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NOTES ON A RECENTLY DISCOVERED POPULATION OF *HADENA ECTYPA* (MORRISON, 1875)
(NOCTUIDAE: NOCTUINAE: HADENINI) IN MASSACHUSETTS

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ABSTRACT. *Hadena ectypa* (Morrison, 1875) (Noctuidae: Noctuinae: Hadenini) is a rarely encountered moth of conservation concern, inhabiting forest and woodland openings and edges in eastern North America. A population discovered in 2002 in Massachusetts (USA) is the first record of this species in New England. *Hadena ectypa* larvae from this population were reared in 2003, 2009, and 2010; the immature stages and life history are described. Parasitism by a species of *Eulophus* Geoffroy, 1762 (Hymenoptera: Eulophidae) and predation by *Toxomerus geminatus* (Say, 1823) (Diptera: Syrphidae) were observed. The native host plant of *Hadena ectypa* is *Silene stellata* (L.) W.T. Aiton (Caryophyllaceae), however, the population in Massachusetts uses introduced *Silene vulgaris* (Moench) Garcke as the primary larval host. *Hadena ectypa* could have adopted *S. vulgaris* as a novel host at any time during the past 200 years. *S. vulgaris* shares a number of traits with *S. stellata* that may have facilitated this host shift. Many of these traits are also shared by another introduced species, *Silene latifolia* Poiret, and while *Hadena ectypa* will feed on this plant in captivity, is not known to use it in the wild. The adoption of *S. vulgaris* as a larval host may allow *Hadena ectypa* to spread to new, weedier habitats, to increase its geographic range, and to increase its propensity for a second annual generation.

Additional key words: calyx, diapause, parasitoid, larval behavior, rearing

Hadena ectypa (Morrison, 1875) is a noctuid moth, one of 140 species in the Holarctic genus *Hadena* Schrank, 1802 (Hacker 1996; Troubridge & Crabo 2002). Fifteen species of *Hadena* occur in North America, most of which are western, with only *Hadena ectypa* and *Hadena capsularis* (Guenée, 1852) occurring in the east (Troubridge & Crabo 2002). *Hadena ectypa* is found from southeastern New York west to Minnesota and Kansas, and south to northern Georgia. It is a rare moth throughout its range, found most frequently in the Appalachian Mountains, from southern Ohio and West Virginia, south to Tennessee and North Carolina (Schweitzer et al. 2011). As larvae, species in the genus *Hadena* are specialized feeders on the flowers and seed capsules of “pinks,” herbaceous plants in the family Caryophyllaceae (Forster & Wohlfahrt 1971; Hacker 1996; Young 1997). Species in the genus *Silene* L. are particularly frequent hosts for *Hadena* (Robinson et al. 2002). The only published larval host for *Hadena ectypa* is starry campion, *Silene stellata* (L.) W.T. Aiton (Robinson et al. 2002), plus one record of a larva on fire pink, *Silene virginica* L. (Kephart et al. 2006). The habitat of *Hadena ectypa* is typically described as forest and woodland openings and edges, though it occurs in more open prairie and savanna habitats in the western part of its range (Metzler et al. 2005). The reported flight season for *Hadena ectypa* extends from late June through early August (Wyatt 1929; Forbes 1954; Rings et al. 1992; Schweitzer et al. 2011), with larvae developing in July and August (Wyatt 1929; Forbes 1954; Crumb 1956; Godfrey 1972).

METHODS AND RESULTS

Fieldwork. A population of *Hadena ectypa* was discovered in Massachusetts (USA), in Hampshire County, town of Huntington, at the Knightville State Wildlife Management Area (WMA). The initial discovery was made when a single adult was captured in a blacklight trap (15 Watt, Leroy Koehn design), set the night of 10–11 September 2002. As both the locality and the date of capture were unusual for *Hadena ectypa*, the identification of the specimen was confirmed by both T.L. McCabe (New York State Museum) and D.F. Schweitzer (NatureServe). Subsequent searches of the literature and collections (including the Harvard Museum of Comparative Zoology, the American Museum of Natural History, the New York State Museum, and the National Museum of Natural History) failed to find any records for *Hadena ectypa* to the north or east of southeastern New York state. Therefore the moth trapped in Huntington, Massachusetts in 2002 appears to represent the first record of *Hadena ectypa* in New England.

Not a single September collection date was found for museum specimens from the Northeast, nor could any reference to such a late flight season be found in the literature, with one exception. In what appears to be the first published life history account for *Hadena ectypa*, Wyatt (1929) describes the rearing of an unspecified number of individuals, collected from *Silene stellata* by A. Herz, one of which emerged on 5 September of the same year. The remaining individuals overwintered as pupae, emerging between 23 June and 25 July of the

following year. Therefore it appears that *Hadena ectypa* has a facultative second generation, which in the wild is probably partial as far north as Massachusetts. In the British Isles, a partial second generation occurs in several species of *Hadena* (Porter 1997).

The discovery of *Hadena ectypa* in Massachusetts presented another mystery: its native host plant, *Silene stellata*, is not known to occur in the state (FNA 2005; Magee & Ahles 2007; Dow Cullina et al. 2011; Haines 2011). On 29 July 2003, the Knightville WMA was visited in the hope of finding larvae of *Hadena ectypa*, and possibly even discovering a population of *S. stellata* in Massachusetts. The Knightville WMA site is at the bottom of a steep-sided ravine, forested with northern hardwoods, hemlock (*Tsuga canadensis* (L.) Carrière), and white pine (*Pinus strobus* L.). The Westfield River flows through the bottom of the ravine. The light trap that caught *Hadena ectypa* in 2002 was set in floodplain forest habitat on the west side of the river, approximately 50 m from the bank. The floodplain forest is on an approximately 100 m wide strip of flat terrain bordering the river, which also includes open fields maintained by infrequent mowing, and a dirt road running parallel to the river. Immediately to the west of the flat strip of terrain, the topography rises steeply and is densely forested.

