably be located in the host stems as was observed

TABLE 3. Other Lepidoptera co-collected with *Papaipema aweme* adults 2009–2016 on 3 or more nights (out of 7 total).

Species	# nights co-documented
Oligia minuscula (Morrison)	7
Nepytia canosaria (Walker)	6
Plusia magnimacula Handfield & Handfield	6
Endothenia hebesana (Walker)	5
Epinotia septemberana Kearfott	5
Hypenodes sombrus Ferguson	5
Lithomoia germana (Morrison)	5
Papaipema appassionata (Harvey)	5
Scoparia biplagialis Walker	5
Sutyna privata (Walker)	5
Xestia dilucida (Morrison)	5
Archips alberta (McDunnough)	4
Crambus bidens Zeller	4
Epiglaea apiata (Grote)	4
Eulithis testata (Linnaeus)	4
Helotropha reniformis (Grote)	4
Lambdina fiscellaria (Guenée)	4
Sympistis dentata (Grote)	4
Tolype laricis (Fitch)	4
Xestia smithii (Snellen)	4
Acleris variana (Fernald)	3
Amphipyra pyramidoides Guenée, 1852	3
Capsula subflava (Grote)	3
Cingilia catenaria (Drury, 1773)	3
Coenophila opacifrons (Grote, 1878)	3
Crambus albellus Clemens	3
Enargia decolor (Walker, 1858)	3
Eremobina claudens (Walker)	3
Eurois occulta (Linnaeus, 1758)	3
Fishia illocata (Walker, 1857)	3
Hypenodes palustris Ferguson	3
Prochoerodes lineola (Goeze)	3
Sparganothis sulfureana (Clemens)	3
Syngrapha epigaea (Grote)	3
Syngrapha octoscripta (Grote)	3

in captivity but this has yet to be confirmed in the wild. As with the adult surveys, larval searches should adjust for advanced or delayed seasons.

Biogeography. The new *P. aweme* localities and refined habitat associations suggest a much broader range of occupancy than is currently documented. The habitats where we found the moth, particularly the patterned peatland examples, are typical of the boreal forest region from Newfoundland to Alaska, and *Menyanthes trifoliata* is similarly distributed (Crum 1988; Wright et al. 1992; USDA, NRCS 2017, pers. obs.). *Papaipema aweme* localities south of the 50th parallel occur along the southern range edge of boreal peatlands, whereas those north of the 54th parallel lie within the habitat range core. Similarly, the Saskatchewan and northern Manitoba localities may lie within the core range of *P. aweme*, and are not necessarily at the northwestern range extreme as suggested by Figure 1. This is supported by the relative ease of the moth's discovery there, since both sites sampled north of the 54th parallel yielded positive results on the first attempt. The site in Manitoba sampled between the 54th and 53rd parallels had negative results but this was on a single night with poor weather (rainy and windy, with only 4 species of moths documented). Further exploration of peatlands at northerly latitudes should be productive both for the discovery of new populations and for range extensions. Promising areas for future surveys include the James Bay Highway in northwestern Quebec, Sundance (along the southern edge of the Hudson Bay Lowlands) in northern Manitoba, and the vicinity of Cold Lake in eastern Alberta.

Papaipema aweme is currently the most northerly known *Papaipema* (Eric Quinter, pers. com.), and given its habitat associations and potential for range extensions it may be the most widespread *Papaipema* in boreal North America.

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