Various open areas within this predominantly forested habitat were searched for species of *Silene*, including the fields, margins of the dirt road, and the river banks. The river has a rocky substrate, with margins of accumulated cobble and sandy soils, which support a narrow strip of herbaceous vegetation between the river and the floodplain forest (Fig. 1). Approximately 450 m to the south of where the *Hadena ectypa* adult was trapped in 2002, growing amongst other herbaceous vegetation on the sandy river bank, a concentration of bladder campion, *Silene vulgaris* (Moench) Garcke, was found. Eight *Hadena ectypa* larvae were found on the *S. vulgaris*, ranging from the second through the fifth instar. Each larva was feeding on a green seed pod (ovary), hidden inside the inflated calyx of a flower just past bloom. In addition, one *Hadena ectypa* egg was found on *S. vulgaris*, laid on the green ovary inside the calyx of a flower. All eight larvae and the egg were collected for rearing. This discovery represents the first record of *Hadena ectypa* using *S. vulgaris* as a larval host, which is of particular interest because *S. vulgaris* is an introduced species from Europe (FNA 2005; Magee & Ahles 2007). At the request of MWN, Lynn Harper (Massachusetts Natural Heritage & Endangered Species Program) searched for additional larvae during a visit to the Knightville WMA on 7 August 2003. One fourth instar larva was found on

S. vulgaris, growing on the river bank at a second location approximately 700 m to the north of where the *Hadena ectypa* adult was trapped. This larva was also collected for rearing.

On 8 August 2004, and again on 23 June 2005, the Knightville WMA was visited in order to more extensively search for other species of *Silene*, and in particular any native species that could serve as larval hosts for *Hadena ectypa*. During the 2004 visit, in addition to searching the river banks, margins of the dirt road, and fields in the vicinity of where *Hadena ectypa* had been found previously, a nearby talus slope and wetland were explored. The canopy on the talus slope is sparse enough to allow growth of herbaceous vegetation in the understory. The wetland is a beaver pond surrounded by open marsh and wet meadow. No species of *Silene* were found on the talus slope or in the wetland. Ragged robin, *Silene flos-cuculi* (L.), was found during the 2005 visit. Like *Silene vulgaris*, *S. flos-cuculi* is an introduced species from Europe (FNA 2005; Magee & Ahles 2007). The *S. flos-cuculi* was growing on the bank and cobble bars along the west side of the river, immediately to the south of where *Hadena ectypa* had been found feeding on *S. vulgaris* in 2003. In 2005, *S. vulgaris* was found growing in the same area as *S. flos-cuculi*, and both plants were searched for eggs and larvae of *Hadena ectypa*. None were found, but it was probably still too early in the season.

The Knightville WMA was not revisited until 26 July and 17 August 2008. The stretch of riverbank where *Hadena ectypa* larvae were found on *Silene vulgaris* in 2003 was checked, and found to be overgrown with Japanese knotweed, *Fallopia japonica* (Houttuyn) Ronse Decraene (Polygonaceae), an invasive species introduced from Asia (FNA 2005; Magee & Ahles 2007). No *S. vulgaris* remained, but a search to the north found about a dozen *S. vulgaris* plants, scattered along an approximately 1 km stretch of the west bank of the river. A few *Silene flos-cuculi* plants were also found along this stretch, as well as a few white campion, *Silene latifolia* Poiré, another introduced species from Eurasia (FNA 2005; Magee & Ahles 2007) that had not been noted during previous visits. The *S. vulgaris*, *S. flos-cuculi*, and *S. latifolia* plants were all searched for *Hadena ectypa* eggs and larvae, but none were found. A few of the *S. vulgaris* plants, however, had feeding damage that may have been caused by *Hadena ectypa* larvae.

The Knightville WMA was visited on 28 July 2009 in order to determine if *Hadena ectypa* still persisted at this site. At the north end of the stretch of river where *Hadena ectypa* had been found in 2003, a half dozen *Silene vulgaris* plants were found growing on the sandy



FIGS. 1-2. **1)** Habitat of *Hadena ectypa* at the Knightville State Wildlife Management Area, town of Huntington, Hampshire County, Massachusetts, USA. This stretch of the Westfield River has a rocky substrate, with margins of accumulated cobble and sandy soils, which support a narrow strip of herbaceous vegetation between the river and the floodplain forest. Photographed 28 July 2009. **2)** Bladder campion, *Silene vulgaris*, growing on the sandy river bank behind the cobble bar in Fig. 1. *Hadena ectypa* was collected from this plant. Photographed 28 July 2009.

bank behind a cobble bar. The habitat (Fig. 1) and *S. vulgaris* (Fig. 2) were photographed at this location. Most of the *S. vulgaris* flowers were just past peak, with petals still present and ovaries small and green. Careful examination of flowers at this stage revealed the presence of *Hadena ectypa*: four first instar larvae, each in its own flower, and two unhatched eggs, both laid on the ovary of a single flower. All four larvae and both eggs were collected for rearing. Also observed on 28 July 2009 were a number of small syrphid flies (Diptera: Syrphidae), including one mating pair, on and around the *S. vulgaris*. In addition, syrphid fly larvae were observed on the *S. vulgaris* flowers. On 3 August 2009 the Knightville WMA was revisited in order to determine if the *Hadena ectypa* population extended further to the south of areas explored previously. At a site on the west bank of the river, approximately 2.6 km to the south of where *Hadena ectypa* was found on 28

July 2009, a single third instar larva of *Hadena ectypa* was found on *S. vulgaris*, and collected for rearing.

The Knightville WMA was revisited on 15, 18, and 20 July 2010. On 15 July 2010, at the same site where *Hadena ectypa* was found on 28 July 2009, five large *Silene vulgaris* plants were thoroughly searched, with hundreds of flowers examined. A total of 25 *Hadena ectypa* larvae were found (two in the second instar and 23 in the third instar), as well as seven shed head capsules (one from the first instar and six from the second instar), and two empty eggshells (both inside the same flower). Two second instar and six third instar larvae were collected for rearing. On 18 July 2010, the river banks to the north were searched, but the only sign of *Hadena ectypa* was a single empty eggshell on one of six *S. vulgaris* plants about 800 m north of where *Hadena ectypa* was found on 15 July. On 20 July 2010, the river banks to the south were searched. At one site



FIGS. 3-4. **3)** *Hadena ectypa*, adult male, reared in 2009. Wingspan 28.5 mm. **4)** *Hadena ectypa*, adult female, reared in 2010. Wingspan 30.0 mm.

approximately 1.8 km south of where *Hadena ectypa* was found on 15 July, one first instar, one second instar, and two third instar larvae were found on six *S. vulgaris* plants, as well as a shed second instar head capsule and seven empty eggshells. The first and second instar larvae were collected for rearing. At a second site about 850 m farther south (close to where *Hadena ectypa* was found on 3 August 2009), one first instar and two second instar larvae were found on four *S. vulgaris* plants, as well as two shed head capsules (one from the first instar and one from the second instar), and three empty eggshells. The first instar larva and one second instar larva were collected for rearing.

Rearing. In 2003, 10 individuals of *Hadena ectypa* were collected as one egg and nine larvae ranging from the second through the fifth instar. In 2009, seven individuals were collected as two eggs, four first instar larvae, and one third instar larva. In 2010, 12 individuals were collected as two first instar larvae, four second instar larvae, and six third instar larvae. Each individual was reared separately in its own plastic vial. In 2003, all larvae were initially fed flowers and ovaries of *Silene vulgaris*, and later switched to flowers and ovaries of *Silene latifolia*, which was accepted. In 2009 and 2010, all larvae were fed flowers and ovaries of *S. vulgaris* exclusively. A 1:1 mixture of peat and sand was provided for pupation. Rearings were kept on a shaded outside porch for a natural photoperiod and temperature regime.

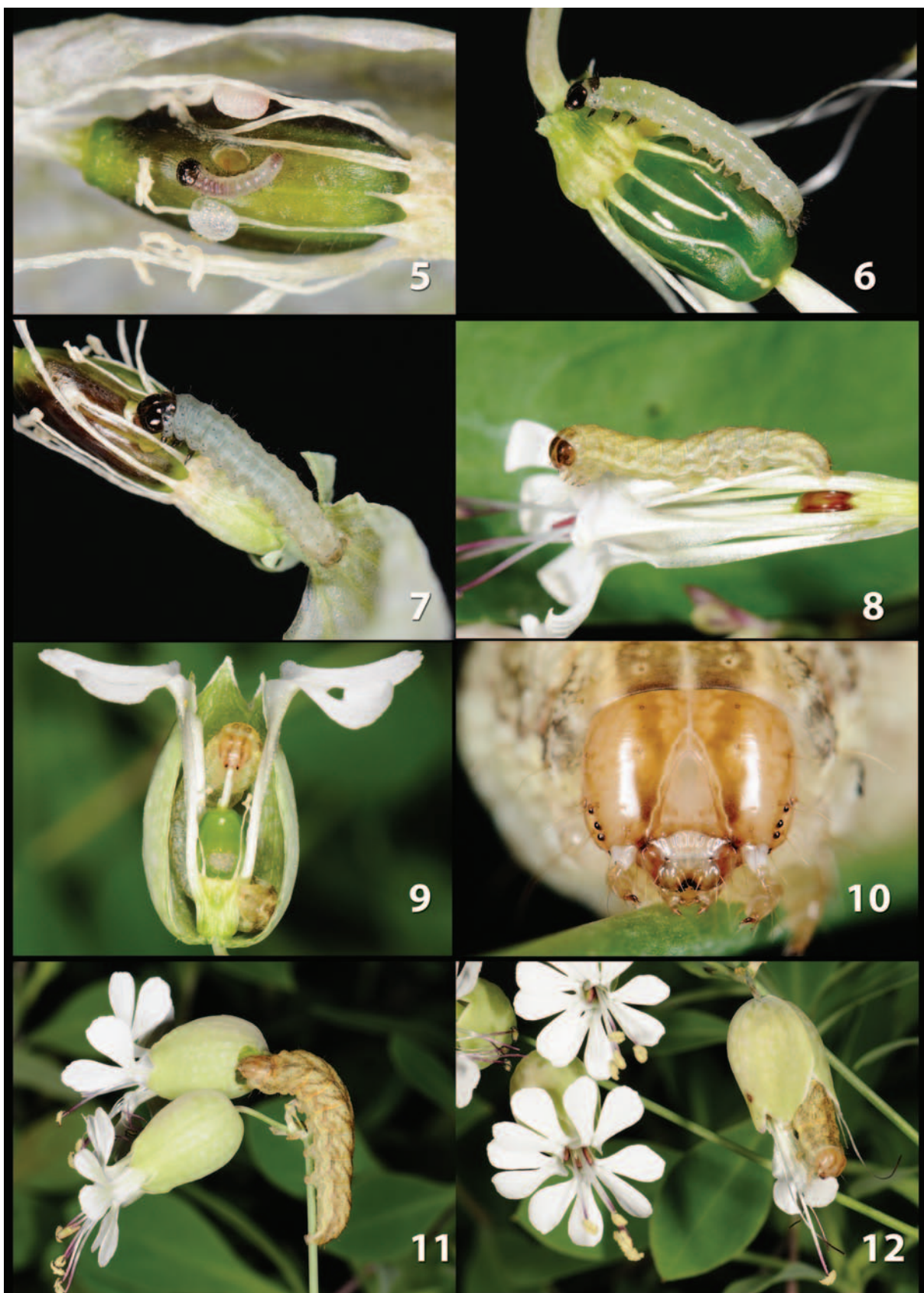
The *Hadena ectypa* egg collected on 29 July 2003 hatched on 31 July, and the fully-grown larva burrowed into the peat/sand mixture for pupation on 21 August, a total larval development time of only 21 days. Of the other eight individuals reared in 2003, one final instar larva was preserved, and the other seven burrowed into the peat/sand for pupation between 10 and 22 August. The eight individuals reared through pupation in 2003 emerged between 29 August and 27 September, with pupal periods ranging from 19 to 37 days (mean of 27 days). Of the seven individuals reared in 2009, three were preserved as larvae, and the other four burrowed

into the peat/sand for pupation between 11 and 17 August. These individuals emerged between 28 August and 9 September, with pupal periods ranging from 17 to 23 days (mean of 21 days). An adult male reared in 2009 is shown in Fig. 3. Of the 11 individuals reared in 2010, four were preserved as larvae, one was preserved as a pupa, and the other six burrowed into the peat/sand for pupation between 26 July and 13 August. These individuals emerged between 13 August and 4 September, with pupal periods ranging from 17 to 22 days (mean of 18 days). An adult female reared in 2010 is shown in Fig. 4.

One fifth instar *Hadena ectypa* larva collected on 29 July 2003 was found dead inside a calyx of *Silene vulgaris* on 3 August, along with 16 live eulophid larvae (Hymenoptera: Eulophidae) that had exited its body. The eulophids pupated almost immediately, and all 16 adults emerged on 10 August. Specimens were preserved, and later identified as belonging to the genus *Eulophus* Geoffroy, 1762 by Dr. Michael W. Gates at the Systematic Entomology Laboratory, Agricultural Research Service, U.S. Department of Agriculture. The specimens could not be identified to species, as the genus *Eulophus* is in need of revision, and species identification requires sorting through primary literature and type specimens that are not readily available.

On 20 July 2010, a syrphid fly larva (likely the same species observed on 28 July 2009) was inadvertently collected along with a *Silene vulgaris* flower and one second instar larva of *Hadena ectypa*. When the contents of the rearing vial were examined that evening, all that remained of the *Hadena ectypa* larva were the head capsule and cuticle. The syrphid larva was kept for rearing and identification. It was fed pre-pupal braconid larvae (Hymenoptera: Braconidae), of which it consumed four over the course of six days. The adult fly emerged on 2 August. The specimen was sent to Michael C. Thomas at the Connecticut Agricultural Experiment Station, who identified it as *Toxomerus geminatus* (Say, 1823).

FIGS. 5-12. [Opposite page] **5)** *Hadena ectypa* egg, hatchling larva, and empty eggshell, all on ovary of *Silene vulgaris* (the calyx has been peeled open). The hatchling has chewed a hole through the ovary wall to feed on the ovules within. Eggs 0.7 mm in diameter, 0.4 mm high. Hatchling larva 1.8 mm long, head capsule 0.35 mm wide. Photographed 29 July 2009. **6)** *Hadena ectypa*, second instar larva on ovary of *Silene vulgaris* (the calyx has been removed). Larva 4.5 mm long, head capsule 0.55 mm wide. Photographed 23 July 2010. **7)** *Hadena ectypa*, third instar larva feeding on ovary of *Silene vulgaris* (the calyx has been peeled back). Larva 6.0 mm long, head capsule 0.80 mm wide. Photographed 2 August 2009. **8)** *Hadena ectypa*, fourth instar larva feeding on petals of *Silene vulgaris* (the calyx has been removed). Larva 13 mm long, head capsule 1.3 mm wide. Photographed 5 August 2009. **9)** *Hadena ectypa*, fifth instar larva feeding on style inside calyx of *Silene vulgaris* (one side of the calyx has been removed). The larva has also chewed a hole through the ovary wall, exposing the ovules within. Larva 18 mm long, head capsule 1.8 mm wide. Photographed 5 August 2009. **10)** *Hadena ectypa*, sixth instar, frontal view of head. Head capsule 2.8 mm wide. Photographed 25 July 2010. **11)** *Hadena ectypa*, sixth instar larva making hole in calyx of *Silene vulgaris*. Larva 25 mm long, head capsule 2.7 mm wide. Photographed 12 August 2009. **12)** *Hadena ectypa*, sixth instar larva half inside calyx of *Silene vulgaris*, feeding on petals. Larva 25 mm long, head capsule 2.7 mm wide. Photographed 12 August 2009.



Deposition of specimens. The single wild-collected *Hadena ectypa* adult was pinned and spread, as were all reared adult moths. Pupal shells were pinned. Larvae and one pupa were preserved in 75% ethanol. *Eulophus* sp. parasitoids were mounted on points. *Toxomerus geminatus* was preserved in 75% ethanol. Specimens were deposited at the Massachusetts Natural Heritage & Endangered Species Program Insect Collection.

Description of immature stages. The following descriptions were prepared with either living specimens or photos of living specimens, and later checked and expanded by examining preserved material. All specimens (N = 29) were from the population at the Knightville State Wildlife Management Area in the town of Huntington, Hampshire County, Massachusetts, USA.

Egg (Fig. 5). Flattened spherical, 0.7 mm in diameter and 0.4 mm high. Micropylar rosette with 10–12 lobes. White in color, chorion with reticulate sculpturing. Black head capsule and lavender gut of first instar larva visible through eggshell prior to hatching.

First instar larva (Fig. 5). Length ~1.8 mm at hatching, growing to 3.0 mm. Head capsule 0.30–0.35 mm wide, smooth and shiny, solid black in color. Prothoracic shield brown upon hatching, becoming gray. Legs gray. Body smooth and pale, grayish white, almost colorless, with minute (<0.1 mm long), tan to dark brown setae, each seta arising from a small gray pinaculum. Spiracles round to slightly oval, outlined with gray. Gut of hatching larva lavender in color, visible through body wall (Fig. 5), fading shortly after hatching.

Second instar larva (Fig. 6). Growing to 5.5 mm in length. Head capsule 0.55–0.60 mm wide, smooth and shiny, solid black in color. Prothoracic shield and legs dark gray. Body smooth and pale, grayish white, almost colorless, with minute (~0.1 mm long), tan to brown setae, each seta arising from a small gray pinaculum. Spiracles round to slightly oval, outlined with gray. Anal shield and posterior of anal prolegs sclerotized, dark gray in color.

Third instar larva (Fig. 7). Growing to 8.0 mm in length. Head capsule 0.75–0.80 mm wide, smooth and shiny, dark brown to black in color. Prothoracic shield dark gray, bisected with a pale gray median stripe and flanked with pale gray on either side. Legs dark gray. Body smooth and pale, greenish gray, with faint, grayish-white dorsal and spiracular lines. Setae minute (~0.2 mm long), tan in color, each arising from a small gray pinaculum. Subdorsal pinacula smaller than lateral pinacula. Spiracles round to slightly oval, tan in color and outlined with gray. Anal shield and posterior of anal prolegs sclerotized and gray in color.

Fourth instar larva (Fig. 8). Growing to 13 mm in length. Head capsule 1.2–1.3 mm wide, smooth and shiny, yellowish tan in color with brown bar extending from vertex to base of frons; vertex and coronal region sometimes more extensively brown, obscuring bar (as in Fig. 8). Ocelli and mandibles dark brown. Color and pattern of prothoracic shield and legs as in the sixth instar. Body smooth and pale, whitish yellow in color, with darker, greenish-yellow markings, pattern elements as in the sixth instar. Dorsal and subdorsal setae with yellow ring around base. Supraspiracular area with greenish-yellow mottling. Spiracles oval, tan in color and outlined with black. Subspiracular area pale yellow, almost white. Ventrolateral area and venter pale yellow, almost colorless. Setae short (<0.3 mm), some on head, prothorax, venter, and ninth and tenth abdominal segments longer (0.3–0.5 mm). Setae tan in color, each thoracic and abdominal seta arising from a minute pinaculum. Subdorsal pinacula smaller than lateral pinacula.

NOTE: Several individuals reared in 2010 were unusually large in the third instar, and had a slightly wider head capsule than is typical at this stage. Furthermore, no fourth instar head capsules could be

found for these same individuals, after they molted to “fifth” instars of typical size and head capsule width. It is possible that these individuals consumed their fourth instar head capsules, or that the capsules were simply lost. However, this also suggests the intriguing possibility that some individuals, under conditions conducive to rapid growth, may skip an instar by combining the third and fourth instars into a single stage. This possibility should be investigated further.

Fifth instar larva (Fig. 9). Growing to 20 mm in length. Head capsule 1.7–1.8 mm wide, smooth and shiny, color and pattern as in the sixth instar. Ocelli and mandibles dark brown. Color and pattern of prothoracic shield and legs as in the sixth instar. Body smooth and yellow in color, with greenish-brown markings dorsally, pattern elements as in the sixth instar. Dorsal and subdorsal setae with yellow ring around base, lateral setae with slightly smaller yellow ring. Supraspiracular area with greenish-brown mottling. Spiracles oval, tan in color and outlined with black. Subspiracular area pale yellow. Ventrolateral area and venter pale yellow, almost colorless. Setae short (<0.4 mm), some on head, prothorax, venter, and ninth and tenth abdominal segments longer (0.4–0.7 mm). Setae tan in color, each thoracic and abdominal seta arising from a minute pinaculum. Subdorsal pinacula about same size as lateral pinacula.

Sixth instar larva (Figs. 10, 11, and 12). Growing to 28–32 mm in length and 4.0–5.0 mm wide at fourth abdominal segment. Head capsule (Fig. 10) 2.7–2.8 mm wide, rounded in frontal view, smooth and shiny; yellowish tan in color with faint, reticulate brown patterning, distinct, brown coronal/frontal stripe extending from vertex to base of frons, and short brown supraocellar stripe. Distance between dorsal adfrontal seta (AF2) and ventral posteriodorsal seta (P1) slightly less than distance between P1 and dorsal posteriodorsal seta (P2). Ocelli dark brown. Antennal base white, antenna yellowish tan. Anteclypeus white, labrum yellowish tan with dark brown edge at notch. Mandible yellowish tan proximally, brown distally, cutting edge dark brown, almost black. Mandible with six teeth on cutting edge, plus one large, triangular inner tooth, which is absent in *Hadena capsularis* (Godfrey 1972, Fig. 42 as compared to Fig. 40). Details of the hypopharyngeal complex are given in Godfrey (1972, p. 26 and Fig. 43). Edges of postgenal sclerites almost touch.

Prothoracic shield with concentration of brown dorsally, bisected with yellow median stripe and flanked with yellow on either side, each seta with yellow ring around base. On first thoracic segment, distance between second dorsal seta (D2) and second subdorsal seta (SD2) greater than distance between D2 and second extra dorsal seta (XD2). Legs yellowish tan, matching lighter portions of head capsule. Metathoracic coxae narrowly separated.

Body smooth and golden yellow in color, with brown markings dorsally, including two parallel dorsal lines, fused between segments, outlining a narrow and broken dorsal stripe flanked by an oblique dorsolateral dash on each segment, creating a “herringbone” pattern of chevrons pointing posteriorly. Each dorsolateral dash (“arm” of chevron) widest dorsally, tapering laterally. Dorsal and subdorsal setae with yellow ring around base (dorsal rings with brown “shadow” on side nearest dorsal line), lateral setae with smaller yellow ring. Supraspiracular area with pale brown mottling. Spiracles oval, tan in color and outlined with black. Height of spiracle on first thoracic segment 1.2 times height of spiracles on first through seventh abdominal segments; height of spiracle on eighth abdominal segment 1.3 times height of those on first through seventh segments. On second abdominal segment, distance between first subdorsal seta (SD1) and spiracle greater than distance between first lateral seta (L1) and spiracle; on eighth abdominal segment, distance between SD1 and spiracle less than distance between L1 and spiracle. Subspiracular area pale yellow; ventrolateral area and venter paler yellow, almost colorless. Setae short (<0.5 mm), some on head, prothorax, venter, and ninth and tenth abdominal segments longer (0.5–1.0 mm). Setae tan in color, each thoracic and abdominal seta arising from a minute pinaculum. Subdorsal pinacula about same size as lateral pinacula. Venter of first and second abdominal segments with setae arising from a prominent pinaculum (Crumb 1956). Crochets uniordinal, number on each proleg: third abdominal segment, 20–23; fourth, 20–24; fifth, 22–26; sixth, 22–28; and tenth, 28–32.



FIGS. 13-14. **13)** *Hadena ectypa*, pupa, lateral. Length 16 mm, width 5.0 mm at third abdominal segment. Photographed 20 August 2009. **14)** *Hadena ectypa*, pupa, ventral. Length 15 mm, width 5.0 mm at third abdominal segment. Photographed 7 August 2010.

Pupa (Figs. 13 and 14). Length 14.5–16.5 mm, width 4.5–5.0 mm at third abdominal segment. Head with bulging eyes and vertex, and dorsal concavity at the epicranial suture. Wings ending at posterior margin of fourth abdominal segment. Maxillae extending past wing margins in prominent ventral lip above articulation of fourth and fifth abdominal segments. Metathoracic legs ending in line with spiracle on fourth abdominal segment, antennae slightly shorter. Mesothoracic legs ending in line with posterior margin of first abdominal segment. Prothoracic legs and labial palpi barely visible. Tenth abdominal segment ending in elongated cremaster with single pair of stout hooks, both tapered and curved inwardly at apex. Integument thin, light orangish brown on wings and other appendages, somewhat thicker and darker, orangish brown on abdominal segments, and considerably thicker and darker brown on eyes, vertex of head, dorsum of head and thorax, and ninth and tenth abdominal segments. Integument smooth on wings and other appendages, with only faint, wrinkled sculpturing under magnification. Wrinkled sculpturing more prominent on head. Dorsum of head, thorax, and anterior half of first through fourth abdominal segments sculptured with numerous minute pits, anterior half of fifth through seventh abdominal segments with pits around entire perimeter, eighth and ninth abdominal segments with pits over entire surface, and tenth abdominal segment smooth. Minute setae present on vertex of head and on dorsum of thorax and abdomen.

Life history notes. In Massachusetts, *Hadena ectypa* adults are active in July, although a small number of individuals may emerge earlier. Moths emerge from their pupae in the early morning, but otherwise all adult activity, including feeding, mating, and oviposition, occurs nocturnally. The egg is laid inside the inflated calyx of a *Silene vulgaris* flower, deposited on the side of a green, immature seed pod (ovary), or on the base of a petal or stamen (Fig. 5). Normally only one egg is laid inside a single flower, but occasionally there are two, or rarely even three. The hatchling larva does not typically consume its eggshell. Instead, upon eclosion, it bores a hole into the ovary and begins to feed on the ovules within (Fig. 5). Normally the larva develops through the third instar inside the ovary of the initial flower. The larva is nearly colorless in the first three instars (Figs. 5, 6, and 7),

which is typical of larvae that feed inside their host plant.

In the fourth instar the larva develops a more distinctive color and pattern (Fig. 8), and by this stage the larva moves to a new flower to find food. Flowers that are blooming, or just past bloom, with a soft, green, immature ovary are preferred. In the fourth and fifth instars, the larva remains inside the inflated calyx of a *Silene vulgaris* flower, both feeding and resting while so hidden (Fig. 9). This presumably affords some protection from predators and parasitoids (Brantjes 1976; Biere et al. 2002; Biere & Honders 2006). The larva enters a calyx through the apical opening, or alternatively, it chews a hole in the base of a calyx (Fig. 11). A larva will sometimes consume an entire flower, including the calyx, but more often it will consume only the petals, stamens, pistil, and ovary, leaving behind an empty calyx when it moves to another flower. Many flowers and ovaries are consumed over the course of development, and a larva feeds exclusively on the plant's reproductive tissues through the fifth instar. In the sixth and final instar a larva will also consume the leaves of *S. vulgaris*, but continues to exhibit a preference for flowers and their ovaries. A sixth instar larva is too large to fit within the calyx of a flower without either the anterior or posterior end of its body protruding (Fig. 12). Many species of *Hadena* feed nocturnally in later instars, hiding under leaves at the base of the plant during the day (Forster & Wohlfahrt 1971; Hacker 1996; Porter 1997); it is likely that sixth instar larvae of *Hadena ectypa* behave similarly.

After each molt, the larva typically consumes its shed cuticle. Under warm conditions and with sufficient high-quality food, larval development is rapid and may be completed within three weeks. The larva burrows

into the soil for pupation, which typically occurs 2 to 3 cm below the surface, in a cell sparsely lined with silk. Most individuals have pupated by late August, and pupae overwinter until the following year. A small number of individuals may emerge in late August and September as a partial second generation.

DISCUSSION

On 24 July 2008, Nelson Bricker (a student of David L. Wagner at the University of Connecticut) found a single prepupal *Hadena ectypa* larva crawling across a road in Canaan, Litchfield County, Connecticut, USA. On 11 July 2009, Wagner returned to the Canaan site (with Alex Meleg and MWN), and found more than a dozen *Hadena ectypa* larvae feeding on *Silene vulgaris* growing along the roadside. The discovery of a second population of *Hadena ectypa* in New England, also feeding on exotic *S. vulgaris*, indicates that the use of this plant is not unique to the population in Huntington, Massachusetts.

Silene stellata, the native host of *Hadena ectypa*, occurs in New York state and Connecticut (FNA 2005; Magee & Ahles 2007). It is a rare plant of conservation concern in Connecticut. Fernald (1950) includes Massachusetts in the range of *S. stellata*, but currently it is not known to occur in the state (FNA 2005; Magee & Ahles 2007; Dow Cullina et al. 2011; Haines 2011). *Hadena ectypa* presumably occurs on *S. stellata* in New York, as this plant is not rare in parts of that state. *Hadena ectypa* may also use *S. stellata* in Connecticut, although this may have been more likely in the past given the plant's current rarity there. If *S. stellata* occurred in Massachusetts historically, it was probably quite rare, as this represents the northeastern edge of its geographic range. Thus it seems only a remote possibility that *Hadena ectypa* ever occurred on its native host plant in Massachusetts.

Specimens of *Hadena ectypa* from southeastern New York at the American Museum of Natural History date back to 1899. However, the first records from Massachusetts and Connecticut are those reported here. This may indicate that use of introduced *Silene vulgaris* as a larval host has facilitated a slight northeast expansion of the range of *Hadena ectypa*. Alternatively, it is possible that *Hadena ectypa* historically occurred on *Silene stellata* in western Connecticut, and maybe even western Massachusetts, but was sufficiently rare to avoid detection.

Native, introduced, and potential larval host plants. *Silene vulgaris* currently occurs across most of the Northeast (Magee & Ahles 2007), and indeed across most of North America (FNA 2005). While the precise site and date of the introduction of *S. vulgaris* from

Europe is not known, herbarium specimens from Massachusetts date back to 1846 (Sorrie 2005). *S. vulgaris* was also reported from Massachusetts by Cutler (1785). Therefore while it is possible that *Hadena ectypa* began to use *S. vulgaris* as a larval host in this area only recently, this host shift could have occurred at any time during the past 200 years. If *S. vulgaris* was first introduced to North America through a port city in the Northeast, such as New York, Boston, or Quebec, and subsequently spread south and west, then *Hadena ectypa* likely first encountered this plant in the region of southeastern New York, western Connecticut, and western Massachusetts. Since its introduction, *S. vulgaris* has spread throughout the entire range of *Hadena ectypa*. It therefore seems likely that *Hadena ectypa* uses *S. vulgaris* as a larval host in other parts of its range, although this has not yet been documented.

There are at least 22 species of *Silene* that occur within the geographic range of *Hadena ectypa*, including eight native species and 14 introduced species (FNA 2005). While it is not unlikely that *Hadena ectypa* uses other native *Silene* spp. as larval hosts, existing data indicate that *Silene stellata* is the primary native host. In addition to oviposition and larval development on *S. stellata*, *Hadena ectypa* adults imbibe nectar from the flowers of *S. stellata*, and in the course of both nectaring and oviposition provide pollination services to this plant (Kephart et al. 2006; Reynolds et al. 2011). Given the intimate ecological relationship between *Hadena ectypa* and *S. stellata*, it seems likely that this plant has particular traits that make it a more favorable larval host for *Hadena ectypa*, as compared to other native species of *Silene*. Traits of *S. stellata* that are beneficial to *Hadena ectypa* include: (1) white flowers with nocturnal scent, which attract nectaring and pollinating moths, and which also help *Hadena ectypa* females find plants upon which to oviposit (Kephart et al. 2006; Reynolds et al. 2011); (2) flowers with a large, inflated calyx, and space between the calyx and ovary, which allows a larva of *Hadena ectypa* to remain hidden from predators and parasitoids while feeding and resting (Brantjes 1976; Biere et al. 2002; Biere & Honders 2006); (3) many flowers per plant, each with a relatively large ovary with many seeds, making it more likely that a larva on any given plant (or small patch of plants) will have sufficient high-quality food to complete development; and (4) asynchronous, staggered flowering and fruiting phenology between plants, as well as asynchronous, staggered development of flowers and fruits on separate stems of individual plants, making food available for a longer period of time, which in turn may facilitate temporal resource tracking, as well as provide a late-

season food source for a facultative second generation of *Hadena ectypa*.

Like *Silene stellata*, *Silene vulgaris* has a peak flowering period of mid- to late summer. Furthermore, *S. vulgaris* shares with *S. stellata* all of the traits favorable to *Hadena ectypa* as listed above (Pettersson 1991a, b), making it a more suitable alternate host plant for *Hadena ectypa* as compared to other species of *Silene*, native or introduced. Indeed, behavioral aspects of the use of *S. vulgaris* by both adults and larvae of *Hadena ectypa* are nearly identical to those observed on *S. stellata* by Reynolds et al. (2011). In its native Europe, *S. vulgaris* is fed upon by at least nine species of *Hadena* (Pettersson 1991a, b; Kephart et al. 2006), indicating that it is a particularly suitable larval host plant for species of *Hadena* in general.

The favorable traits of *Silene stellata* and *Silene vulgaris* are also shared by *Silene latifolia*, another common and weedy species introduced to North America prior to 1850 (Sorrie 2005), which has since spread throughout the range of *Hadena ectypa*. However, unlike *S. stellata* and *S. vulgaris*, the flower of *S. latifolia* has a calyx that is densely covered in trichomes, as well as a constricted apical opening that is blocked by contracted petals during the day (Kephart et al. 2006). This may make access to the interior of the flower more difficult for *Hadena ectypa*. When the *Hadena ectypa* larvae reared in 2003 were initially offered sealed flowers of *S. latifolia*, they chewed away at the trichomes, but seemed to have difficulty accessing the interior of the calyx. Subsequently the calyces were split open, and the larvae responded by immediately entering them and feeding on the green ovaries, thereafter ignoring the trichome-covered calyces. It should be noted, however, that *S. latifolia* is used as a larval host by at least three other species of *Hadena* in its native Eurasian range (Kephart et al. 2006). Furthermore, Blair & Wolfe (2004) have shown that North American populations of *S. latifolia* invest less in defensive traits (dense calyx trichomes and thick ovary wall) as compared to European populations, perhaps because of ecological release from *Hadena* species and other herbivores in the native range (Wolfe 2002). It therefore seems quite possible that *Hadena ectypa* could adapt to the use of *S. latifolia* in North America.

Another possible barrier to the use of *Silene latifolia* by *Hadena ectypa* is that this plant is dioecious, and many populations have two to six times more staminate than pistillate flowers (Brantjes 1976). In Europe, *Hadena bicruris* (Hufnagel, 1766) feeds on *S. latifolia*, and females exclusively oviposit in the pistillate flowers of this plant (Brantjes 1976). This is important because staminate flowers do not have an ovary to feed a

developing larva, and moreover, staminate flowers drop off of the plant a few days after pollination (Brantjes 1976). It is not necessary for *Hadena ectypa* to discriminate between flowers of its native host, as *Silene stellata* is hermaphroditic, or between flowers of *Silene vulgaris*, as this species is gynodioecious. Therefore *Hadena ectypa* may not have the ability to discern pistillate from staminate flowers, and if it were to oviposit indiscriminately on flowers of *S. latifolia*, this plant could serve as a population sink.

Use of a novel host plant: effects on phenology, habitat, and geographic range. All of the *Hadena ectypa* adults reared in 2003, 2009, and 2010 emerged in August or September of the same year, confirming that this species has a facultative second generation. In insects with facultative induction of diapause, the choice between either continuous development or diapause is determined by environmental cues; typical cues include photoperiod, temperature, and food quality and quantity (Tauber et al. 1986; Leather et al. 1993). The captive rearings reported here were kept in a warm environment and offered an abundance of high-quality food; as a result, larval growth was rapid, and none of the reared individuals entered pupal diapause.

As far north as Massachusetts, it seems likely that most wild *Hadena ectypa* enter pupal diapause, although a partial second generation does occur, as indicated by the adult caught in a light trap the night of 10–11 September 2002. The offspring of moths breeding in September in Massachusetts must have a low probability of surviving to pupation, except in years with exceptionally warm weather in September and October. In addition to cooling temperatures, flowers and fruits of *Silene vulgaris* become scarce late in the season. However, the asynchronous, staggered flowering phenology of *S. vulgaris*, both between and within individual plants, may provide a sufficient late-season food source in some years. Interestingly, *S. vulgaris* continues to flower and fruit later in the season than *Silene stellata* (Gleason & Cronquist 1991; FNA 2005). Therefore the phenology of this novel, introduced host plant may increase survival of second-generation individuals of *Hadena ectypa*, and thereby increase the propensity for a second annual generation in this species. Future investigation of this topic could provide some interesting insights.

Hadena ectypa has always been considered a rare moth (Wyatt 1929). It is currently a species of conservation concern, subject to anthropogenic threats including habitat loss to development, grazing of larval host plants by artificially abundant deer, and degradation of habitat by invasive exotic plants (Schweitzer et al. 2011). Ironically, the introduction of

Silene vulgaris may “rescue” *Hadena ectypa*, as this plant is now relatively common and weedy in North America, with a much larger geographic range than *Silene stellata* (FNA 2005). Adoption of *S. vulgaris* as a larval host may allow *Hadena ectypa* to spread to new, weedier habitats, to increase its geographic range, and to increase its propensity for a second annual generation.

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